Review of the Environmental and Socio-economic Impacts of Marine Pollution in the North and Central Coast Regions of British Columbia

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Executive Summary

Marine environmental quality concerns exist around a number of human activities taking place on BC's North and Central Coast regions, including sewage and waste disposal, mining and smelter activities, various large industrial operations, port expansions, increased shipping, offshore oil and gas development, and tourism activities. These projects can have significant environmental and socio-economic impacts on First Nations and the region's communities. This report focuses on the region defined by the Pacific North Coast Integrated Management Area (PNCIMA). This area is important for food, social and ceremonial fisheries for First Nations, as well as commercial and recreational fisheries. The number of potential marine pollution issues which may impact this region is vast, and covers both locally generated point source pollutants and globally produced non-point source pollutants; however, this report attempts to provide a preliminary review of the some of the possible impacts, monitoring, and mitigation measures for many of these pollution issues. **Table ES 1** gives a brief summary of various pollution issues described in this report.

Table ES 1. Summary of environmental and socio-economic impacts of marine pollution in the North and Central Coast regions and some potential mitigation measures.

Pollution Issue	Environmental and Socio-economic Impacts	Relative Significance to Region (High, Moderate, Low)	Mitigation Measures
PCBs	Immunosuppression; endocrine disruption; carcinogenic; food-chain contamination	Moderate	Control of local point source polluters
Dioxins and furans	Toxic; immunosuppression; carcinogenic; liver damage; food-chain contamination	Moderate	Control of local point source polluters
PDBEs	Toxic; food-chain contamination	Moderate	Control of local point source polluters
PAHs	Toxic; carcinogenic; food-chain contamination	Moderate	Control of local point source polluters
Organochlorine pesticides	Toxic; immunosuppression; carcinogenic; endocrine disruption; food-chain contamination	Low	International actions to prevent release
Phthalate esters	Endocrine disruption	Moderate	National and international actions to prevent use
Mercury	Toxic; brain and kidney damage; birth defects; food-chain contamination	Low	Control of local point source polluters
Copper	Toxic	Moderate	Control of local point source polluters
Cadmium	Immunosuppression; kidney damage; carcinogenic	Moderate	Control of local point source polluters
Lead	Toxic to waterfowl and eagles	Moderate	Control of local point source polluters
Sewage	Eutrophication; oxygen-depletion; elevated levels of trace metals; contamination of fish and shellfish with disease-causing organisms; aesthetics	High	Restrictions on types of substances which may be discharged into the wastewater system; reduction of wastewater volume; better location of outfall; better sewage treatment systems
Oil	Water soluble fractions can be very toxic to marine organisms; high molecular weight fractions bioaccumulate and cause chronic effects; sheltered tidal flats and salt marshes are heavily impacted by spilled oil; seabirds are most at risk to oiling; fisheries, tourism, and recreation activities can be seriously impacted	High	Control of local point source polluters; prevent transport of oil through sensitive areas; better vessel maintenance
Ports, marinas, and harbours	Impacts associated with sewage, antifouling paints, chemicals associated with boat maintenance, chronic oil pollution, and creosote-treated wood	High	Installation of washrooms and pump out stations; zero discharge boat repair facilities; use of less toxic antifouling paints

Pollution Issue	Environmental and Socio-economic Impacts	Relative Significance to Region (High, Moderate, Low)	Mitigation Measures
Wood preservatives and anti-sapstains	Toxic; some forms may bioaccumulate	Moderate	Use of floating concrete in dock structures
Antifouling paints	Highly toxic	Moderate	TBT has been banned; encourage use of less toxic antifouling compounds
Marine traffic	Impacts associated with sewage, grey water, chronic oil pollution, discharge of hazardous wastes, and ballast water	High	Improved vessel waste treatment systems; better monitoring of vessel discharges; actions taken by owners of small vessels to reduce discharge of pollutants
Ballast water	Main pathway for introduction of alien invasive species to local waters; may alter local food chains, have impacts on aquaculture, increase fouling organism problems, or increase incidences of toxic red tides	Moderate	Better monitoring of ballast water exchange
Whale watching tours	Behavioral changes in whales; inability to locate prey and communicate with each other	Low	Follow the whale watching guidelines set out by DFO
Vessel wakes	Shoreline erosion; human safety; siltation in recreational areas; property damage; siltation in spawning and feeding habitats	Low	Reduce vessel speed; better hull design
Noise	Impacts on feeding, breeding, schooling, etc.	Low	Better hull and prop designs; improved technology
Offshore oil and gas	Smothering of benthic organisms by drilling mud; sublethal effects of chemicals released in produced water; possible oil spills	Moderate	Creation of strong guidelines by the stakeholders which clearly define how and where offshore oil and gas development can take place
Agriculture	Agricultural runoff containing nutrients, pathogens, and sediment which may cause excessive algal growth, decrease oxygen levels, or result in toxicity to fish	Low	Proper management of wastes; application of soil conservation principles
Finfish aquaculture	Organic wastes which may alter the biogeochemistry of benthic sediments; eutrophication; chemotherapeutants which may create drug resistance in native microbial populations; sea lice, bacterial, and viral impacts on wild fish; genetic and ecological risk related to escaped farmed salmon	Low	Transition of ocean-based closed containment systems
Shellfish aquaculture	Risk of infection to wild species; reduction in phytoplankton biomass from grazing	Low	Good site selection
Pulp and paper mills	Oxygen depletion resulting from high levels of TSS and BOD which may kill marine organisms; toxic dioxins and furans	Low	Secondary treatment of effluent; use of chlorine-free bleaching processes
Pesticides	Low levels of toxicity to aquatic organisms	Low	Buffer zones and pesticide free zones around streams and water bodies
Fire control chemicals	Toxic surfactants in fire suppressant foams	Low	Not used extensively in coastal regions
Log storage, handling, and booming operations	Sediment smothering, scouring, and compaction; reduction of dissolved oxygen in sediments; production of toxic leachates; changes in flora and fauna diversity and abundance	Moderate	Better siting; adhering to best management practices
Erosion	Increased siltation and turbidity resulting in smothering of benthic organisms and reduced photosynthesis in marine algae	High	Alternative methods to clear-cutting; better road design

Pollution Issue	Environmental and Socio-economic Impacts	Relative Significance to Region (High, Moderate, Low)	Mitigation Measures
Mining	Low pH levels caused by ARD can kill marine life; toxic heavy metals; processing chemicals can be toxic to humans and wildlife; smothering of aquatic organisms by sediments	High	Treatment and storage of mine tailings to avoid ARD and toxicity
Coalbed methane	Impacts on land from road and well development; impacts on water quality and soil from saline produced water; use of toxic substances to fracture coal seams; release of carcinogenic substances during flaring; methane migration into water supplies and soils	Moderate	Better siting requirements, with buffer zones and setbacks from sensitive areas; disallow use of toxic fraccing compounds; avoid habitat fragmentation and maintain biodiversity; locate wells away from ground water supplies
Smelting	Dieback in plants and decalcification in mammals from fluorides released into the air; aluminum toxicity to fish and aquatic insects; carcinogenic PAHs in water; health effects on workers in plant	High	Scrubbers; new technologies; abstraction and treatment
Landfills	Potential source of contamination for soil, groundwater and air; groundwater leachates may result in marine pollution	Moderate	Waste reduction; development of solid waste management plans
Ocean dumping	Effects on the abundance and species composition of benthic communities	Low	Waste reduction; extensive permitting and monitoring
Global warming	Increased frequency and severity of extreme weather; rising sea level; changes in ocean circulation; effects on energy transfers between trophic levels; higher mortality in salmon; decreased ocean productivity; increased ocean acidity; upwelling of water low in dissolved oxygen; floods; storm damage; saltwater intrusion into groundwater supplies; increased temperatures in surface and deep ocean waters	High	Reduction in greenhouse gas emissions on both an individual and global scale
Coast Guard and military	Impacts associated with ship-based pollutants; lead, cadmium, and mercury in discarded batteries; mercury from lighthouse beacons	Low	Work is underway to assess and rectify waste disposal issues
Seafood processing plants	Waste streams high in BOD with limited treatment	Low	Better waste stream treatment (e.g., secondary)
Abandoned sites	Variable, depending on the site	Moderate	Location and assessment of sites
Liquid natural gas	Potential of large LNG release and possible explosion	Low	Improvements in transport and handling safety have significantly reduced risks
Methanex	Release of methanol and ammonia	Low	Better control of point source releases; better regulation

The North and Central Coast region is a vast, relatively unpopulated, and relatively pristine area when compared with other parts of British Columbia. However, it is not unaffected by marine pollution. Both historical and current pollutants are having an impact throughout the region. Additionally, global pollutants, such as POPs and greenhouse gases, can also affect our region. Thus, if we wish to have a healthy environment in which to live, grow, work, and play, we must act on a both an individual and political level to prevent pollutants from damaging our marine ecosystem.

1. Introduction

Marine environmental quality concerns exist around a number of human activities taking place on BC's North and Central Coast regions, including sewage and waste disposal, mining and smelter activities, various large industrial operations, port expansions, increased shipping, offshore oil and gas development, and tourism activities. These projects can have significant environmental and socio-economic impacts on First Nations and the region's communities. This report provides a preliminary review of the possible impacts, monitoring, and mitigation measures for many of the existing and potential marine pollution issues on the North and Central Coast.

This report focuses on the region defined by the Pacific North Coast Integrated Management Area (PNCIMA). The PNCIMA's boundaries were based primarily on ecological characteristics, including oceanic currents and physiographic considerations, and encompass approximately 280,000 km^2 (this includes associated watersheds; **Figure 1**). It extends from the outer limit of the foot of the continental slope in the west, to the coastal watersheds in the east. The Canada-US border for Alaska is the northern boundary. Brooks Peninsula on NW Vancouver Island, Quadra Island, and Bute Inlet form the southern boundary (Hillier and Gueret 2007, Lucas et al. 2007).

This area is important for food, social and ceremonial fisheries for First Nations, as well as commercial fisheries and recreational fisheries. Aquaculture development is also a key issue in the area, as are tourism, transportation, and potential offshore energy development (Hillier and Gueret 2007).

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. For each topic, the general situation on the BC coast is discussed first, followed by specifics on North and Central Coast issues, where available.

Figure 1. Study area for this report as defined by the boundaries of the PNCIMA (data: DFO 2007a).

2. Contaminants and Pollutants in the Marine Environment

Contaminants and pollutants can be defined as:

- **Contaminants** - substances, including those found naturally, that are present at concentrations above natural background levels, or whose distribution in the environment has been altered by human activity (BCMOE 2006b).
- **Pollutants** - contaminants whose concentration in the environment are high enough to result in adverse effects (GESAMP 1983).

An adverse effect can include (Haggarty et al. 2003):

- harm to aquatic life
- hazards to human health
- hindrances to human activities (swimming restrictions, invertebrate harvesting closures, etc.)
- reductions in intrinsic value of the environment

Factors that determine whether a chemical contaminant poses a risk of harm are (Haggarty et al. 2003):

- quantity or concentration of the contaminant
- sensitivity of the target organism or habitat
- duration of exposure of the target organism or habitat

Effects of contaminating substances can be observed at all levels of biological organization, including cellular, organ, whole organism, and population or community levels. The impact of a contaminant depends on the physical-chemical properties of the contaminant, its sources, pathways and sinks, as well as the chemical and biological processes of the ecosystem. Some important chemical and physical properties of a contaminant include its volatility, solubility, adsorption, and stability (Haggarty et al. 2003, Pierce et al. 1998).

The following terminology is used to describe some of the properties of contaminants (BCMOE 2006b, Haggarty et al. 2003, Pierce et al. 1998):

- **Source** - the point of origin of the contaminant. Sources can be further defined as either point or non-point sources:
    - **Point Source** – a source with a defined origin or specific outlet, such as discharge pipes releasing industrial and municipal effluents.
    - **Non-Point Source** – a source with a diffuse origin such as watershed, agricultural, or urban run-off and long-range transport by atmospheric or marine processes.
- **Pathway** - where and how the contaminant is distributed. Pathways may be biological, chemical or physical in nature, or a combination of these.
- **Sink** - where a contaminant accumulates (e.g. sediments).
- **Volatility** - the ease with which a liquid turns into a gas at a given temperature. Volatility is determined by the chemical's **vapor pressure** (the pressure of a vapor when it is in equilibrium with its liquid or solid form). Volatility affects the transport of substances by the atmosphere. Chemicals with high vapor pressures, and thus high volatility (e.g., trichloroethylene), are likely to become widespread in the world's atmosphere.
- **Solubility** – the maximum amount of a substance that will dissolve in a given amount of liquid at a given temperature. Chemicals with high solubility in water can be transported by water currents. Chemicals with high solubility in lipids (e.g., DDT) have a tendency to accumulate in the fat (lipid) tissues of organisms. Chemicals with low water solubility and high lipid solubility are said to be **hydrophobic**. Hydrophobic substances often attach to particulates and accumulate in sediments.

- **Adsorption** – the process by which molecules of a gas or liquid accumulate on the surface of a solid. This determines the **partitioning**, or distribution, of molecules between the "free" (dissolved) form and the "bound" (adsorbed) form. Whereas liquids and gases form currents and remain in motion, particles tend to settle out. If the particles have adsorbed contaminants, sinks of contaminants can be created where **sedimentation** (settling) is highest. Chemicals which bind to particles (e.g., lead, PAHs, PCBs, dioxins, furans) end up in sediments and soils near their sources. The particle size and organic content of the sediments can affect the rate of accumulation of these chemicals.
- **Stability** or **persistence** – the tendency of a contaminant to resist degradation, and thus to remain unchanged in the environment for long periods of time. Persistent chemicals which are accumulated by organisms (e.g., methylmercury, PCBs, PAHs) have the greatest potential to cause toxic effects.

Uptake of contaminants by biota (living organisms) can be either **passive** or **active**. Passive accumulation occurs by adsorption across cell membranes. It is more common at lower trophic (feeding) levels. For example, both phytoplankton and clams passively accumulate chemicals across their cell membranes (whole cell adsorption in phytoplankton and adsorption across the gills in clams). Active accumulation is more common at higher trophic levels where animals accumulate contaminants by ingesting contaminated prey (Haggarty et al. 2003).

Once a contaminant has entered an organism, it may accumulate through several processes:

- **Bioconcentration** – the process which occurs when uptake from the water is greater than excretion.
- **Bioaccumulation -** the process which occurs when chemical substances are ingested and retained by organisms, whether directly from the environment (passive) or through consumption of contaminated food (active). Bioaccumulation occurs within a trophic level (Pierce et al. 1998).
- **Biomagnification -** the process which occurs when there is a cumulative increase in the concentration of a persistent substance in successively higher levels of the food chain (Haggarty et al. 2003).

Persistent chemicals with high lipid solubility can be readily bioaccumulated. Persistent chemicals tend to biomagnify as they move up the food chain (Pierce et al. 1998). The degree to which a contaminant will be bioaccumulated and biomagnified in an organism depends on many factors (Cretney and Yunker 2000):

- concentration of the contaminant
- chemical properties of the contaminant
- trophic level of the organism
- preferred food of the organism
- feeding rate of the organism
- ability of the organism to uptake the contaminant
- excretion rate of the contaminant from the organism
- growth rate of the organism
- longevity of the organism

The chemical and physical properties of a contaminant determine its transportation pathway (**Figure 2**). Chemicals which have low volatility or solubility are not transported very far, and will have effects which are more localized in nature. Volatile and soluble chemicals can be transported great distances, and may have long-ranging or even global distributions and impacts (Haggarty et al. 2003).

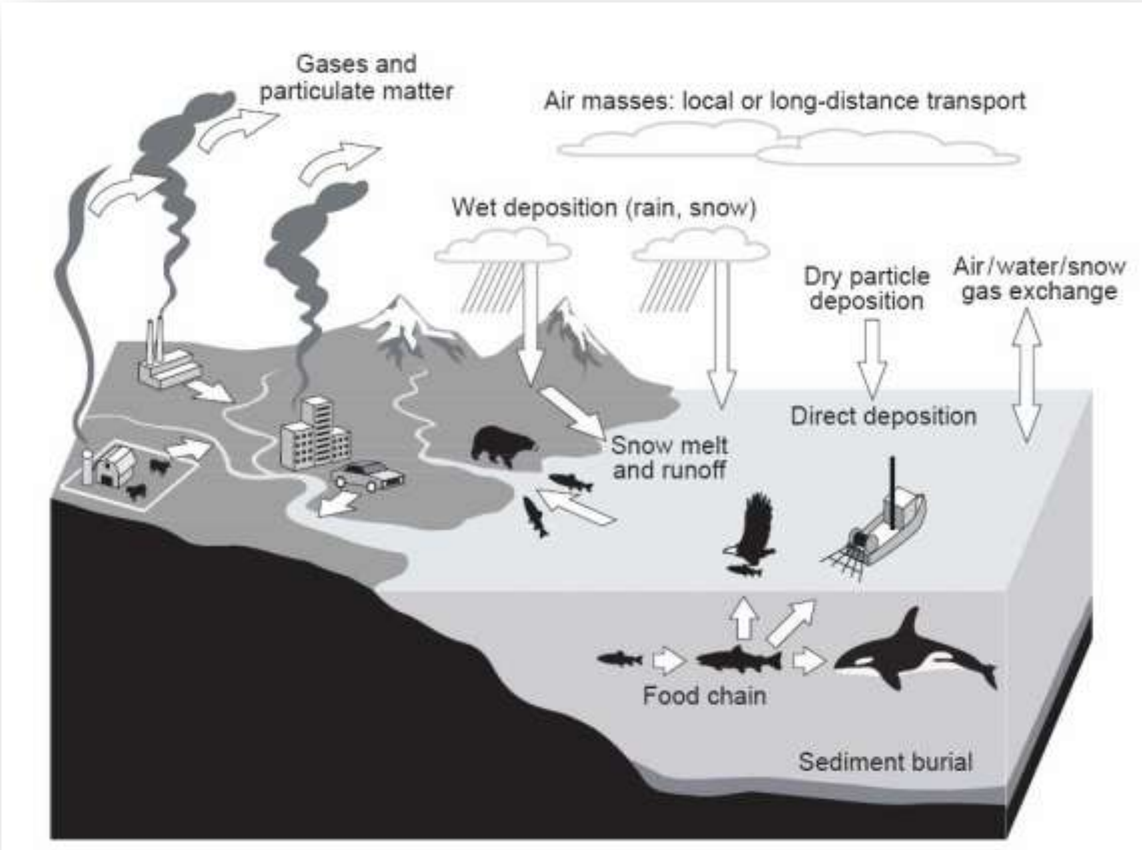

Figure 2. Transportation pathways of chemical contaminants in the environment (source: Ross and Birnbaum 2003).

Contaminants may be discharged directly into water near the shoreline or into rivers that carry the contaminants to the marine environment. Solubility in water will influence how far contaminants will be transported by water masses. Chemicals that are readily adsorbed onto particulate matter (organic or inorganic) in the water column will be transported until they settle onto the bottom through sedimentation. Properties of the particles such as size, surface area, and amount and type of organic matter will determine how much of the chemical will be adsorbed and the distance the particles will be transported. Contaminated sediments may be gradually covered over by new material brought down by rivers or carried along in coastal currents (BCMOE 2006b, Haggarty et al. 2003).

Contaminants may also be emitted into the atmosphere from combustion, incineration, and industrial processes, or as vapors re-emitted from chemical residues already in the environment. The vapor pressure of a chemical will determine how far it will be transported in the atmosphere, and consequently how widely distributed it will be. Highly volatile contaminants remain in vapor phase in the atmosphere, where they travel on prevailing winds, and are thus widely distributed throughout the world's atmosphere (Haggarty et al. 2003). When the air masses containing these volatile contaminants reach cool regions, such as mountaintops and high latitudes, the contaminants condense and may dissolve in the water or snow (BCMOE 2006b). Thus, these chemicals may accumulate in the ice or snow until they are released into ecosystems through snow melt and spring runoff (Li and Macdonald 2005). Many small lakes and reservoirs in the Rocky Mountains fed by glacial runoff contain concentrations high enough to affect wildlife at the top of the food chain (Hempel 2000). Less volatile compounds will adsorb more readily to atmospheric particles and will not travel far from their sources. These particles may be directly deposited on land or water as dust, or may be carried back to the surface by precipitation (Haggarty et al. 2003).

Though sinks can be considered as an eventual repository for chemicals, they can also act as a source of chemicals. Contaminants in sinks can be disturbed by natural events such as tides and storms, bioturbation, and activities including dredging, trawling and ship passage. Contaminants can also be recycled by benthic biota in proximity to the sink and proceed through the food web (Haggarty et al. 2003).

3. The National Pollutant Release Inventory

Established in 1992, the Canada's **National Pollutant Release Inventory** (NPRI) now tracks release, disposal, and recycling of more than 300 pollutants by industrial, commercial, and institutional facilities. Legislated under the Canadian Environmental Protection Act, 1999, the NPRI requires companies to report annually to the government on releases and transfers of key pollutants. This information is available to the public in an annual report and through an online database (BCMOE 2007f).

Facilities which report to NPRI include companies and public utilities involved in the following activities and products (BCMOE 2007f):

- chemical products
- metal products
- mineral products
- rubber products
- food products
- textiles
- electrical equipment
- pulp and paper
- cement
- oil and gas extraction
- mining and smelting
- waste handling
- incineration
- wood preservation
- printing

Note, however, that educational and research institutions, vehicle repair shops, and those involved in growing and harvesting in the agriculture, forestry, and fisheries sectors are exempt from reporting to NPRI.

Reported on-site discharges of contaminants to the environment include unintentional (spills and leaks) or intentional releases (emissions to air from stacks, discharges to surface waters), and on-site disposal (to landfills, to underground injection) within the boundaries of the facility site (BCMOE 2007f).

4. Measuring Effects of Contamination

A variety of techniques are used to identify and measure the responses of the environment to chemical contaminants.

4.1. Cellular Responses

Organisms may react to toxic contamination with a number of physiological changes at the cellular level in an attempt to detoxify the contaminant and reduce the harmful effects of substances that cannot be readily excreted. Biochemical responses include increases (induction) or decreases (inhibition) in the activity of various enzymes. These enzymatic changes are usually measured in fish (Addison 1996). These enzymes are often termed molecular biomarkers:

- **Molecular biomarkers** - biological indicators that signal a changed physiological state, stress, or injury due to disease or the environment. They can be the products (e.g., metallothioneins, mixed function oxygenases) of physiological responses to exposure to toxic compounds. Their presence will indicate that the animal has been under stress. Measuring the concentration of biomarkers can give an indication of the exposure to toxins (Clark 2001).

Molecular biomarkers are potentially useful in warning of the effects of pollution (Addison 1996).

4.2. Whole Organism Responses

Toxicity (or **acute toxicity**) essentially reflects the extent to which a substance is poisonous or how large a dose is required to kill an organism. The more toxic the substance is, the smaller the lethal dose. Toxicity is measured in the laboratory in several ways (Clark 2001):

- **Median lethal dose (LD_{50})** - the amount of a substance which produced death in 50% of a sample population
- **Median lethal time (LT_{50})** – the time it takes for 50% of the sample population to die at a given concentration of a substance
- **Median lethal concentration (LC_{50})**, measured over 48 or 96 hours - the amount of a substance which is needed to kill half of a group of experimental organisms in a given time.

Exposure to a toxic chemical at low concentrations may not produce death, although sublethal effects may occur (Haggarty et al. 2003):

- **Sublethal effects** (also referred to as **chronic toxicity**) - the potential long term effects which could result from exposure to small amounts of a toxin over time. Chronic toxicity may impact different parts of the body than acute toxicity. Examples of sublethal effects include major physiological stress, tumors, or developmental abnormalities that would likely result in early death. Sublethal effects should not be overlooked as they may lead to early mortality or reduced reproductive output.

Sublethal effects can be identified in natural populations exposed to a toxin (e.g., ingestion of crude oil by gulls causing damage to the intestine and liver) or by laboratory tests (e.g., sub-lethal concentrations of copper sulfate have been shown to cause the production of abnormal larvae in the polychaete *Capitella capitata*) (Clark 2001).

Another way to measure sublethal effects and the impacts of stress on whole-organisms is the physiological test termed scope for growth.

- **Scope for growth** – a measure of the excess energy accumulated by an organism after its current energy demands are met. The excess energy is usually directed to growth or reproduction (Addison 1996). Animals under stress will use energy differently than unstressed animals, and may have less energy to put towards reproduction or growth, thereby reducing the individual's fitness.

Scope for growth is most commonly measured in sessile bivalves, particularly blue mussels (Haggarty et al. 2003).

4.3. Population Responses

Measuring the toxicity of a contaminant in an individual, even if it causes mortality to that individual, is not sufficient to show how that contaminant will cause changes at the level of the population (Haggarty et al. 2003).

Mortality that results in a prolonged population reduction for a species can have serious impacts on the species. The abundance of a species is measured by **population density** (number of individuals of a particular species per unit area or unit volume) or **biomass** (total weight of a particular species per unit area or volume). Monitoring changes to a population can be extremely difficult. Good, baseline pre-impact data is required in order to evaluate the post-impact population estimates and determine what level of damage has occurred. Even if good baseline data exists, large population fluctuations may mask the effects of the impact, and a complete understanding of the natural population variability is required to analyze the data (Hilborn 1996).

Certain types of species are often the focus for studies on population change. These include species of high conservation value (seabirds, marine mammals), commercial species (salmon, shellfish), key species (dominant herbivores, important predators), or indicator species (*Capitella*, mussels). However, these species may not always be good indicators of the overall impact of the pollutant on the community. Therefore, the pollution impact may also be measured at the community level (Haggarty et al. 2003).

4.4. Community Responses

Many statistical methods exist to look at community change, such as (Clark 2001):

- diversity and dominance
- graphical representations of communities, including rarefaction curves (plots of the total number of individuals counted with repeated samplings versus the total number of species found in each of those samplings)
- multivariate analysis such as non-metric multi-dimensional scaling (MDS), cluster analysis, and principal component analysis (PCA)

Sampling methodology must be carefully designed in order to have the power to demonstrate that changes to community structure are associated with a specific stressor. Failure to do so can lead to faulty conclusions about the impacts of a pollutant (Peterson et al. 2001).

4.5. Ecosystem Responses

Ultimately, we would like to be able to measure the impacts of various activities on the ecosystem as a whole. However, this can be very difficult, as we often do not possess the necessary information about the structure and function of the ecosystem in order to achieve this. In addition, impacts would need to be very widespread or drastic in order to show conclusive effects at the ecosystem level. One instance where we may be witnessing widespread ecosystem change is the response of arctic ecosystems to global climate change (Haggarty et al. 2003).

Figure 3 shows the relationships between the various levels of impacts caused by exposure to a toxic pollutant. Note that while biochemical responses may be very rapid and specific, they have relatively low ecological relevance. On the other hand, community changes are slow and have low specificity, but they are more ecologically relevant. Another way of looking at this is that measurements of biochemical responses can anticipate future ecological changes whereas measurement of community responses are more indicative of past ecological changes (Addison 1996).

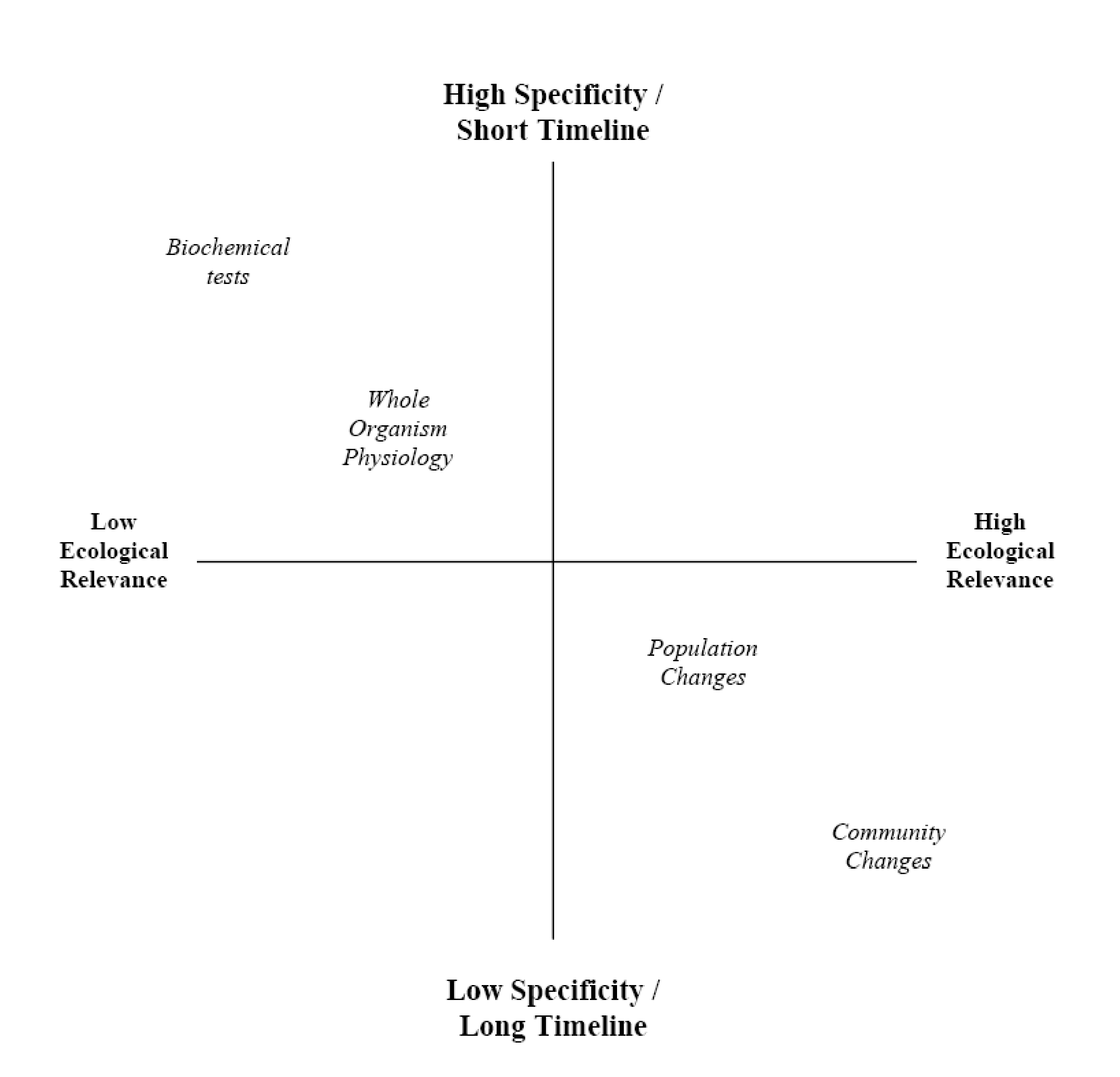

Figure 3. Ecological relevance, specificity and timelines of biological effects measurements (modified: Addison 1996).

5. Overview of the North and Central Coast Environment

5.1. Area and Population

The marine component of the PNCIMA covers approximately 102,000 km^2 of ocean (**Figure 1**). While the associated terrestrial watersheds are not technically included as part of the PNCIMA, terrestrial issues may have a direct and significant bearing on marine pollution affecting the area. These associated watersheds comprise approximately 178,000 km^2 of land (Figure 1). Thus, for the purpose of this report, the North and South Coast region, as defined by the PNCIMA, covers a total area of approximately 280,000 km^2.

Several Regional Districts are located within the boundaries defined by the PNCIMA (**Figure 4**). For each regional district, the land area that falls within the PNCIMA is given in **Table 1**. The Kitimat-Stikine and Skeena-Queen Charlotte Regional Districts make up the greatest land area in the PNCIMA region, with the Central Coast, Mount Waddington, and Bulkley-Nechako Regional Districts taking up much of the remaining land area.

Table 1. Regional Districts located within the PNCIMA (data: BCMOE 2006b, SC 2007).

Regional District	Land Area within PNCIMA (km^2)
Kitimat-Stikine	68,583
Skeena-Queen Charlotte	57,229
Central Coast	36,144
Mount Waddington	30,238
Bulkley-Nechako	23,208
Stikine	11,242
Cariboo	8,670
Comox-Strathcona	7,557

Population data for 90 census subdivisions contained within the PNCIMA were used to estimate the population of the region (**Table A 1**). The total population for the area was estimated to be 126,444 (**Table 2**). 42% of this population lives in three main cities (Terrace, Prince Rupert, and Campbell River). **Figure 5** shows the locations of all the cities, district municipalities, towns, and villages within the region defined by the PNCIMA.

Table 2. Estimated population within the PNCIMA (data: BC Stats 2006a, SC 2007, 2008).

Census Subdivision Type	Population (2006)	Aboriginal Population (2006)
City (CY)	53,320	9,395
District Municipality	17,560	2080
Town (T)	7,765	915
Village (VL)	6,030	1,165
Regional District (RDA)	27,283	2920
First Nations Community (IRI, NL, NVL)	14,486	13,997
Total	**126,444**	**30,472**

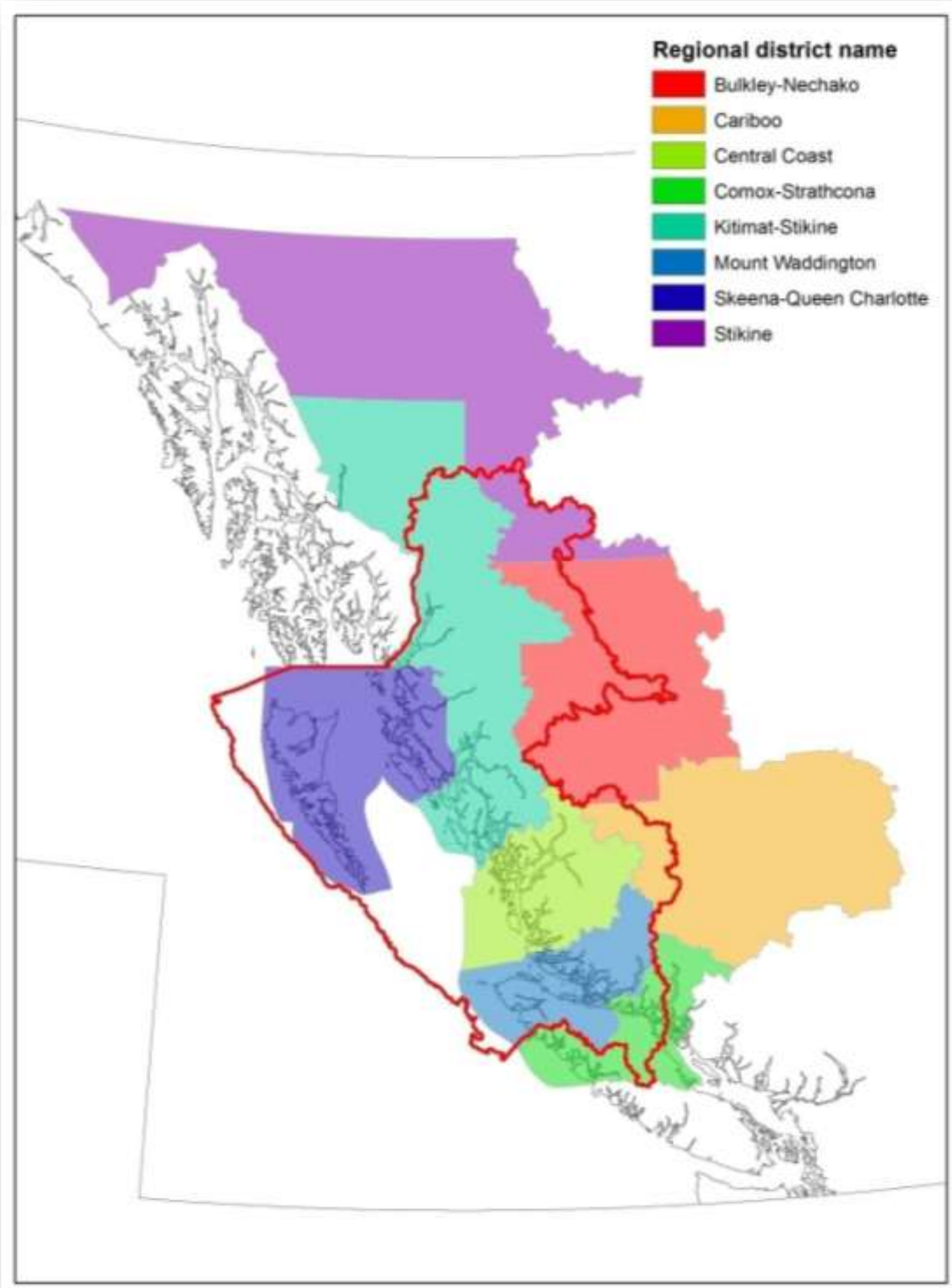

Figure 4. Regional districts contained within the PNCIMA region (data: SC 2007).

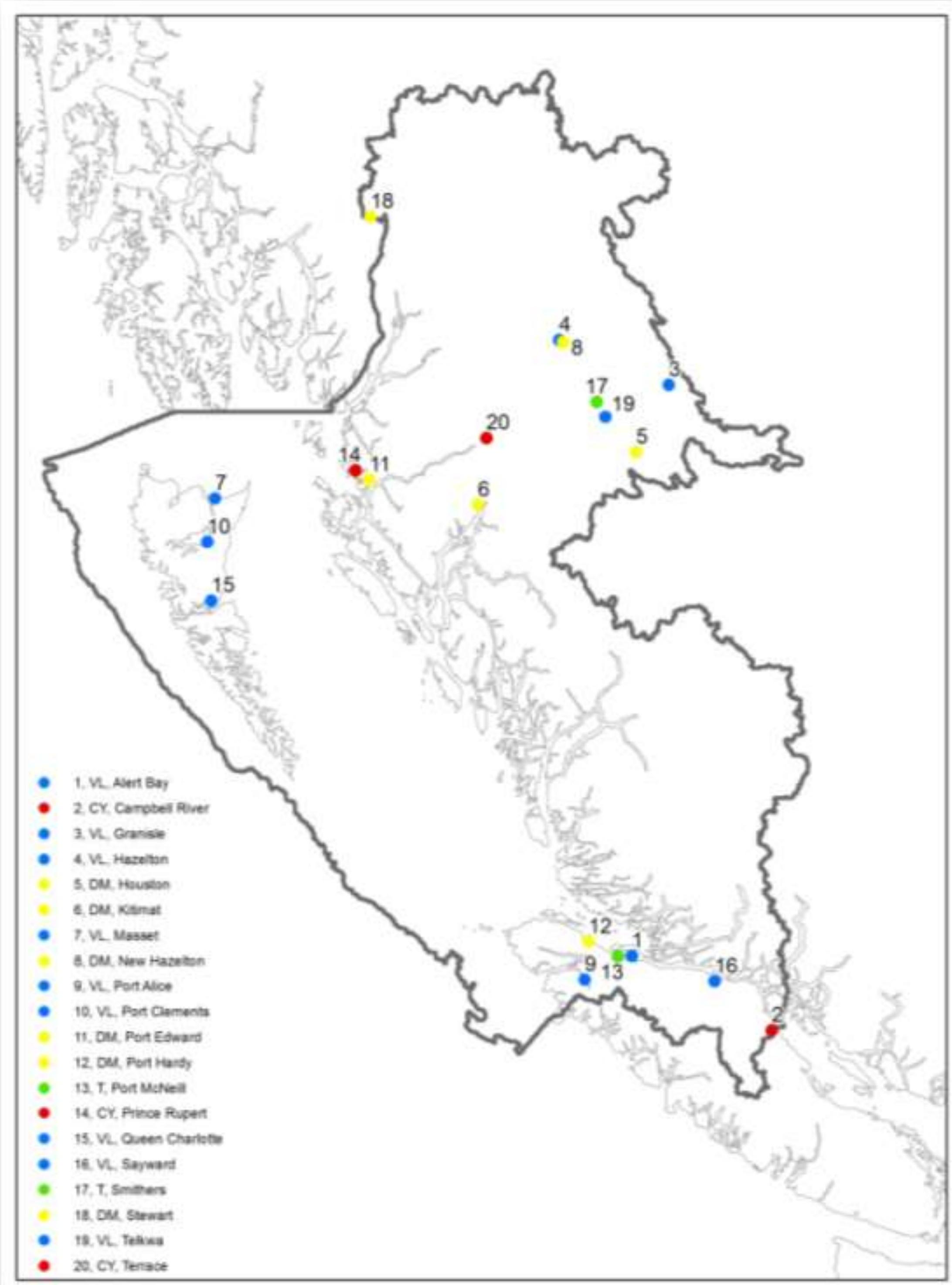

Figure 5. Cities, district municipalities, towns, and villages located within the PNCIMA (data: BC Stats 2006a, SC 2007). CY = City; DM = District Municipality; T = Town; VL = Village.

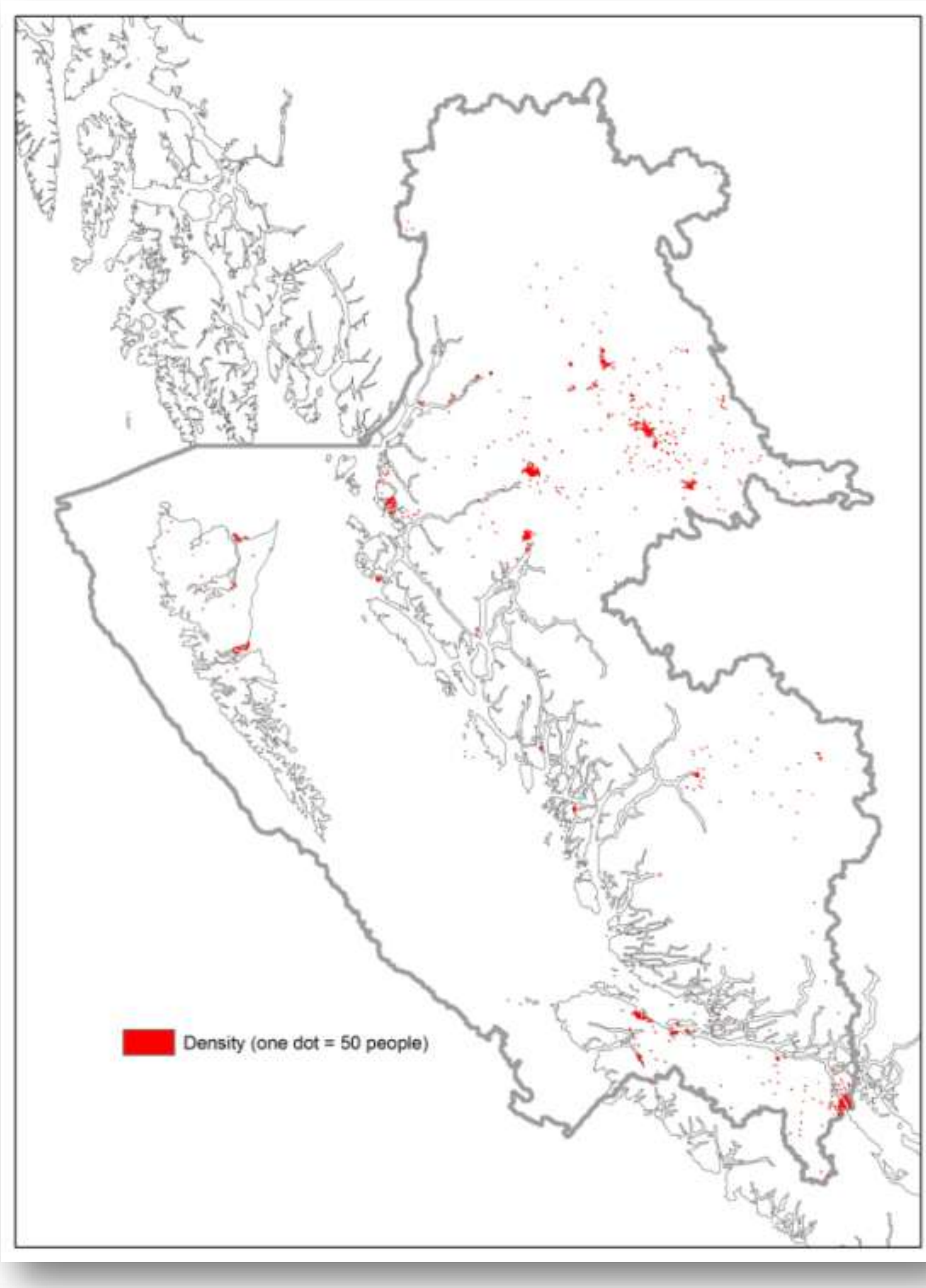

Figure 6. Population density in the PNCIMA (modified: BC Stats 2007).

Throughout most of the PNCIMA region, the population density is very low (**Figure 6**). The larger population clusters occur along the coast (Campbell River, Port Hardy, Queen Charlotte, Masset, Prince Rupert, Port Edward), at the head of Douglas Channel (Kitimat), and along the Skeena River (Terrace, Hazelton, Smithers, Telkwa, and Houston). In the Skeena-Queen Charlotte Regional District, density actually decreased somewhat between 1976 and 2003, probably because of the downturn in the forest and fishing industries in this area (BCMOE 2006b). For most of the region, population is expected to increase slowly over the next 25 years (Kitimat-Stikine - 13% increase; Skeena-Queen Charlotte - 12% increase; Bulkley-Nechako - 13% increase; Cariboo 5% - increase) (BCMOE 2006b). However, both the Central Coast and the Stikine Regional Districts are predicted to have no growth in the future (population growth is being balanced by out-migration and population aging) (Terry et al. 2000). Mount Waddington Regional District is predicted to have a 3% decrease in population. This estimated drop is part of an ongoing reaction to the closing of the Island Copper Mine, timber harvesting reductions, and a down-turn in salmon fisheries with the associated vessel buybacks (BCMSRM 2002). By contrast, Comox-Strathcona, the most southerly regional district in the PNCIMA region, is expected to have a 33% increase in population.

5.2. First Nations

Much of the central and north coast is comprised of First Nation traditional territory (**Figure 7**). There are 10 Treaty Societies representing 40 First Nations, as well as 18 independent First Nations, in the PNCIMA (**Table 3**). In 2005, the reported registered First Nations population (DIAND 2006) for the PNCIMA region was 49,072 (**Table 4**). 43% of this population lived on reserve. In the 2006 census (SC 2008), approximately 30,472 people, or 24% of the total population, indicated that they had Aboriginal identity. Of this group, 46% live in First Nations communities on reserves in the area (**Table 2**). **Figure 8** shows the locations of all the First Nations communities within the PNCIMA which reported a resident population during the 2006 census.

Table 3. Treaty Societies and First Nations in the PNCIMA region.

Treaty Societies	First Nations
Carrier Sekani Tribal Council	Nadleh Whut'en First Nation, Nak'azdli First Nation, Saik'uz (Stony Creek) First Nation, Stellat'en First Nation, Takla Lake First Nation, Tl'azt'en First Nation, Ts'il Kaz Koh (Burns Lake) First Nation, Wet'suwet'en (Broman Lake) First Nation
Council of the Haida Nation	Masset First Nation, Skidegate First Nation
Gitxsan Treaty Society	Gitanmaax First Nation, Gitsegukla First Nation, Gitwangak First Nation, Glen Vowell First Nation, Kispiox First Nation
Hamatla Treaty Society	Kwiakah First Nation, We Wai Kai (Cape Mudge) First Nation , We Wai Kum (Campbell River) First Nation
Maa-nulth First Nations	Huu-ay-aht First Nations, Ka:'yu:'k't'h'/Che:k:tles7et'h' (Kyuquot) First Nations, Toquaht First Nation, Uchucklesaht First Nation, Ucluelet First Nation
Musgamagw Tsawataineuk Tribal Council	Kwicksutaineuk-Ah-Kwaw-Ah-Mish First Nation, Tsawataineuk First Nation
Nisga'a Tribal Council	Gitwinksihlkw First Nation, Kincolith First Nation, Laxgalts'ap First Nation, New Aiyansh First Nation
Office of the Wet'suwet'en	Hagwilget First Nation, Moricetown (Kya Wiget) First Nation
Tsimshian First Nations	Gitga'at (Hartley Bay) First Nation, Kitasoo/Xai'xais First Nation, Kitselas First Nation, Kitsumkalum First Nation, Metlakatla First Nation
Winalagalis Treaty Group	Da'naxda'xw (Tanakteuk) First Nation, Gwa'Sala-Nakwaxda'xw (Tsulquate) First Nation, Quatsino First Nation, Tlatlasikwala (Nuwitti) First Nation
Independent First Nations	Cheslatta Carrier First Nation, Gitanyow First Nation, Gitxaala First Nation, Gwawaenuk First Nation, Haisla First Nation, Heiltsuk First Nation, K'ómoks First Nation, Kwakiutl First Nation, Lake Babine First Nation, Lax-Kw'alaams First Nation, Mamalilikulla-Qwe'Qwa'Sot'Em First Nation, 'Namgis First Nation, Nee-Tahi-Buhn First Nation, Nuxalk First Nation, Skin Tyee First Nation, Tlowitsis First Nation, Wuikinuxv (Oweekeno) First Nation, Yekooche First Nation

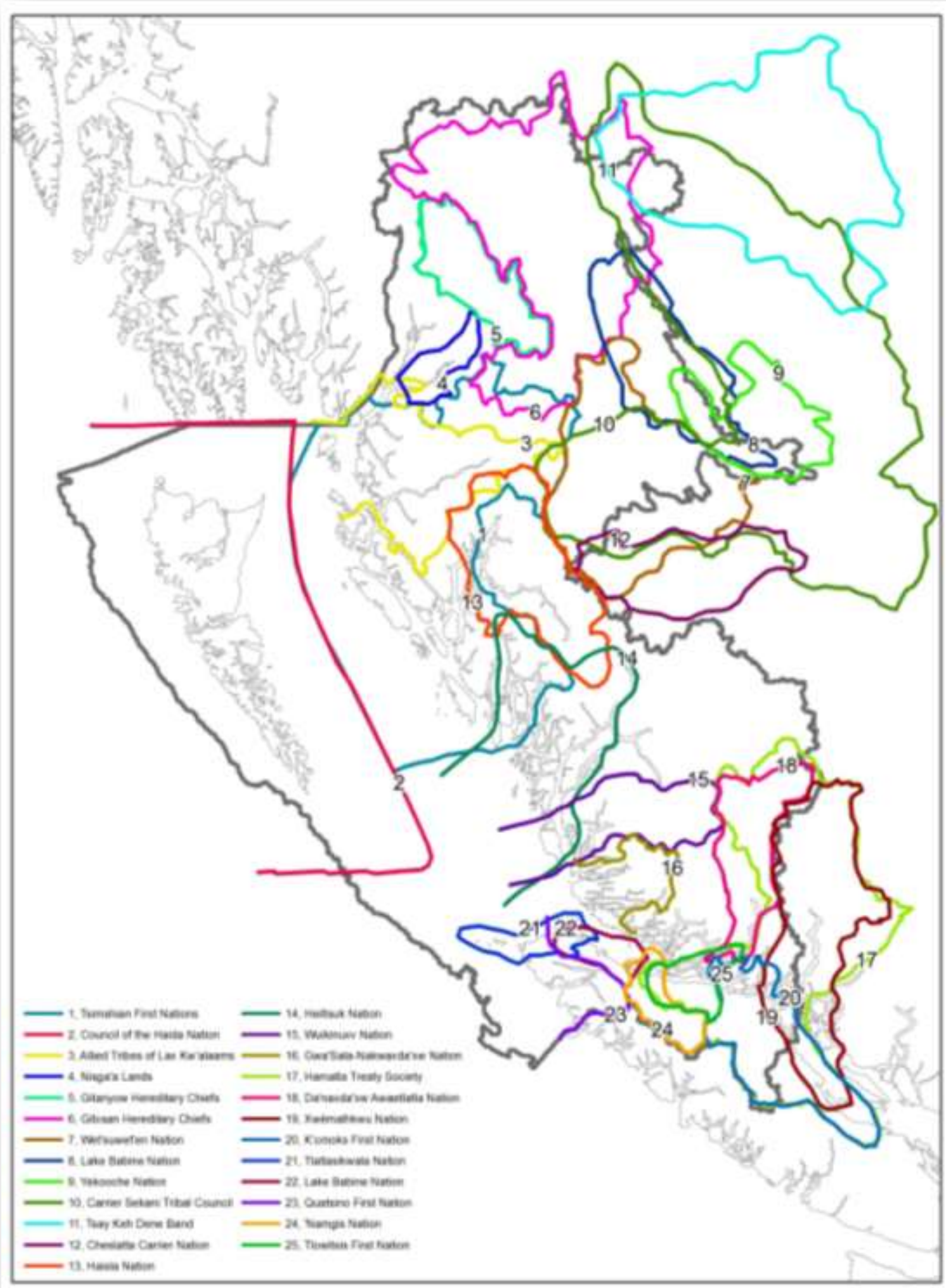

Figure 7. Approximate boundaries of traditional territories in the PNCIMA region as described in First Nation Statements of Intent to negotiate treaties which have been submitted to, and accepted by the BC Treaty Commission (modified: BC Treaty Commission 2007).

Table 4. Registered First Nations population in 2005 (DIAND 2006).

First Nation	Total Population	On Reserve	Off Reserve
Cheslatta Carrier First Nation	302	138	164
Da'naxda'xw (Tanakteuk) First Nation	182	51	131
Gitanmaax First Nation	2,038	855	1,183
Gitanyow First Nation	706	403	303
Gitga'at (Hartley Bay) First Nation	655	179	476
Gitsegukla First Nation	874	473	401
Gitwangak First Nation	1,088	487	601
Gitwinksihlkw First Nation	373	225	148
Gitxaala First Nation	1,678	527	1,151
Glen Vowell First Nation	380	196	184
Gwa'Sala-Nakwaxda'xw (Tsulquate) First Nation	745	512	233
Gwawaenuk First Nation	40	19	21
Hagwilget First Nation	672	234	438
Haisla First Nation	1,560	669	891
Heiltsuk First Nation	2,130	1,179	951
Huu-ay-aht First Nations	598	113	485
Ka:'yu:'k't'h'/Che:k:tles7et'h' (Kyuquot) First Nations	485	175	310
Kincolith First Nation	1,854	412	1,442
Kispiox First Nation	1,417	727	690
Kitasoo/Xai'xais First Nation	499	308	191
Kitselas First Nation	493	173	320
Kitsumkalum First Nation	645	211	434
K'ómoks First Nation	280	118	162
Kwakiutl First Nation	654	304	350
Kwiakah First Nation	0	0	0
Kwicksutaineuk-Ah-Kwaw-Ah-Mish First Nation	267	66	201
Lake Babine First Nation	2,181	1,411	770
Laxgalts'ap First Nation	1,564	545	1,019
Lax-Kw'alaams First Nation	3,005	788	2,217
Mamalilikulla-Qwe'Qwa'Sot'Em First Nation	372	53	319
Masset First Nation	2,581	814	1,767
Metlakatla First Nation	728	109	619
Moricetown (Kya Wiget) First Nation	1,776	704	1,072
Nadleh Whut'en First Nation	411	251	160
Nak'azdli First Nation	1,674	788	886
'Namgis First Nation	1,557	910	647
Nee-Tahi-Buhn First Nation	131	58	73
New Aiyansh First Nation	1,724	891	833
Nuxalk First Nation	1,398	914	484
Quatsino First Nation	417	204	213
Saik'uz (Stony Creek) First Nation	855	534	321
Skidegate First Nation	1,373	779	594
Skin Tyee First Nation	133	52	81
Stellat'en First Nation	405	221	184
Takla Lake First Nation	632	328	304
Tlatlasikwala (Nuwitti) First Nation	52	37	15
Tl'azt'en First Nation	1,462	565	897
Tlowitsis First Nation	355	96	259
Toquaht First Nation	112	13	99
Tsawataineuk First Nation	506	180	326
Ts'il Kaz Koh (Burns Lake) First Nation	97	40	57
Uchucklesaht First Nation	180	25	155
Ucluelet First Nation	607	214	393
We Wai Kai (Cape Mudge) First Nation	867	364	503
We Wai Kum (Campbell River) First Nation	616	313	303
Wet'suwet'en (Broman Lake) First Nation	208	113	95
Wuikinuxv (Oweekeno) First Nation	267	109	158
Yekooche First Nation	211	160	51
Total	**49072**	**21337**	**27735**

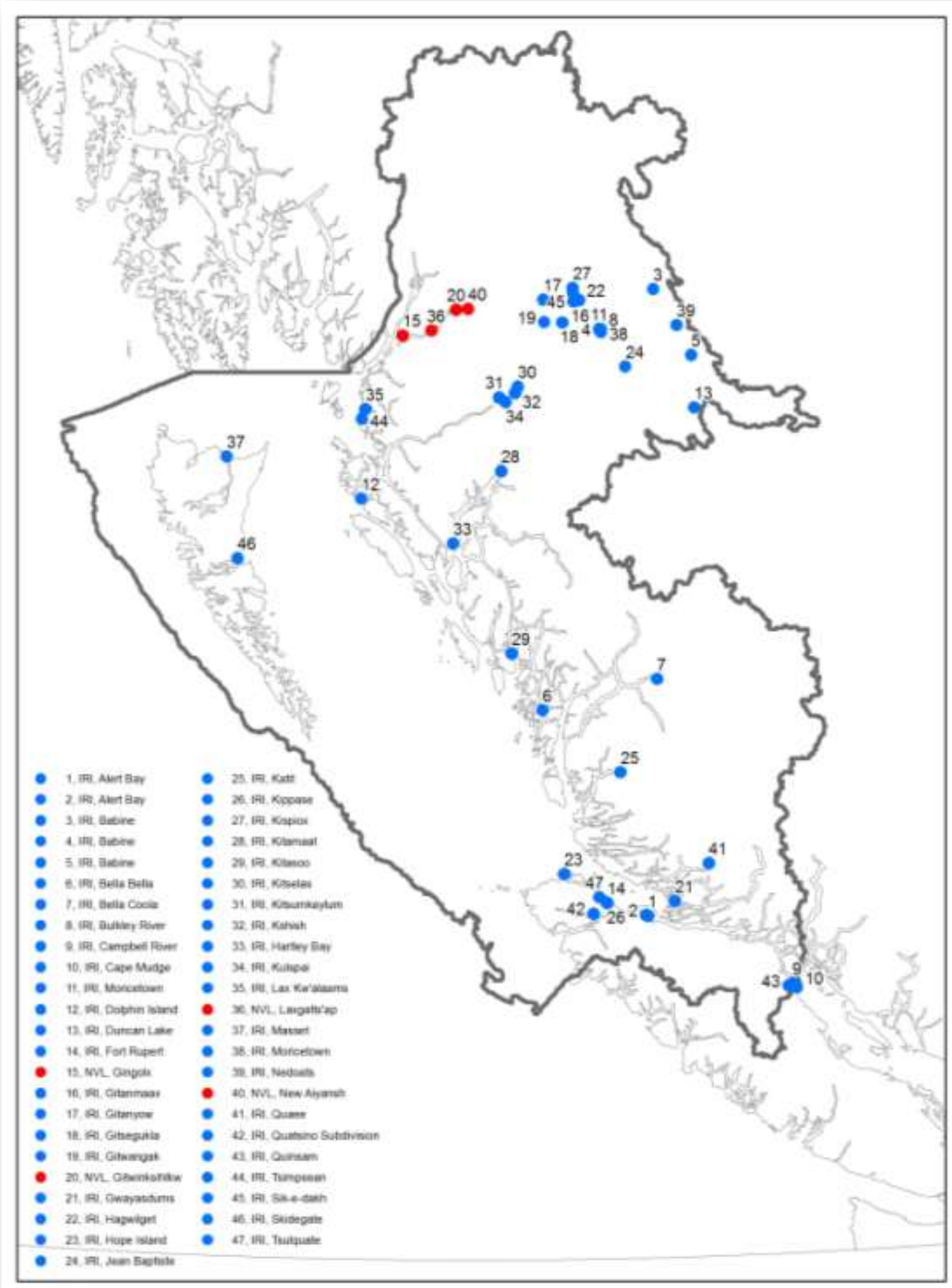

Figure 8. First Nations communities located within the PNCIMA which reported a resident population during the 2006 census (data: BC Stats 2006a, SC 2007). IRI = Indian Reserve; NVL = Nisga'a Village.

First Nations continue to exercise legal Aboriginal rights which include fishing, shellfish harvesting and marine plant collection. Aboriginal food harvesting is economically significant to First Nations households, supplementing other incomes and food supplies. For example, the Gwawaenuk First Nation members all have specific resource use areas and are highly dependent on marine resources for food, cultural use, and to subsidize family income (BCMSRM 2002). Further north, the Tsimshian use a wide array of resources from the lands and sea within their traditional territory. They harvest many food resources from the sea, including eulachon, herring, smelt, lingcod, rockfish, sturgeon, perch, halibut and flounder. Waterfowl and sea mammals, such as seals, sea lions and porpoises, are also hunted. Beach foods such as sea urchins, crabs, clams, mussels, cockles, abalone, scallops and others are gathered, and constitute a large part of their diet. Seaweed and roe on kelp are also important to the Tsimshian (BCMSRM 2005a). Similar examples can be provided for every First Nations group living on the coast.

Concerns that communities engaged in subsidence food gathering may be exposed to elevated levels of persistent organic pollutants (POPs) and heavy metals (e.g., mercury) present in aquatic foods have been raised elsewhere. Groups of special concern include First Nations, Inuit, sport fishing families and some immigrant communities, since their diets all consist of a high proportion of aquatic foods (Kuhnlein 1995, Mos et al. 2003, Pellettieri et al. 1996, van Oostdam et al. 1999). For example, the Inuit of Arctic Canada have been shown to have up to seven times higher levels of POPs in their breast milk than average (non-subsistence, southern) Canadians as a result of their consumption of traditional foods such as fish, whale and seal meat (Dewailly et al. 1989). Though a similar study has not been completed in the PNCIMA region, a recent survey was carried out to assess the relative importance of traditional foods in the diet of the Sencoten people, on Southern Vancouver Island (Mos et al. 2003). They found that the people surveyed continued to show a high reliance on traditional food items, particularly salmon, despite the community's close proximity to an urban centre. First Nations peoples in the PNCIMA region may rely on an even greater proportion of traditional food items due to the remote nature of many of their communities (**Figure 8**).

5.3. Physical Environment

The Pacific North Coast Integrated Management Area covers a wide array of coastal environments, ranging from the Queen Charlotte Islands in the North to the northern end of Vancouver Island in the south. There are 32 major ecosections (based on the Ecoregion Classification of British Columbia) found within the PNCIMA (**Figure 9**). A brief description of each ecosection's major environmental characteristic and its area within the PNCIMA is given in **Table 5**.

The western side of the Queen Charlotte Islands, with its narrow continental shelf, has the greatest wave exposure on the BC coast. The low lying mountain ranges of the Queen Charlotte Islands produce only minor orographic effects (effect which occurs when moist air flowing from the ocean encounters a mountain barrier and is forced up over the mountains; the air continues to cool as it rises, and the moisture condenses and precipitates as rain or snow on the windward side of the mountain; this creates high rainfall on the windward [west] side and rain shadows on the lee side). Winters are mild. While precipitation occurs frequently, there is little accumulation, and no permanent snow or ice is formed in the mountains. Local rivers have relatively small watersheds. As a result, 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, have rocky shorelines cut by narrow, deep inlets. The northeast corner of Graham Island is an exception, where sand beaches dominate, and a huge, shallow, sandy bank forms much of the floor of northwestern Hecate Strait (Johannessen et al. 2007a).

The North Coast mainland is protected from wave exposure by the Queen Charlotte Islands and many low-lying, smaller islands and deep, narrow straits and channels. As a result, this region experiences mild winters and frequent rainfall. The mainland Coast Mountains are a high elevation, granitic mountain range which has undergone glacial erosion. This glacial carving has created long, deep, steep-sided inlets. The orographic effect of these high coastal mountains is significant, and coastal communities in this area have some of Canada's highest recorded rainfall volumes. At higher elevations, snow and ice accumulate, producing meltwater discharge peaks in the 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 (Johannessen et al. 2007a).

The Central Coast has a prevailing wet climate which generates large volumes of runoff on the mountain slopes from heavy rainfall or melting snow. Slope stability is maintained by rapid drainage through the forest soils of the steep slopes; however, landslides often occur where drainage is altered or impeded. Nutrient-laden sediment carried down to the marine environment by water drainage has formed numerous estuaries throughout the Central Coast, and contributes to the high productivity levels of nearshore coastal waters. Coastal and marine habitats of the Central Coast are highly diverse, and range from high energy ocean conditions to sheltered fjords (CCLCRMP 2001).

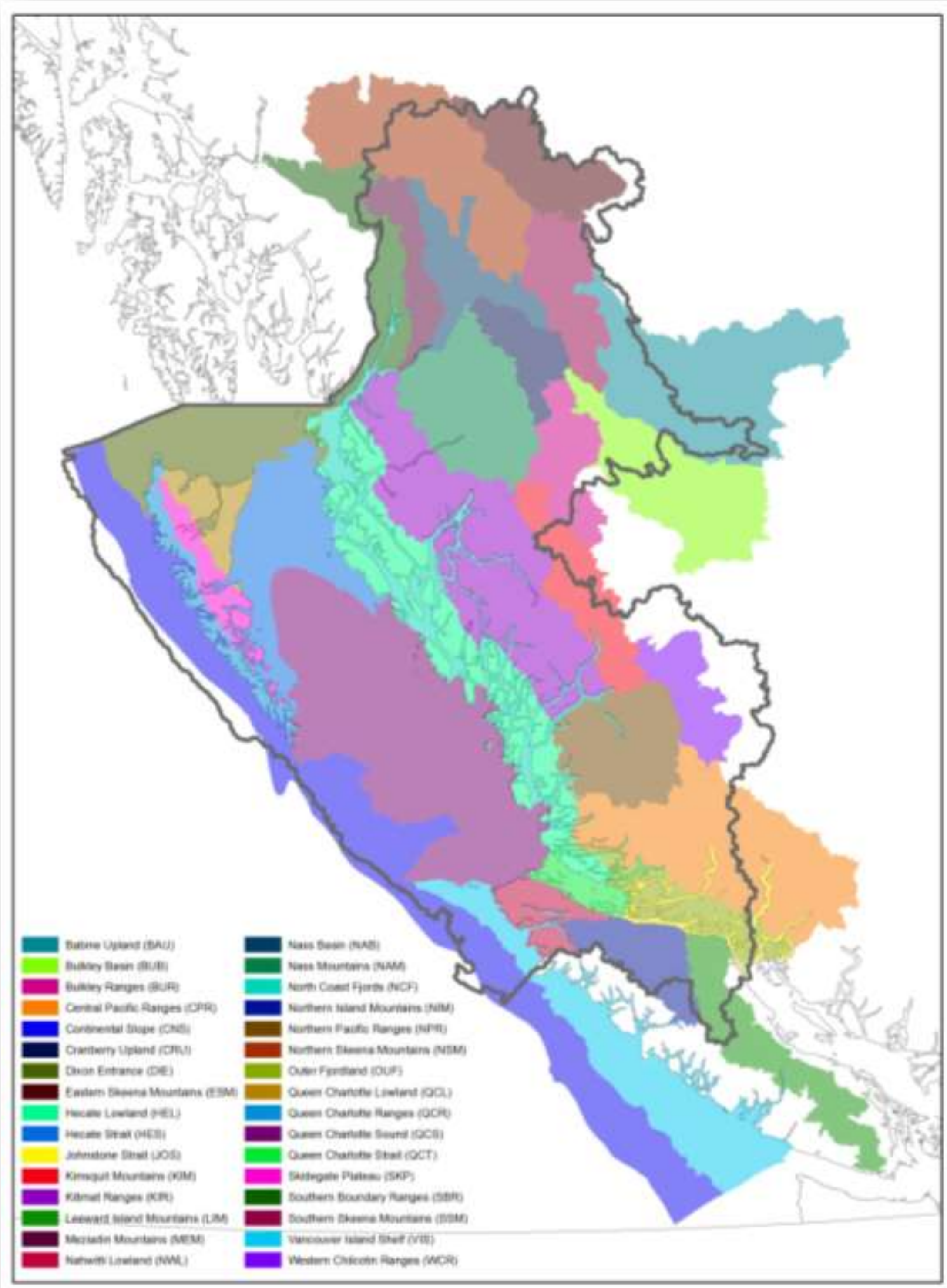

Figure 9. Major ecosystems located within the PNCIMA (modified: Hectares BC 2006).

The northern end of Vancouver Island is dominated by the waters, beaches and islands of the Queen Charlotte Sound. The mainland side of the Sound is fully exposed to the impact of wind and waves generated in the open Pacific, while the Vancouver Island side is more sheltered. Queen Charlotte Strait is a more protected, broader stretch of open water which begins at the Storm Islands and ends to the east in the Broughton Archipelago complex. The Archipelago is composed of several major islands and narrow passages, along with hundreds of smaller islands, islets and rocks. Johnstone Strait is south of the Archipelago, and follows the Vancouver Island shoreline south to the Strait of Georgia. East of Johnstone Strait and the Broughton Archipelago lay Kingcome and Knight Inlets, both long, narrow fjords, fed by rivers originating in ice fields of the Coast Ranges. Knight Inlet extends almost 100 km further inland beyond the boundary the PNCIMA. The uplands surrounding these water bodies are geographically very diverse. They range from the low elevation Nahwitti Lowlands in the west to the high elevation Northern Island Mountains and Coast Ranges on the mainland. Steep sided fjords carved out by advancing glaciers predominate on the mainland coast. The numerous island complexes and groups, including the Broughton Archipelago, vary in topography from rugged to low relief landscapes. Streams on Vancouver Island tend to flow throughout the year, with peak flows normally occurring during the winter due to high precipitation. On the mainland side, streams are largely fed by Coast Range ice caps and snow melt, and are subject to high flows in the spring (BCMSRM 2002).

The major river systems within the PNCIMA are shown in **Figure 10**. The Skeena and the Nass are the largest two river systems, draining approximately 56,000 km^2 and 24,000 km^2, respectively. They dominate the drainage patterns in the North Coast. In the Central Coast, the river systems are smaller, with the largest three being the Dean. Atnarko, and Klinaklini Rivers. Northern Vancouver Island has four major rivers systems – the Nimpkish, Adam, Salmon, and Quinsam Rivers. The major drainage basins in the PNCIMA are shown in **Figure 11**.

Table 5. Descriptions of the major ecosections located within the PNCIMA (BCMOE 1996, Demarchi 1996, Howes et al. 1997, North Coast LRMP Government Technical Team 2003).

Ecosection	Ecoprovince	Area within PNCIMA (km^2)	Description
Queen Charlotte Sound (QCS)	Coast and Mountains (COM)	36597	A deeply dissected shelf area with several large intervening banks; exposed to oceanic waves allowing for oceanic water intrusions
Kitimat Ranges (KIR)	Coast and Mountains (COM)	22645	An area of subdued, yet steep-sided mountains, east of the Hecate lowlands; includes both the windward and the leeward slopes of the Kitimat Ranges; receives the greatest frequency of frontal weather systems on the coast, but the lower Coast Mountain barrier and the long fjords allow some of the moist coastal air to flow eastward to the interior, thereby reducing the overall precipitation
Continental Slope (CNS)	Coast and Mountains (COM)	20635	A marine ecosection consisting of a steep sloping shelf; has strong across slope and down slope turbidity currents; is an upwelling zone and has productive coastal plankton communities and unique assemblages of benthic species; transitional area between the continental slope and the abyssal plain
Hecate Lowland (HEL)	Coast and Mountains (COM)	15436	An area of low relief, consisting of islands, channels, rocks and lowlands adjacent to Hecate Strait and Queen Charlotte Sound; has been heavily glaciated as evidenced by large areas of glacially abraded, exposed bedrock surfaces; topography is rough, but total relief does not exceed 650 m; climate is dominated by frontal systems moving in from the Pacific Ocean and subsequently lifting over the Coast Mountains to the east; windward rainfall is heavy, but it is less intense than in other coastal stretches due to the significantly lower Coast Mountain Barrier
Hecate Strait (HES)	Coast and Mountains (COM)	12829	A broad semi-enclosed estuarine waterway located between the mainland coast, the Queen Charlotte Islands and northern Vancouver Island; is a very shallow strait dominated by coarse bottom sediments; has semi-protected waters with strong tidal currents that promote "mixing"
Nass Mountains (NAM)	Coast and Mountains (COM)	12532	A mountainous area west of the Kitimat Ranges; climate is somewhat transitional between coastal and interior regimes; consists of the north-west portion of the Hazelton Mountains, bisected by the Skeena, Cedar and Kitsumkalum Rivers, with the Nass River forming the northern boundary; Kitsumkalum Lake is the largest lake in the ecosection
Central Pacific Ranges (CPR)	Coast and Mountains (COM)	11377	Forms a portion of the southern-most mountain range of the Coast Mountains in British Columbia; is an area of rugged, low relief, consisting of inlets, sounds, islands and peninsulas, east of Johnstone Strait and Seymour Narrows
Northern Skeena Mountains (NSM)	Sub-Boreal Interior (SBI)	11025	Consists of high rugged mountains; is formed largely of folded sedimentary rocks, divided into ranges by prominent northwest trending valleys; has many glaciers persist especially in the north; has a moist, coast/interior transitional climate resulting from prevailing westerly winds which bring Pacific air over the Coast Mountains and up the Skeena, Nass and Iskut valleys - these uplifting air masses contain much of the precipitation that escapes inland through the "coastal gap"; during winter and early spring, frequent outbreaks of Arctic air result in very high snow fall
Dixon Entrance (DIE)	Coast and Mountains (COM)	10850	Located between northern Graham Island and Prince of Wales and Dall Islands in southeastern Alaska; has a strong freshwater discharge influence from the Skeena, Nass and other rivers
Northern Pacific Ranges (NPR)	Coast and Mountains (COM)	9865	An area of steep, rugged, often ice-capped, mountains located in the northern portion of the southern-most mountain range of the Coast Mountains in British Columbia
North Coast Fjords (NCF)	Coast and Mountains (COM)	9338	A marine ecosection consisting of deep narrow fjords cutting into high coastal relief; very protected waters with restricted circulation and often strongly stratified; low species diversity and productivity due to poor water exchange and nutrient depletion; unique species assemblages in benthic and planktonic communities

Ecosection	Ecoprovince	Area within PNCIMA (km^2)	Description
Babine Upland (BAU)	Sub-Boreal Interior (SBI)	7423	A rolling upland with low ridges and several large lakes in the depressions; bounded by the Hazelton Mountains, the Skeena and Omineca Mountains and the Fraser Plateau
Eastern Skeena Mountains (ESM)	Sub-Boreal Interior (SBI)	7284	Lies leeward of the Skeena Mountains; has wide valleys with high isolated mountains
Southern Skeena Mountains (SSM)	Sub-Boreal Interior (SBI)	7173	Consists of a narrow range of mountains to the east of the Nass Basin and the west of the Nechako Plateau; climate is variable, being wetter and milder on the west side and drier and colder on the east side; Skeena Mountains are underlain by folded sedimentary rocks and divided into ranges with prominent northwest trending valleys; most of the ecosection is drained by the Skeena River; most of the low elevation valleys are disturbed by logging, mining, and exploration activity
Nass Basin (NAB)	Coast and Mountains (COM)	6216	A broad low elevation basin of low relief, surrounded by high mountains rising abruptly at its edge; includes the mid and upper Nass River valley, the mid Skeena River valley and the saddle between the two watersheds; climate is influenced by the coastal air which penetrates far inland, causing heavy winter snow packs and cool moist summers
Kimsquit Mountains (KIM)	Coast and Mountains (COM)	5483	An area similar to the Kitimat Ranges Ecosection.
Western Chilcotin Ranges (WCR)	Central Interior (CEI)	5274	An area of high, moist, rugged mountains, located just south of the low Kitimat Ranges
Bulkley Ranges (BUR)	Central Interior (CEI)	4808	A narrow mountain area located leeward of the rounded Kitimat Ranges; comprised of the leeward portion of the Bulkley Ranges, within the Hazelton Mountains; characterized by rugged mountains, with serrate peaks above 2000 m, and wide, flaring valleys with floors at 1000 m elevation; between the steep alpine and the U-shaped valleys are upland plateaus of alpine tundra; moist Pacific air invades this area through numerous low mountain passes, while cold Arctic air frequently stalls along its eastern boundary
Northern Island Mountains (NIM)	Coast and Mountains (COM)	4733	A partial rain shadow of wide valleys and mountains located in the northern portion of Vancouver Island
Meziadin Mountains (MEM)	Coast and Mountains (COM)	4406	A rugged mountain area which lies on the leeward side of the Boundary Ranges; has a strong rain shadow, as the western summits protect this area from the moist Pacific air; cold interior air can build up in this ecosection, providing some drying, although the interaction of cold and warm air can lead to heavy snowfalls; mountain summits have small icefields or glaciers
Southern Boundary Ranges (SBR)	Coast and Mountains (COM)	4347	A large block of rugged, ice-capped, granitic mountains that are dissected by several major river valleys; forms the eastern or interior-most segment of the Northern Coastal Mountains which extend through both Alaska and British Columbia; most of this ecosection occurs in British Columbia; tends to be lower in elevation than the Central and Northern Boundary Ranges, with a greater proportion of summits and ridges that were over-ridden by glacial ice; climate is more coastal, due to Portland Canal and Observatory Inlet, which bisect the ranges as far north as the Cambria Icefield
Cranberry Upland (CRU)	Coast and Mountains (COM)	4297	An area similar to the Nass Mountains Ecosection.
Outer Fjordland (OUF)	Coast and Mountains (COM)	3853	An area of rugged, low relief, consisting of inlets, sounds, islands and peninsulas, east of Johnstone Strait and Seymour Narrows
Bulkley Basin (BUB)	Central Interior (CEI)	3578	A broad gently rolling lowland area (the Fraser Plateau); is largely uncut by waterways, except for some long, linear lakes within the Nechako, Endako, and Bulkley River valleys; has a continental climate with rain shadow effects from the coastal Mountains; much of the land, especially in the valley bottoms, has been cleared and converted to cultivated fields, pastures and urban development

Ecosection	Ecoprovince	Area within PNCIMA (km^2)	Description
Queen Charlotte Ranges (QCR)	Coast and Mountains (COM)	3541	Very wet, rugged western side of the Queen Charlotte archipelago; hyper-oceanic climate is wetter than that of other parts of the archipelago, with the summers being cool, wet and humid with rare dry spells and the winters being cool and very wet, with an ephemeral snowpack at lower elevations; clouds and fog are common and relative humidity is high throughout the year
Skidegate Plateau (SKP)	Coast and Mountains (COM)	3405	A plateau in the lee of the Queen Charlotte Mountains; consists of eroded floodplains, table-topped hills and flat ridges; climate is cool, temperate and oceanic, with a high frequency of cloud cover and fog; precipitation is somewhat reduced; introduced species such as raccoon and rats compete with native species, while others such as Sitka black-tailed deer significantly alter vegetation communities
Nahwitti Lowland (NWL)	Coast and Mountains (COM)	3375	A lowland area which is often poorly drained.
Queen Charlotte Lowland (QCL)	Coast and Mountains (COM)	3288	An area of low relief, poor drainage and extensive muskeg and wetland located on northeastern Graham Island; climate is cool, temperate and oceanic , with a high frequency of cloud cover and fog; leeward location of the lowland in relation to the Queen Charlotte Mountains results in reduced precipitation; several introduced species, such as raccoon, Sitka black-tailed deer and Rocky Mountain elk, have become established on the islands and compete with native species or damage plant communities
Vancouver Island Shelf (VIS)	Coast and Mountains (COM)	2988	A marine ecosection consisting of a narrow gently sloping shelf; open coast with oceanic wave exposures; has a northward flowing, coast-hugging buoyant currant due to freshwater influence; seasonal upwelling occurs at the outer margin; highly productive with a neritic planktonic community; forms the northern limit for hake, sardine, northern anchovy, and Pacific mackerel; has a productive benthic community; forms rich fishing grounds for benthic fish and invertebrates
Leeward Island Mountains (LIM)	Georgia Depression (GED)	2875	Is a mountainous area from the crest of the Vancouver Island Ranges to the Nanaimo Lowlands; is an area of reduced rainfall
Queen Charlotte Strait (QCT)	Coast and Mountains (COM)	2699	A predominantly shallow (< 200 m) marine ecosection; has high relief with deeper fjords; has high current and is well mixed; has moderate to high salinities with some freshwater inputs in the inlets and fjords; very important for marine mammals; forms a migratory corridor for anadromous fish; moderate shellfish habitat
Johnstone Strait (JOS)	Coast and Mountains (COM)	1647	A marine ecosection with narrow constricted channels; has protected waters with strong currents; is well-mixed and poorly stratified; forms a migratory corridor for anadromous fish; has a rich sessile, hard substrate community and a diverse assemblage of benthic fish species

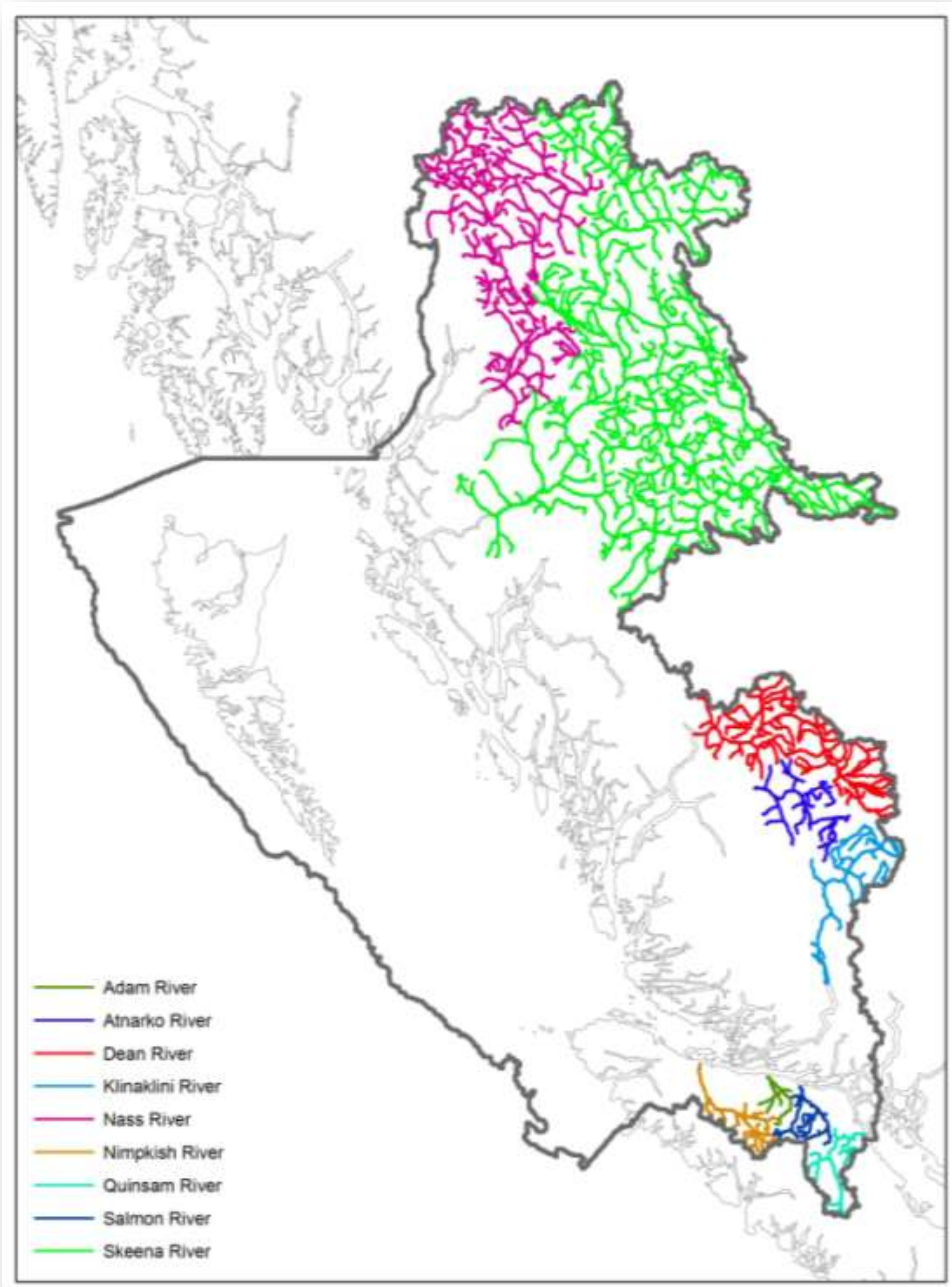

Figure 10. Major river systems within the PNCIMA (NRC 2007c).

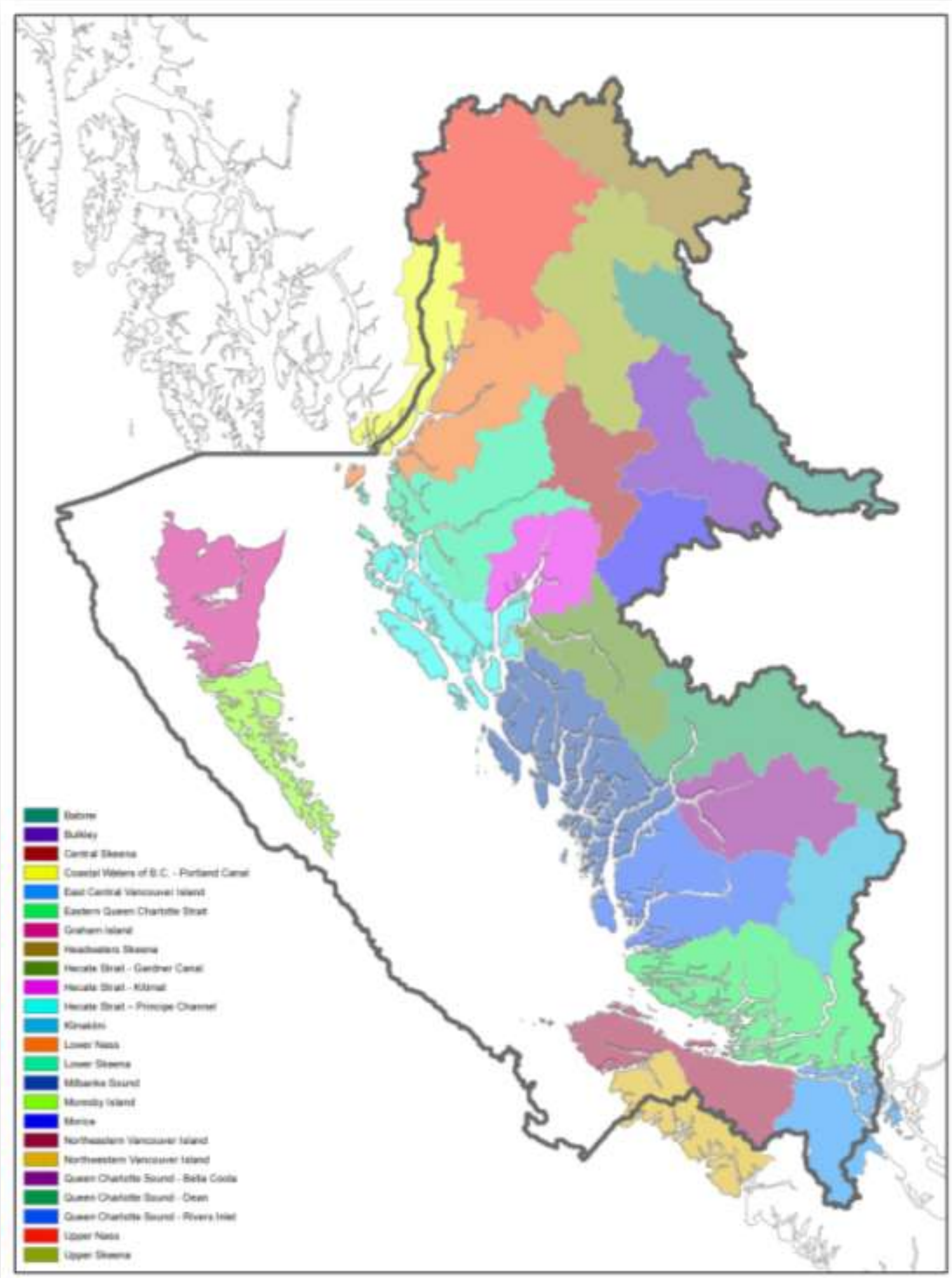

Figure 11. Major drainage basins in the PNCIMA (NRC 2007b).

5.4. Oceanography

Marine currents in the PNCIMA are generated by wind, freshwater input, and ocean floor topography. There are three major marine currents affecting the British Columbia coast (Thomson 1981):

- **Alaska Current** - a broad, slow, cold-water drift that flows from the Central Pacific eastwards to the BC Coast then curves northward off the continental shelf of the Queen Charlotte Islands; nearshore currents are stronger in the summer than winter
- **California Current** - a southward-flowing current that is poorly defined and variable, particularly at its northern range off British Columbia, Washington and Oregon; during extended periods of northwest winds in the summer, the current gains importance
- **Davidson Current** - a much smaller northward-flowing coastal current which shifts the California Current offshore in the late fall or early winter

The waters of the PNCIMA form a transitional region north of the northern end of the California Current and south of the southern end of the Alaska Current (**Figure 12**). Brooks Peninsula, on northwest Vancouver Island, is generally considered to be the dividing point between the Alaska Current and the California Current. Whereas the California Current is characterized by moderate to strong upwelling in the summer, the Alaska Current is characterized by winter downwelling. In the PNCIMA waters, summer upwelling may occur, but it is generally weak and persists only for a few months (Lucas et al. 2007).

The winds in the PNCIMA are driven by two atmospheric pressure systems over the Pacific Ocean. 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 driver of surface currents in the winter. Coastal currents are forced by these winds to flow to the northwest alongshore, forming the southern end of the Alaska Current. As a result, water is pushed north through Hecate Strait and northwest out of Dixon Entrance (**Figure 13**). In some regions of Queen Charlotte Sound, Hecate Strait and Dixon Entrance, the currents are forced by the bottom topography to flow westward, or even upwind; however the overall surface flow is alongshore. The North Pacific High dominates in summer and produces mild winds from the northwest. Its influence is stronger along southern portions of the coast. Thus, in the summer winds have less effect on currents, and sea floor topography and freshwater driven circulation dominate. This results in a general seaward flow of surface waters and landward flow of bottom waters (**Figure 13**) (Johannessen et al. 2007a, Lucas et al. 2007).

Due to the ocean floor topography, 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 (Johannessen et al. 2007a).

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 (rotate clockwise) and tend to move westward away from the coast (Crawford 2002). They can be over 200 km in diameter, 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 (Johannessen et al. 2007a).

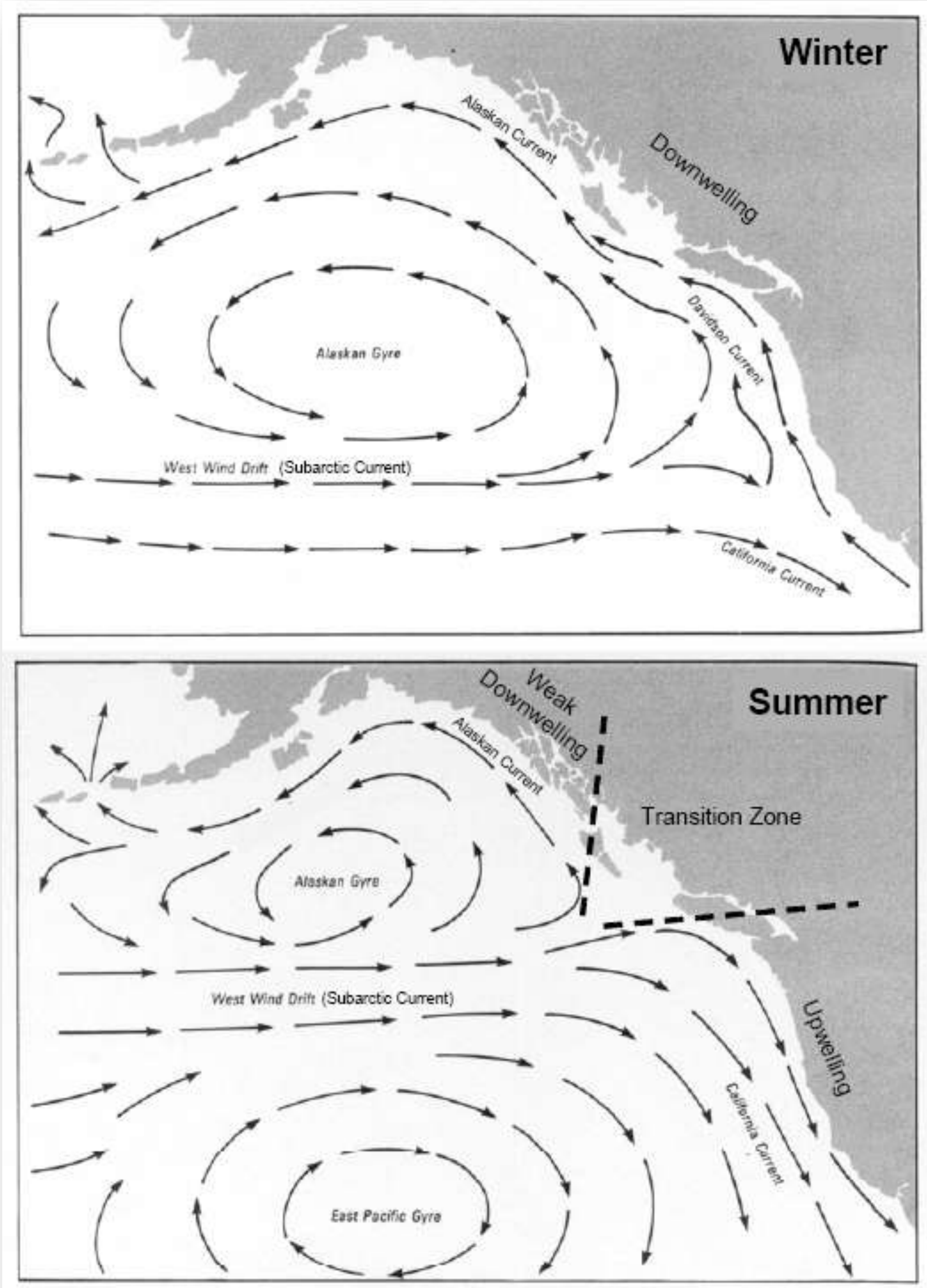

Figure 12. Ocean circulation in the northeast Pacific in summer and winter (modified: Chevron Canada Resources Ltd 1982).

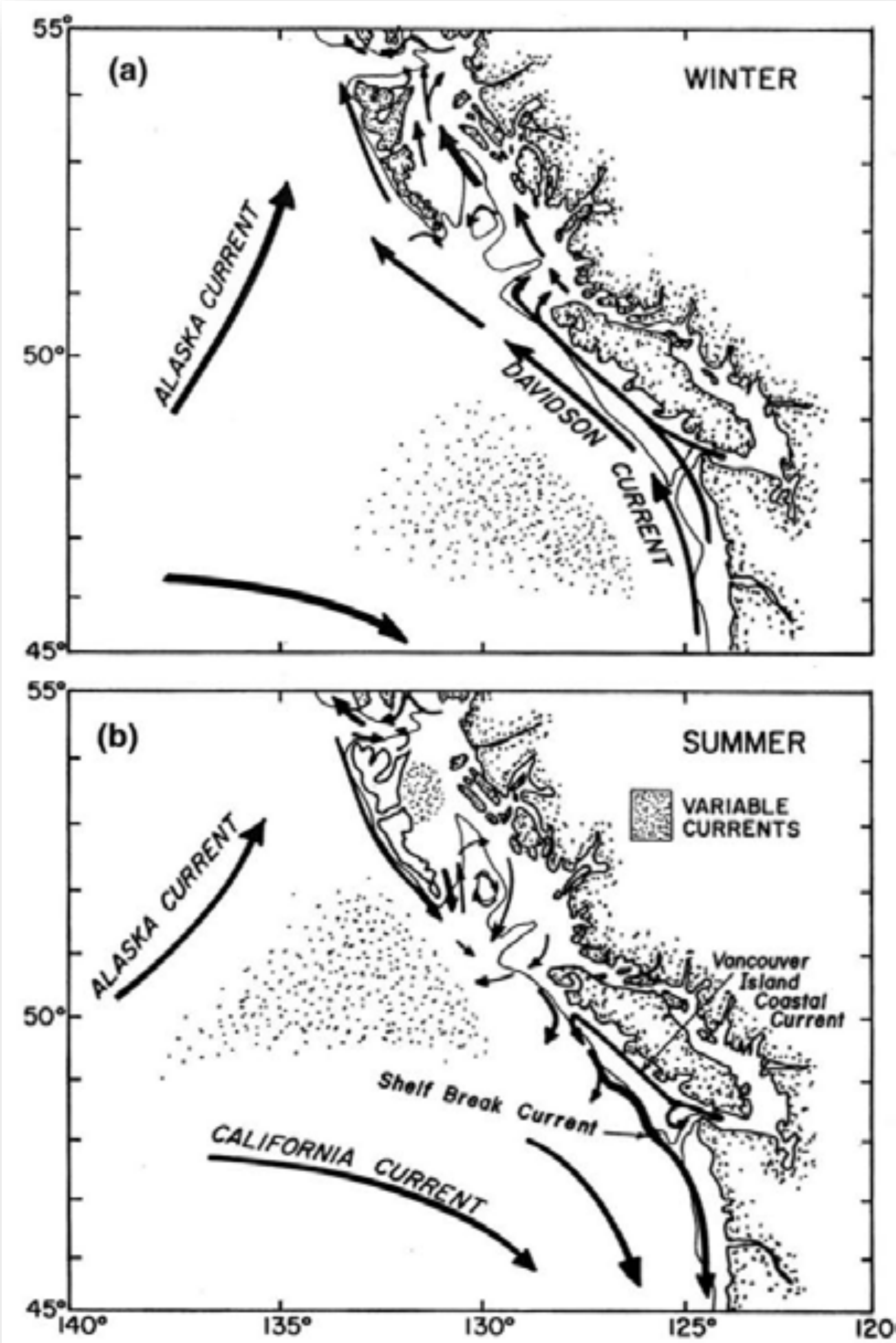

Figure 13. Ocean circulation off BC in summer and winter (source: Thomson 1981).

Estuaries are common in the PNCIMA. An estuary is a semi-enclosed region (e.g., an inlet or bay) where large amounts of freshwater (usually from a river) mix with ocean water. Freshwater runoff from rivers set up current patterns in coastal basins and inlets as a result of the density difference between fresh and salt water. This type of current pattern is known as estuarine circulation. Because freshwater is lighter than saltwater, it floats on the surface of marine water. This thin, fresh surface layer entrains (mixes) with more saline waters from below as it flows seaward. The entrainment of seawater into the surface layer causes the salinity and thickness of the layer to increase down the inlet. Underlying the surface outflow is an inflowing layer of more oceanic water which replaces the seawater that has mixed with, and is being carried out with, the surface layer. This sets up a counter-current circulation with surface water flowing seaward and deeper water flowing up inlet. No net increase in volume occurs, as the surface layer entrains an amount of water equal to that which flows up the inlet in the deep water layer. This two-way circulation is particularly well established during periods of large river runoff and when strong down-inlet winds aid the entrainment process (Haggarty et al. 2003, Thomson 1981). Estuaries are classified based the degree of stratification of the two layers (**Figure 14**). Estuaries act as nutrient traps where river-borne organic and inorganic materials collect, making them biologically active areas that support large populations of mammals, birds, invertebrates and fishes. They are also areas where pollutants can be trapped and accumulated (**Figure 15**).

Tides in the PNCIMA are generally mixed semi-diurnal (having two highs and two lows every 24.75 hours, but with successive highs or lows of unequal height). Variability occurs at fortnightly periods (e.g., the 14 day spring/neap cycle of large and small tidal ranges) and over monthly and seasonal time scales. The tide floods into Queen Charlotte Sound, and then turns northwards and progresses up Hecate Strait; the ebb outflow is in the opposite direction. As the tide moves north through Hecate Strait, the mean tide range increases from about 3 m at the entrance to Queen Charlotte Sound to about 5 m midway up Hecate Strait. Tidal currents generally have speeds of about 0.5 m/s during the large spring tides and about half that during the weaker neap tides. During spring tides, the strong tidal currents over the shallow banks may mix deeper, nutrient-rich water up to the surface where it is available to phytoplankton. Tidal fronts often define the boundaries of these well-mixed regions, and these frontal zones tend to concentrate plankton. This, in turn, attracts fish, birds and other marine life (Lucas et al. 2007). Tidal currents can be large in restricted channels (speeds of up to 2 m/s were recorded near Cape St. James; Crawford 1997). Within the coastal inlets and fjords, the tidal currents generally weaken, but can be strong in some of the narrow coastal passageways (speeds of up to 7.5 m/s occur in Nakwakto Rapids at the entrance to Seymour/Belize Inlets; CHS 2008).

The outer coast is wind and wave swept, and some inside regions, such as Dogfish Banks, experience sediment transport and shoreline erosion due to wind-forced waves. Inside channels and inlets are much more protected from waves and winds, and along many of these channels the trees extend right down to the high-tide line (Lucas et al. 2007).

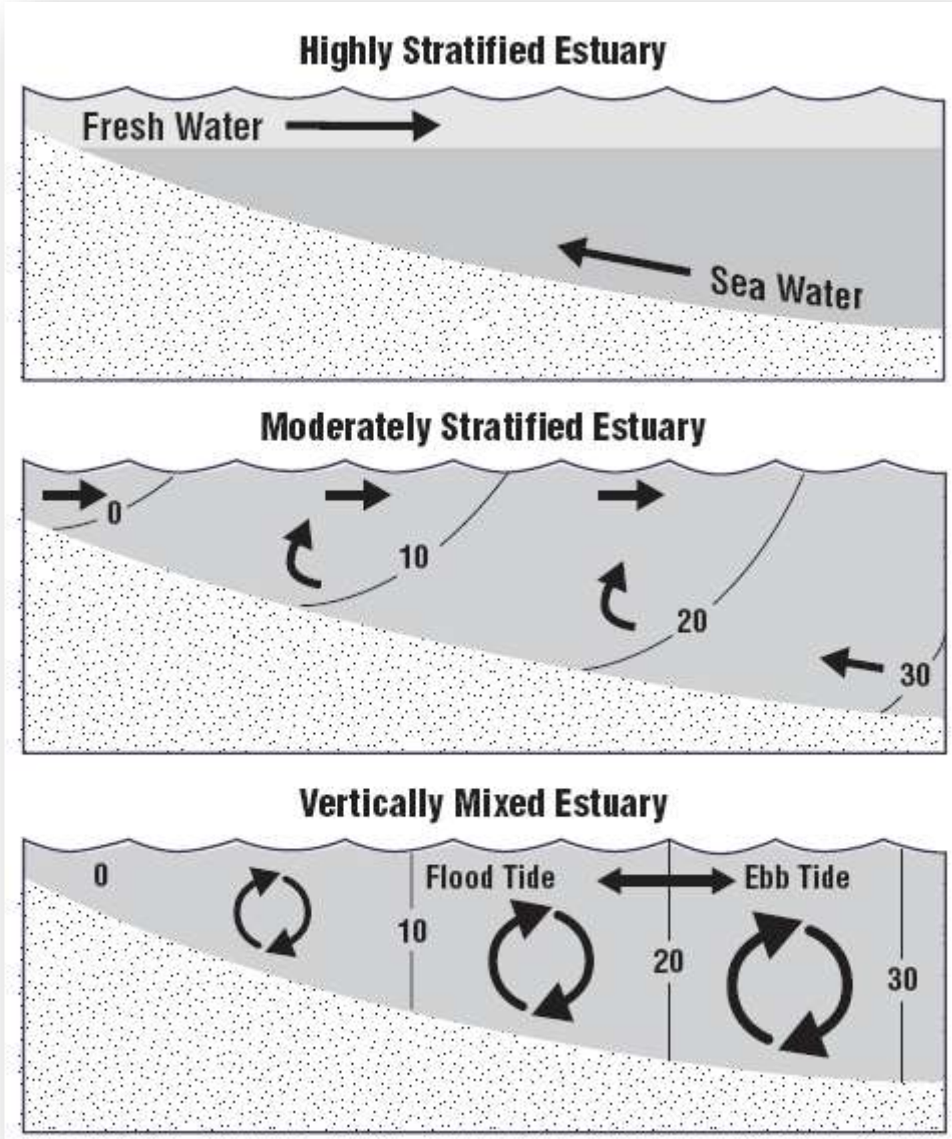

Figure 14. The three major types of estuaries based on degrees of stratification: highly stratified, moderately stratified, and vertically mixed (modified: Levinton 1982). Numbers refer to salinity in parts per thousand.

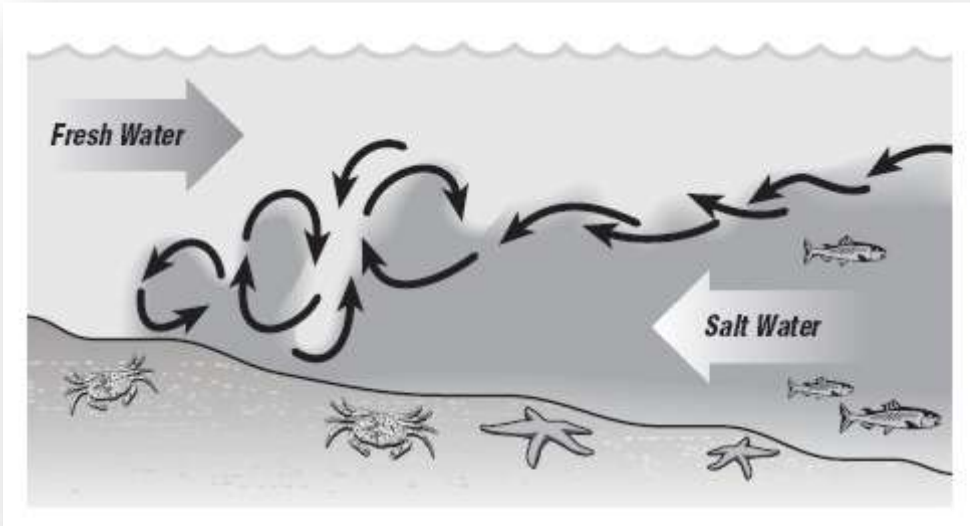

Figure 15. A turbidity maximum may occur in an estuary where the outflowing freshwater meets the inflowing seawater. This is caused by two processes: (1) flocculation - a process in which particles of clay and organic matter stick together, as a result of chemical reactions with the salt ions in the seawater, and form larger flake-like particles, called flocs or floccules, that may come out of solution; and (2) resuspension of bottom sediments in response to the turbulence created when the two water layers mix. The turbidity maximum is an area where both nutrients and pollutants can accumulate (source: National Estuary Program 2006).

5.5. Cimate

The proximity of the Pacific Ocean moderates the climate of the PNCIMA region, producing relatively warm winters and cool summers as compared with the interior of British Columbia. In winter, storm winds transport heat across the central Pacific, and in summer, northwest winds bringing relatively cooler air masses onto the coast. The position and strength of two large scale pressure systems over the northeast Pacific control much of the weather and climate conditions in coastal BC. The Aleutian Low tends to dominate in winter. Storms track along its southern edge across the Pacific bringing warmth and abundant rain to the BC coast, making it the wettest place in Canada. The position of the air pressure system often causes winter storms to hit the Central and North Coast of BC more frequently than the southern coast. This results in the highest rainfall totals occurring within the PNCIMA area. The North Pacific High dominates in summer, and tends to deflect storms northward during this time (Lucas et al. 2007).

The presence of the Coast Mountains produces very high rainfall on their coastal side, particularly along the north and central mainland coast (Lucas et al. 2007). These cool, wet conditions support lush and diverse temperate rainforest vegetation (BCMSRM 2005a). Areas in the rain shadow of the coastal mountains receive significantly less rainfall (Lucas et al. 2007).

The climate of each region within the PNCIMA depends largely on the region's position relative to the air pressure systems, and the degree of orographic effect generated by the mountains within the region. **Table 6** gives some of the climate statistics for several communities within the PNCIMA. Total precipitation ranges from a maximum of 334 cm in Port Alice to a minimum of 51 cm in Smithers. Precipitation decreases as one moves away from the ocean and the climate becomes more continental in nature.

Table 6. Climate statistics for selected communities within the PNCIMA (data: EC 2006a).

Location	Lowest Daily Minimum Temperature (°C)	Highest Daily Maximum Temperature (°C)	Total precipitation (cm)	Snowfall (cm)
Oceanic climates				
Port Alice	1.5	11.7	334	38
Prince Rupert	-2.1	16.7	259	126
Kitimat	-5.5	21.2	219	424
Port Hardy	0.8	17.9	187	56
Stewart	-6.2	19.8	184	572
Alert Bay	1.5	18.2	159	63
Campbell River	-2.0	23.1	145	109
Sandspit	0.7	17.9	140	62
Continental climates				
Terrace	-6.4	21.3	132	375
Hazelton	-12.3	23.3	61	185
Smithers	-12.7	21.6	51	204

The waters around the Queen Charlotte Islands as well as the central coast area are some of the windiest in Canada. In the summer, the North Pacific High produces north to northwesterly winds along the coast. In the winter, the Aleutian Low pressure produces winds from the south to southeast. The prevailing winds are modulated by coastal topography, and may interact with eastward bound high and low pressure systems, thus producing intense storms, particularly in the winter. Strong winds, high seas and strong currents are produced during these storm events. Storm-derived currents, in combination with bathymetry and a stratified water column produce complex circulation patterns. These currents create one of the major challenges to understanding the fate and dispersal of contaminants discharged or spilled into the marine environment (Haggarty et al. 2003). Additionally, high winds, in combination with strong currents, may interact with the shallow bottom topography found in many regions of Queen Charlotte Sound and Hecate Strait to generate very large surface waves (Strong et al. 2002).

5.6. Habitats

The wide variety of marine life found in the PNCIMA region can largely be 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. In addition to varied habitat types, the consistent upwelling of cold, nutrient-rich waters in many areas of the PNCIMA, in conjunction with strong tidal mixing, makes it an ideal environment for a vast assemblage of marine life (Johannessen et al. 2007a). Coastal, nearshore habitats that are generally considered to have the highest ecological significance are estuaries, salt marshes, sea grass beds and tidal flats, canopy kelp beds, subtidal rocky reefs, and localized nutrient-rich upwelling areas (CCLCRMP 2001). Some of the more important and/or unique habitats in the PNCIMA are described below:

- **Hexactinellid sponge reefs**. These are globally unique biological structures. Found at depths of 165-230 m in the Queen Charlotte Sound and Hecate Strait (**Figure 16**), sponge reefs are up to 18 m high, can cover up to 300 km^2, and are thought to have existed in these areas for 8,500-9,000 years. Similar sponge reefs were formerly abundant in many parts of the ocean in the geological past, but are now only found in a few areas in British Columbia. Submersible studies have shown that fauna associated with the reefs differs from adjacent areas. The sponge reefs are vulnerable to impacts from mobile fishing gear, dredging, excessive sedimentation and pollution (Conway 1999, Haggarty et al. 2003).

- **Eelgrass beds.** Eelgrass beds are highly productive nearshore habitats supporting fish communities, invertebrates, and algae that contribute to productive fish habitat. They are particularly sensitive to habitat alteration and destruction through dragging, dredging, or construction. They are also sensitive to shading, sedimentation and increased temperature (Haggarty et al. 2003).
- **Kelp forests.** Canopy kelp beds are generally located along exposed and semi-exposed coastlines, and in areas of upwelling or high current channels where nutrient levels are high and a rocky substrate is available. The kelp fronds are attached by a “holdfast” to rocky substrates. They grow from the zero tide level, or just above, to about 12 m below the zero tide, depending on the water clarity. Kelp may grow on unstable substrates such as cobble, but beds tend to be more ephemeral in such areas. Kelp forests are highly productive nearshore habitats. The structure of kelp forests is strongly influenced by abiotic factors such as nutrients, light, storms, temperature, salinity, and biotic factors such as grazing. The amount of grazing by herbivorous invertebrates influences both the amount of kelp and the species composition. Areas of very high urchin abundance can have all the kelp removed, and are then referred to as “urchin barrens”. Sea otters, which control the population of urchins and other invertebrates, greatly influence the amount and composition of kelp. Kelp forests are important habitats for fishes, such as rockfish, sculpins, and surfperch, as well as numerous invertebrates (CCLCRMP 2001, Haggarty et al. 2003).
- **Rocky reefs.** Reefs are areas with hard rocky bottoms, often with a complex topography created by rocky outcrops and regions of boulders and/or cobble. Rocky reefs provide stable surfaces for the attachment of invertebrates such as anemones, polychaetes, ascidians (tunicates), corals, and sponges. They support a diverse community of invertebrates, fishes, and micro- and macro-algae. The rocky walls of current-swept, nutrient-rich passages are particularly productive. Inhabitants of rocky reefs include rockfish, greenlings, sculpins, wolfeels, and numerous epilithic (attached to rock) invertebrates. Fifteen species of rockfish have been reported from the hook and line fishery. Lingcod, an economically important species caught in rocky habitats, use crevices for egg incubation. Typical epilithic invertebrates include serpulid polychaete worms, brachiopods, cup corals, sponges and stylasterine coral. Prawns are also found in rocky habitats, and are caught in commercial trap fisheries (CCLCRMP 2001, Haggarty et al. 2003, Levings et al. 2002).
- **Sand and gravel beds**. Sand and gravel beds are an important habitat for many commercial species such as Dungeness crab, English sole, rock sole, and Pacific cod. Nearshore sand and gravel habitats are particularly important nursery habitats for juvenile fishes. Infauna (animals living in the substrate) sampling and stomach content analysis of fishes and crabs from sand and gravel provide an insight into some of the components of the food web. Important prey items include sandlance, herring, demersal fishes (sculpins, gobies, pricklebacks and gunnels), and various types of shrimp, crabs, amphipods, polychaete worms and mollusks. Sand and gravel bottoms are particularly important for sandlance, a major prey item of fishes and seabirds (Haggarty et al. 2003).
- **Mud substates**. Regions with muddy sediments are important rearing and adult habitats for several species of shrimps (humpback shrimp, spiny pink shrimp, pink shrimp, sidestripe shrimp). Bottom fish that use this habitat include flathead sole, Pollock, Pacific tomcod, and the dwarf wrymouth. These species feed on invertebrates, including shrimp. Heart urchin is a dominant infauna species in muddy fjord habitats (Haggarty et al. 2003, Levings et al. 2002).
- **Estuaries**. Estuaries are some of the most highly productive habitats in the coast zone. While estuaries typically have a low diversity of planktonic and benthic species that can tolerate fluctuating salinity regimes, those species that are present tend to be abundant. Wildlife and fish species are attracted to this abundant food source and the shelter from the surrounding lands (CCLCRMP 2001).

Figure 16 shows the Provincial and Federal Parks, protected areas, and conservation areas in the PNCIMA. **Table 7** summarizes the number, areas, and purposes of the various parks and protected areas in the region. A total of 73,308 km^2 (in 392 areas) has some level of protection.

Table 7. Types of parks and protected areas within the PNCIMA region (data: BCMSRM 2005b, DFO 2007a, GeoBC 2008a, NRC 2007a).

Type	Number within the PNCIMA	Total area within the PNCIMA (km^2)	Purpose
National park	1	1,481	To protect nationally significance areas of exceptional natural and cultural heritage values (West Coast Environmental Law 2001)
National marine conservation area	1	3,551	To protect nationally significance areas of exceptional natural and cultural heritage values where outstanding matters (e.g., aboriginal rights and title) still need to be resolved (West Coast Environmental Law 2001)
Rockfish conservation areas	79	3,413	To protect rockfish from all mortality associated with recreational and commercial fisheries in order to alleviate further rockfish population declines (DFO 2006)
Provincial park	97	14,719	To protect and preserve the natural resources and natural environment of an area for the inspiration, use, and enjoyment of the public; to provide protection from all commercial resource extraction, for the purpose of protecting a system of representative and special landscapes and features; to serve outdoor recreation, tourism, environmental education and heritage appreciation purposes (BCMOE 1996, West Coast Environmental Law 2001)
Conservancy	67	10,283	To retain a roadless area in a natural condition for the preservation of its ecological environment and scenic features (West Coast Environmental Law 2001)
Heritage trail	1	< 1	To protect a trail of historic significance (e.g., used by First Nations for trading, travel and hunting, trails or wagon roads built in goldrush days) (West Coast Environmental Law 2001)
Ecological reserve	32	400	To reserve areas of Crown land for ecological purposes (e.g., for scientific research, as representative examples of natural ecosystems, as preserves for rare or endangered native plants and animals, as areas that contain unique and rare examples of botanical, zoological or geological phenomena); to protect and preserve representative and special natural ecosystems, plant and animal species, features and phenomena while keeping human intervention to a minimum and allowing natural change to proceed unimpeded [established under the Ecological Reserve Act] (BC Parks 2008, BCMOE 1996, West Coast Environmental Law 2001)
Protected area	12	300	To protect and preserve representative and special natural ecosystems, plant and animal species, features and phenomena while keeping human intervention to a minimum and allowing natural change to proceed unimpeded [established under the Protected Areas of British Columbia Act] (BC Parks 2008)
Study area	1	1,215	To protect a Cabinet-approved area that is being considered for protected areas status (BCMOE 1996)
Wildlife management area	4	5	To manage areas of wildlife habitat in order to meet the needs of regionally, provincially, or nationally significant species that are not necessarily considered to be at risk or to address the needs of species that require larger tracts of land to address their habitat needs (West Coast Environmental Law 2001)
Proposed wildlife management area	1	24,704	To manage areas of wildlife habitat in order to meet the needs of regionally, provincially, or nationally significant species that are not necessarily considered to be at risk or to address the needs of species that require larger tracts of land to address their habitat needs (West Coast Environmental Law 2001)
Total	**392**	**73,308**	

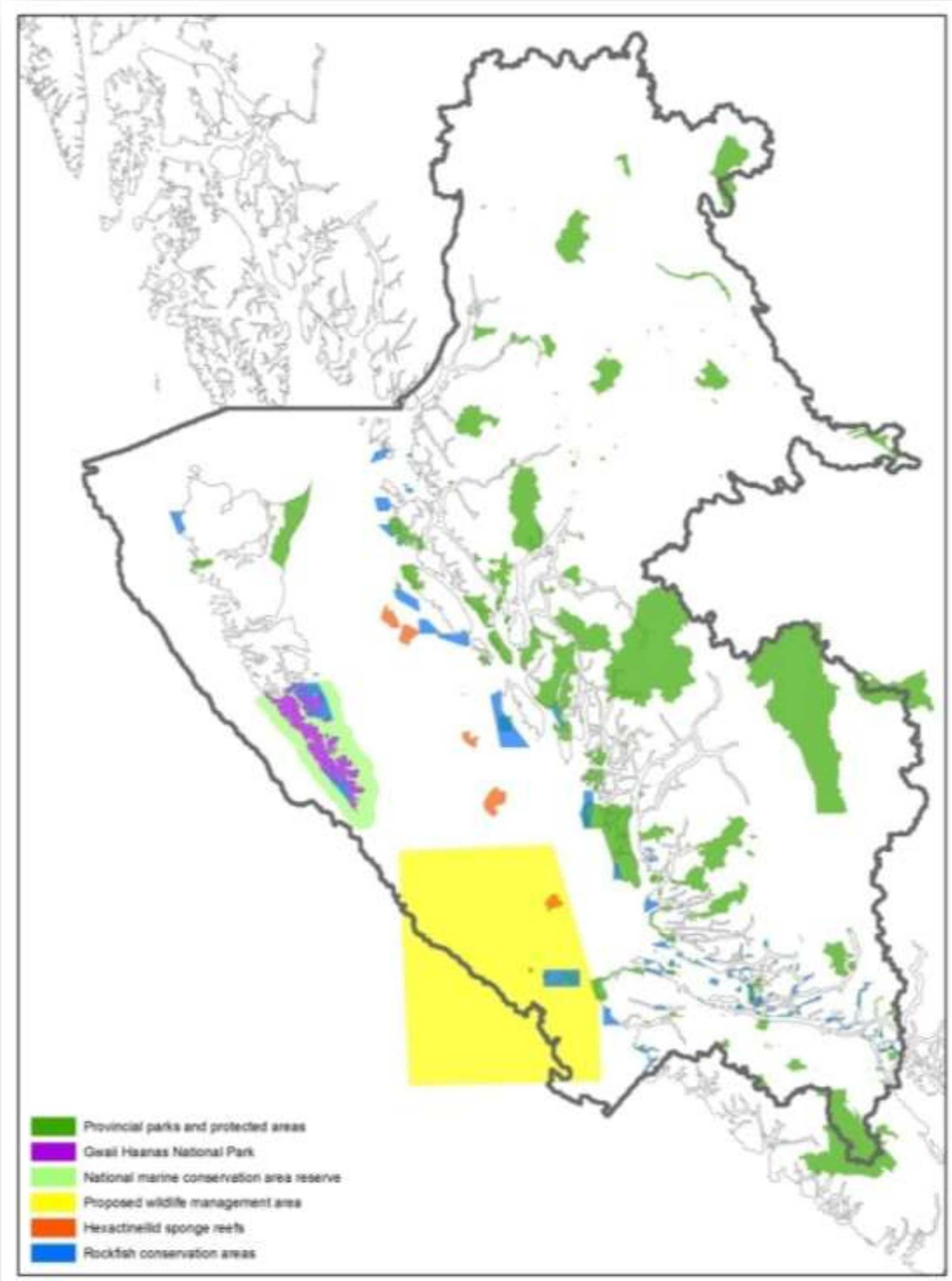

Figure 16. Parks, protected areas, and conservation areas within the PNCIMA (data: BCMSRM 2005b, DFO 2007a, GeoBC 2008a, NRC 2007a).

6. Persistent Organic Pollutants as Global Pollutants

6.1. Pollution Sources

Many of the anthropogenic (human-produced) substances that find their way into the marine environment as pollutants belong to a group of substances known as persistent organic pollutants (POPs). They persist for a very long time in the environment because they resist being broken down by chemical and microbial processes. Since they have a long residence time in the environment, they tend to become widely dispersed from their sources. Thus, although they may have entered the environment as point source pollutants, ultimately, they end up as globally-distributed non-point source pollutants. POPs include a wide variety of chlorinated and other halogenated chemicals, such as dioxins and furans, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and other less well understood chemicals (BCMOE 2007c).

POPs were mostly used in industrial applications or are byproducts of incineration or other industrial processes; some were used as insecticides. As a group, POPs vary greatly in their toxicity, persistence in the environment, and how they are transported once they enter the environment. Many are now banned, or are subject to stringent regulations controlling their use and release. After restrictions on their production and use came into effect from the 1970s onward, concentrations of several POPs in the Canadian environment decreased substantially. Because they resist chemical decomposition, however, the contaminants already in the environment continue to circulate and, for this reason, they are often referred to as legacy POPs (BCMOE 2007c).

6.1.1. Long-Range Transport of POPs in the Pacific

Persistent chemicals have been found in environments that are significant distances from the original sources of the contaminants. The Arctic, as well as alpine lakes and glaciers, has become polluted with a number of POPs and other toxic substances. One transport process involves the volatization of toxic substances in warmer climates, atmospheric transportation, followed by condensation in colder climates. Atmospheric transportation is very complex, and depends on the pollutant’s chemical and physical properties (Macdonald et al. 2003).

Westerly winds in the North Pacific transport volatile and particulate contaminants from Eurasia across the ocean to North America, primarily along mid-latitudes. For instance, in a large dust storm event, dust from the Gobi Desert in Asia was tracked and took a week to be transported across the Pacific (Macdonald et al. 2003). As a result of this atmospheric circulation pattern, pollutants from Asia have been detected in Washington State (Jaffe et al. 1999). Following bans and restrictions of PCBs and DDT, their concentration in the North Pacific decreased rapidly. However, this trend does not hold in all locations. Concentrations of PCBs, and the pesticides DDT, hexachlorohexane (HCH) and hexachlorobenzene (HCB) have not been decreasing in the Bering Sea because atmospheric deposition exceeds the sedimentation rate (Macdonald et al. 2003).

Ocean currents provide another pathway for long-range transportation of POPs (Macdonald et al. 2003). Currents from the south may transport contaminants to BC (Pierce et al. 1998). Pollutants which tend to be more soluble in water will be deposited in the ocean through rainfall, fog, or air-sea exchange, rather than remain in the atmosphere. Transport of pollutants from place to place via ocean currents takes much longer than transportation in the atmosphere. While atmospheric transport may take a period of days to weeks (with speeds in the range of m/s), ocean transport is measured in years (with speeds in the range of cm/s) (Macdonald et al. 2003). The amount of POPs delivered to the Arctic by atmospheric transport is approximately five orders of magnitude higher than the amount of POPs delivered by oceanic transport (Wania 1998).

6.1.2. Legacy POPs

Legacy or classic POPs include compounds that were produced in large quantities in the 1950s and 60s, but were banned, or restricted, in the 70s and 80s in North America and Europe. Legacy POPs include PCBs, dioxins, furans, HCB, PCP and organochlorine (OC) pesticides such as DDT, aldrin, dieldrin, endrin, chlordane, heptachlor, mirex, lindane, and toxaphene. Today, the concentrations of many of these pollutants are declining or are stable; however, legacy POPs still in use in other parts of the world can be transported long distances and deposited in the environment in areas at great distances from the source. Another issue of concern is that sites contaminated with legacy POPs will take many years to remediate (Haggarty et al. 2003).

6.1.3. PCBs

Polychlorinated biphenyls (PCBs) are a class of stable, waxy or oily compounds. They were used as heat-resistant coolants or insulators in electrical equipment, as plasticizers, solvents, and degreasers, in inks, paints, and pesticides, and in several industrial processes. There are 209 different forms (or congeners) of PCBs based on a common chemical structure. Although structurally related, these forms differ in their toxicity and fate in the environment. The PCBs sold and used commercially were mixtures of congeners (BCMOE 2006b, 2007c, Haggarty et al. 2003).

Restrictions on industrial uses of PCBs began around 1971 (BCMOE 2006b). Manufacture, import, and most non-electrical uses of PCBs were banned in North America in 1977, and it was made illegal to release PCBs to the environment in 1985. Canadian legislation allows PCB-filled equipment to be used until the end of its service life, but handling, storage, and disposal are subject to stringent government requirements. As a result of these measures, the quantity of PCBs in use declined by 54% between 1992 and 2003 (EC 2005b). The forestry sector is the largest user of PCB-containing electrical equipment in BC; BC Hydro is second (Kay 1989).

Most PCBs now enter the environment through leaks or improper disposal of waste oils and electrical equipment (BCMOE 2007c). PCBs have been detected in municipal sewage, and are found in marine sediments associated with industrial, urban and port activities. PCBs in sediments around pulp mills are likely the result of leaks of PCB-containing electrical equipment (Haggarty et al. 2003). PCBs have also been found in marine sediments and biota in remote parts of the world such as the Antarctic and Arctic, where the only explanation for their presence is long-range transport (Moore et al. 2002b).

6.1.4. Dioxins and Furans

The dioxins (polychlorinated dibenzo-p-dioxins) consist of a group of 75 congeners. Furans (polychlorinated dibenzo-p-furans) are a group of 135 congeners. Dioxins and furans are extremely long lived, and have a half life (the time it takes for one half of a given weight of the substance to break down) that ranges from 10 years to centuries (Grant and Ross 2002). Dioxins and furans are produced unintentionally as the byproducts of industrial activities, such as chlorine bleaching in pulp mills and incineration of municipal and industrial wastes. They may also be generated naturally by forest fires and volcanic activity. Dioxins first appeared in sediments in the early 1960s when pulp mills converted to chlorine liquid bleaching. Dioxins and furans are structurally similar to PCBs, and were unintended contaminants of commercial PCB formulations and some herbicides. Although trace amounts continue to be produced by industrial incineration, environmental concentrations of dioxins and furans have decreased with the phase-out of PCBs and changes in pulp and paper mill technology. Because dioxins and furans have a strong affinity for sediments, however, they will remain in the marine environment for decades, and will eventually be buried by accumulating sediments (BCMOE 2006b, 2007c, Haggarty et al. 2003).

6.1.5. PBDEs

Polybrominated diphenyl ethers (PBDEs) are widely used today as flame retardant chemicals in consumer products. One form used in polyurethane foam has been phased out, but others are added to plastics used in furniture upholstery, carpet backings, electrical insulation, computer and TV cases, and other consumer goods (BCMOE 2007c). PBDEs can be released into the environment during production, but the main environmental source is escape from consumer products during use and after disposal (BCMOE 2006b).

Production of PBDEs ramped up during the 1970s. Three commercial mixtures of PBDEs have been manufactured, octaBDE, pentaBDE, and decaBDE. Both octaBDE and pentaBDE have been banned by the European Union (EU), and were discontinued in 2004 by the only North American manufacturer. DecaBDEs are not currently regulated, and continue to be used around the world. Approximately 80% of the decaDBE produced worldwide is used in the plastics and electronics industry in the manufacture of circuit boards, wire coatings, and mobile telephone equipment. The remaining 20% is used for textiles, upholstery, cables, and insulation materials (BCMOE 2006b, 2007c). In December 2006, Environment Canada proposed the Polybrominated Diphenyl Ethers Regulations under CEPA, which would prohibit the manufacture of all PBDEs (none are currently manufactured in Canada) as well as the use, sale, and import of pentaBDE and two other less used forms, tetraBDE and hexaBDE. The proposed regulations do not ban the import or use of the most common mixture, decaBDE, therefore a formal Notice of Objection has been filed by environmental groups (BCMOE 2007c).

6.1.6. PAHs

Polycyclic aromatic hydrocarbons (PAHs) are generally thought to be the most widespread of the organic contaminants (Garrett 2004). Spilled oil is the best-known source of PAH contamination; however, the highest concentrations at contaminated sites have come from petroleum refining processes and coal tar production. PAHs are found in industrial liquid effluents, including those from pulp mills and aluminum smelters, and are often found in harbours (BCMOE 2006b). Other sources include contamination from liquid petroleum products and creosote, as well as from urban activities (roads, wastewater treatment plants, urban runoff). Atmospheric sources of PAHs include fossil fuel combustion and slash burning (Yunker 2000). Atmospheric deposition is thought to be the major source of PAHs in most aquatic systems (Garrett 2004). PAHs may also be produced by natural sources such as oil seeps, coal, plant debris, and forest fires (BCMOE 2006b).

There are three main ways in which PAHs can be produced (Dahle et al. 2006):

- **Petrogenic ("oil" genesis).** PAHs of petrogenic origin are formed by low to moderate temperature diagenesis (a chemical, physical, or biological change undergone by a sediment after its initial deposition) of sedimentary organic matter to form fossil fuels (e.g., oil, gas, or coal).
- **Biogenic ("bio" genesis)**. PAHs of biogenic origin are generated by biological processes or by the early stages of diagenesis in marine sediments.
- **Pyrogenic ("fire" genesis).** PAHs of pyrogenic origin are formed as a result of both natural (volcanism or hydrothermal transformation of organic matter) and anthropogenic (combustion of fossil fuels and recent organic material) processes.

On the basis of their chemical structures, PAHs can be separated into two groups (BCMOE 2006c, Webster et al. 2000):

- **Parent PAHs.** These are PAHs with no other hydrocarbons attached to them. They are mainly produced by pyrogenic (combustion) processes, and often occur naturally.
- **Alkyl PAHs.** These are PAHs with carbon chains (alkyl groups) attached to them. They are mainly produced by lower temperature (e.g., petrogenic) processes.

In petroleum products, the amount alkyl PAHs is much greater than the amount of parent PAHs. As petroleum products age, the percentage of alkyl PAHs increases compared to parent PAHs.

Because there are natural sources for both, the levels of parent and alkyl PAHs found in the environment as a result of human activity can only be determined when compared against the natural background level at an unaffected site (Yunker et al. 2002).

6.1.7. Organochlorine Pesticides

Pesticides are agents used to control pests. Examples include insecticides (to control insects), herbicides (to control plants/weeds), fungicides (to control fungi), and biocides (to control a wide variety of biota). Most pesticides are applied to terrestrial environments in urban, forest, and agricultural settings. They enter aquatic environments through runoff in streams, sewers, and wastewater treatment plants, groundwater discharge, and aerial spray drift. Persistent pesticides can also be transported large distances by oceanic or atmospheric currents. OC pesticides, including aldrin, dieldrin, chlordane, DDT, alpha-hexachlorocyclohexane (α–HCH) and toxaphene, are now largely banned (Haggarty et al. 2003).

DDT (dichlorodiphenyl trichloroethane) was used in Canada to control biting insects and agricultural and forest pests from 1947 to 1969. DDT breaks down in the environment to form DDE (dichlorodiphenyl dichloroethylene). DDE was also a contaminant in DDT formulations. DDT was banned in Canada in 1972 after it was discovered that metabolites of the pesticide (mainly DDE) were bioaccumulating in tissue of predatory birds and causing egg-shell thinning and breakage. Its use is also currently prohibited in the United States and Europe. However, DDT continues to be used elsewhere in the world on agricultural crops and to control mosquitoes that carry malaria. DDE residues from past pesticide use are still measurable in soil, sediment, and wildlife. These residues continue to be augmented by atmospheric transport of DDE from other continents where DDT is still in use (BCMOE 2007c).

6.1.8. Other POP Contaminants

Several other POPs are potential marine pollutants:

- **Alkylphenol ethoxylates** - surfactants widely used in detergents, pesticides, shampoos, and pulp mill processing (Johannessen et al. 2007a).
- **Fluorinated organic compounds (FOCs)** - used as surfactants in products such as emulsifying agents, water repellents, fire retardants, wax, carpet cleaners, and non-stick coating. There have been some voluntary reductions in the production and use of these compounds (CBC News 2006b). Other FOCs are in the process of being banned or restricted (CBC News 2006a).
- **Phthalate esters** - used as softeners in plastics and are also found in personal care products, pesticides, and lubricants (Johannessen et al. 2007a).

6.2. Environmental and Socio-Economic Impacts

Persistent organic pollutants have a broad range of toxic effects, including disruption of hormone and immune systems of mammals. POPs include a wide variety of chlorinated and other halogenated chemicals, such as dioxins and furans, polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers (PBDEs), and other less well understood chemicals. They are fat soluble, and since organisms are unable to break them down metabolically, they accumulate in fat reserves. Through the process of bioaccumulation, they become more concentrated as living organisms take them up and store them faster than they can be broken down or excreted. When contaminated organisms are eaten by other animals, the compounds become biomagnified in the predators, and often reach high levels at the top of the food chain. This means that POPs may accumulate in wildlife to concentrations that affect their health or risk the health of humans who consume them (BCMOE 2007c). Killer whales in British Columbia are a prime example of this process (Grant and Ross 2002, Ross et al. 2000). Ironically, animals themselves can become significant vectors of contaminant transport (Wania 1998). For instance, a study in Alaska showed that salmon transported POPs from the open ocean into rivers and lakes where they spawned. These POPs then entered the local food chain, and were passed to non-anadromous fish in a nearby lake where no salmon had spawned (Ewald et al. 1998). Contaminants may also be transferred to terrestrial ecosystems through consumption of salmon by beers, wolves and other predators and scavengers (Haggarty et al. 2003).

6.2.1. Endocrine Disruption

Many POPs have endocrine disrupting properties, in addition to other toxic effects. Endocrine disrupting substances (EDS) mimic or block vertebrate steroid hormones by interacting with the hormone receptors in the body. Typical effects include feminization of male animals or masculinization of females (Matthiessen et al. 2000), eggshell thinning in birds, and disruption of vitamin A and thyroid hormone physiology in mammals. A major British research project on endocrine disruption in the marine environment (EDMAR) found feminization of flounder and of blenny (a small forage fish) in some estuaries (DEFRA 2003). The EDS also appear to affect behavior in many fish, mice, birds, and primates. Recent studies found changes in social and mating behavior, increases in hyperactivity and aggression, impaired motor skills, and reduced ability to learn (Clotfelter et al. 2004, Zala and Penn 2004). Although the impacts of EDS have not been as well studied in BC, elevated levels of egg proteins have been found in male rockfish (West et al. 2001b) and English sole (Lomax et al. 2001) from sites in Puget Sound.

6.2.2. Toxic Equivalents

A system has been devised to estimate the combined toxic effect of the most common forms (congeners) of dioxins, furans, and PCBs. Each congener is assigned a toxic equivalency factor (TEF) relative to the most toxic dioxin (2,3,7,8-TCDD), which has been assigned a TEF of 1 (**Table 8**). There are some differences in sensitivity between organisms. When comparing organisms, a lower TEF value for the same congener indicates that an organism is less sensitive to that congener. The toxicity of a congener (toxic equivalent concentration or TEQ) is calculated by multiplying its TEF by the concentration found in the environment. The total toxicity of a PCB, dioxin, or furan mixture is estimated by summing the TEQs of all the congeners (BCMOE 2006b).

Table 8. Examples of toxic equivalency factors (TEFs) for mammals, birds, and fish (source: Van den Berg et al. 1998).

	Congeners	Mammals	Birds	Fish
Dioxins	2,3,7,8-TCDD	1	1	1
	1,2,3,7,8-PCDD	1	1	1
	1,2,3,4,7,8-HCDD	0.1	0.05	0.5
	OctaCDD	0.0001	0.0001	<0.0001
Furans	2,3,7,8-TCDF	0.1	1	0.05
	1,2,3,7,8-PCDF	0.05	0.1	0.05
	2,3,4,7,8-PCDF	0.5	1	0.5
	1,2,3,4,7,8-HCDF	0.1	0.1	0.1
	OctaCDF	0.0001	0.0001	<0.0001
Non-ortho PCBs	PCB#77	0.0001	0.05	0.0001
	PCB#126	0.1	0.1	0.005
Mono-ortho PCBs	PCB#105	0.0001	0.0001	<0.000005
	PCB#123	0.0001	0.00001	<0.000005

6.2.3. Specific Toxic Effects of POPs

The specific toxic effects of POPs depend on their chemical structure. Some examples of the types of toxicity associated with the most common POP pollutants are as follows:

- **PCBs.** The characteristics of PCBs that make them desirable for industrial applications, such as their stability, are the same ones that make them a significant problem in the environment. They are lipophilic ("fat-loving"; e.g., tend to accumulate in fats), hydrophobic ("water-fearing"; e.g., do not dissolve easily in water), and are not readily metabolized. Thus, they tend to bioaccumulate (Haggarty et al. 2003). PCBs have a wide range of toxic effects. They affect the immune, reproductive, neurological, and endocrine systems of mammals, including causing cancer. One group of PCB congeners is similar in structure and toxicity to dioxins. Other PCB congeners have toxic effects that stem from their metabolic breakdown into highly toxic intermediate compounds which affect thyroid and vitamin A physiology (Safe 1993). The toxicity and properties of the congeners largely depend on the number and positions of chlorine atoms in the molecule. The most toxic PCB congener presents about one-tenth the risk to humans of the most toxic dioxins (BCMOE 2006b).

- **Dioxins and furans.** Dioxins and furans are very toxic and bioaccumulate in animals and humans (Grant and Ross 2002). Long-term exposure in mammals to dioxins can affect reproduction, cause cancer and birth defects, damage the liver, and suppress the immune system (EC 1990). People exposed to dioxins and furans may develop chloracne (a skin condition caused by acute exposure), liver and immune system dysfunction, and show other sensory and behavioral effects (BCMOE 2006b). The US Environmental Protection Agency has classified dioxins as probable human carcinogens (ATSDR 1998). Rainbow trout exposed to the most toxic dioxin cogener died at concentrations as low as 40 parts per quadrillion (Mehrle et al. 1988).

- **PBDEs.** PBDEs are less toxic than PCBs, but are structurally similar, and have similar environmental properties. They are generally soluble in fat, and biomagnify within the food chain, but they are more susceptible to environmental degradation than PCBs (BCMOE 2007c). The toxicity of PBDEs is related to the number of bromine atoms contained within the molecule. In mammals, toxicity of PBDEs congeners is believed to increase as the number of bromine atoms in the molecule decreases (Gill et al. 2004). Additionally, it has been shown that the smaller molecules bioaccumulate more readily, and account for most of the environmental residues (Rayne and Ikonomou 2002). PBDEs are broken down in surface water and sediment through microbial degradation and other metabolic processes (Gouin and Harner 2003). As they break down in the environment or in animal tissues, PBDEs lose bromine atoms, which transforms them into more toxic, mobile, and bioaccumulative forms (EC 2006b).

- **PAHs**. Both alkyl and parent PAHs have similar toxicity; however alkyl PAHs persist in the environment for a longer time, are less water soluble, and tend to bioaccumulate to a greater degree than parent PAHs (Irwin et al. 1997). While PAHs may bioaccumulate to some extent, depending on the ability of different organisms to metabolize them, they do not tend to biomagnify up the food chain (BCMOE 2006b). There is some concern that the metabolic breakdown of several PAH cogeners produces metabolites that are far more carcinogenic and hazardous than the parent compounds (Irwin et al. 1997). Total PAHs as low as 1 mg/kg have been shown to induce tumors in brown bullhead catfish (Eisler 1987).

- **Organochlorine pesticides.** OC pesticides are highly persistent, bioaccumulative, and toxic. Many are endocrine disruptors, carcinogenic, and cause immunosuppression (Grant and Ross 2002). DDT is an OC pesticide which was once in common use. DDE is produced in most animals when the body attempts to break down and excrete DDT. DDE is a highly persistent, endocrine disrupting chemical (BCMOE 2007c).

- **Alkylphenol ethoxylates.** Few of these compounds have been studied, but a number are known endocrine disruptors (Johannessen et al. 2007a).

- **Phthalate esters.** Some of these compounds are confirmed or suspected endocrine disruptors at very low concentrations (Jobling et al. 1995, Myers 2002).

6.2.4. Impacts on Fish

Most contaminant research in fish has been carried out on salmonids. Although some POPs may be accumulated by the salmon from contaminated nearshore juvenile habitats, salmon mainly accumulate contaminants in the open ocean. Many salmon stocks undertake long migrations in the North Pacific Ocean, and some species (chinook, sockeye, coho) can spend up to 5 years in the Pacific. Adult chinook salmon returning to Puget Sound have been shown to have 2.2 mg/kg (live weight) of PCBs in their tissues. 99% of this PCB load was estimated to accumulate during their time in the open ocean (Arkoosh et al. 1991). Returning adult chinook in BC also had appreciably higher (>90%) POP loads than out-migrating smolts (Ross, unpublished data, as cited in Haggarty et al. 2003). Sockeye salmon were shown to transport POPs from the open ocean to lakes in Alaska (Ewald et al. 1998, O'Neill et al. 1998). Ultimately, the source of these contaminants found in salmon may be atmospheric deposition of the POPs into the Pacific Ocean (Ross et al. 2000). Accumulation of these contaminants by salmonids can then be transferred to their predators (such as killer whales), as well as transported back into coastal areas such as spawning streams and lakes (Ewald et al. 1998). Also, since POPs are lipophilic, they can be passed from the adult female to the concentrated food stores in the eggs (Giesy et al. 1999). Thus the next generation of salmon begins life with an existing POP burden.

Other fish, such as rockfish and flatfish, may also accumulate POPs in their tissues. Unlike salmon, which accumulate contaminants from widespread sources, fish that remain resident in coastal waters are likely to accumulate contaminants from more localized sources. For example, rockfish and flatfish in industrial parts of Puget Sound have been found to have high levels of contamination in comparison to less industrial and urban areas such as the San Juan Islands (O'Neill et al. 1998, West et al. 2001a, West et al. 2001b).

6.2.5. Impacts on Birds

In birds, the impact of organochlorine pesticides is apparent in thinner eggshells, which are easily damaged, lowering reproductive success (BCMOE 2006c). The Canadian Wildlife Service of Environment Canada (CWS) has been monitoring contaminant compounds (PCBs, dioxins and furans, PBDEs, DDE, chlordane, and dieldrin) in bird eggs since the 1970s (BCMOE 2007c). The levels of contaminants in bird eggs were determined by the Environment Canada national laboratory (Elliott et al. 1998, Elliott et al. 2000, Elliott et al. 2001, Elliott et al. 2005, Harris et al. 2003a, Harris et al. 2003b, Harris et al. 2005). Concentrations of dioxin-like compounds (dioxins, furans, non-ortho PCBs) are presented as toxic equivalent concentrations (TEQs) (Van den Berg et al. 1998). The following species were monitored:

- **Great blue heron (*Ardea herodias*).** Herons feed mainly on small fish, and changes in the amount of contaminants entering the food chain are rapidly reflected in contaminant levels in their prey, and later in their eggs. The coastal populations of herons are year-round residents, although they move small distances between different seasonally preferred forage grounds. As a result, contaminants in their eggs reflect the local conditions of the intertidal and estuarine forage sites near each colony. The CWS has monitored pollutants in more than 20 great blue heron colonies since the 1970s. Three colonies in the Georgia Basin were chosen for in-depth monitoring: a University of British Columbia colony, which reflects non-point source urban pollution; a Nicomekl colony, representing a rural habitat that should be less exposed to industrial contaminants; and a Crofton colony, chosen to reflect point-source pollution from a nearby pulp and paper mill (Elliott et al. 2001, Elliott et al. 2005, Harris et al. 2003a).

- **Double-crested cormorants (*Phalacrocorax auritus*).** Cormorants specialize on foraging prey (fish, crustaceans) from the waters and sea floor in the intertidal zone. Contaminant levels in their eggs tend to reflect contaminant loads in the sediments of this zone. Cormorants are also resident birds, although their movements during non-breeding season may be over a somewhat greater distance than herons. CWS began monitoring pollutants in double-crested cormorant eggs from the colony on Mandarte Island in the Georgia Basin in 1970 (Elliott et al. 2005, Harris et al. 2003b, Harris et al. 2005).

- **Osprey (*Pandion haliaetus*).** Ospreys are a migratory species that winters in Mexico and Central America. Ospreys return to nesting sites in the Pacific Northwest approximately one month before laying eggs. In that time, they consume large amounts of fish from the local river systems. Consequently, contaminants in their eggs largely reflect local environmental conditions. CWS monitored toxins in osprey eggs from upstream and downstream of pulp mills located at Kamloops on the Fraser River and Castlegar on the Columbia River in the early and late 1990s (Elliott et al. 1998, Elliott et al. 2000, Elliott et al. 2005).

Long-term monitoring of contaminants in bird eggs shows that, in general, overall levels of legacy POPs have decreased in the environment since the 1980s (**Figure 17**). This is consistent with efforts to phase-out and eliminate these compounds, which began in the late 1970s and became more stringent in the 1980s and 1990s (BCMOE 2007c). However, the continued presence of these compounds in eggs many years after they are no longer used in Canada demonstrates both the very long persistence of these chemicals in the environment and the ongoing atmospheric deposition of compounds (Wilson et al. 1996).

Although DDT was banned in Canada in 1969, the breakdown product DDE is still present in the environment. These DDE residues have two possible sources: (1) they may be persistent in BC soils and sediments from past agricultural use, or (2) they may be transported by the atmospheric from regions where DDT is still used for insect control (BCMOE 2007c). These two sources of residues create two distinct patterns in contaminant levels of birds' eggs. In areas where DDT was once used and is now banned, for example in the Strait of Georgia, concentrations of DDT in birds' eggs have declined (Whitehead 1989). In contrast, concentrations in populations from remote locations, where DDT has never been used, have not declined due to long-range atmospheric transport (Addison 1998, Elliott et al. 1989).

The rapidly increasing contaminant level of a newer class of compounds, the PBDEs, reflects the widespread use and release of these compounds since the 1970s when production began to expand. Limited phasing out of PBDEs began in 2004, with the voluntary restriction of some groups of congeners. One group, the decaBDEs, is still in use around the world. It is not known what effect the toxicity from these chemicals may be having on birds, especially in combination with other stressors such as loss or degradation of habitat (BCMOE 2007c).

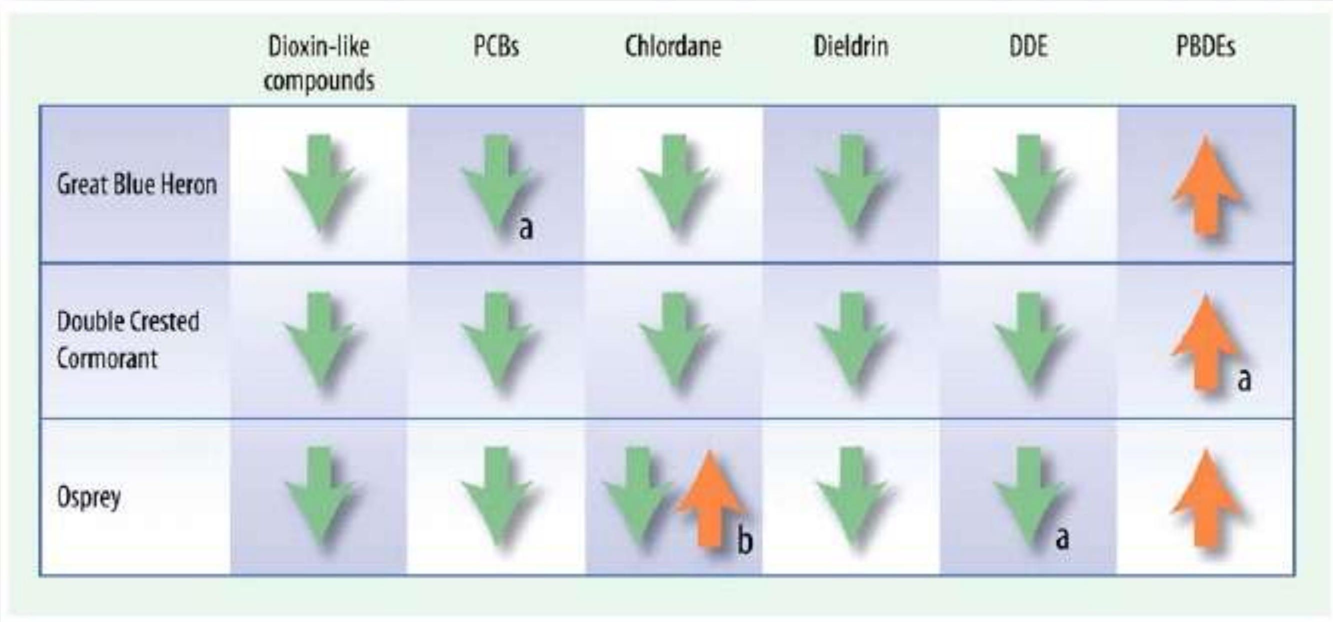

Figure 17. Contaminant trends in bird eggs in British Columbia from earliest sample year to most recent sample year (range 6-32 years) (source: BCMOE 2007c). Note: (a) Contaminants increased mid-cycle of trend period; (b) chlordane levels increased in osprey on Fraser River but decreased in osprey on Columbia River to a much greater extent.

Although not one of the species studied in British Columbia, bald eagles may be at risk as a result of long-range transport and deposition of chemicals used in other parts of the world. Organichlorine pesticides and PCBs have been found in bald eagles in the Aleutian Islands, Alaska (Estes et al. 1997).

6.2.6. Impacts on Marine Mammals

Persistent organic pollutants (POPs) enter the marine food chain when organisms at the bottom of the food web, such as plankton, accumulate the contaminants from water, sediment, and food. These POPs biomagnify and become more concentrated as they move up the food chain to seals and killer whales (BCMOE 2007c).

Blubber samples were collected with biopsy darts (non-lethal sampling) from killer whales of both sexes and various ages in three coastal populations (northern residents, southern residents, and transients; **Figure 18**) and were analyzed for PCBs, dioxins, furans, and PBDEs (Rayne et al. 2004, Ross et al. 2004). Transient killer whales are predators on other marine mammals, whereas both southern and northern populations of resident killer whales eat mainly fish. Since killer whales travel over a large area and feed on salmon that accumulate contaminants from their time at sea, contaminants found in their tissues may reflect the general state of contamination in the Pacific Ocean ecosystem (BCMOE 2007c). Of the three BC groups of killer whales tested, PCB concentrations were the lowest in the northern resident whales and highest in the transient population (**Figure 19**). Although the two groups of resident whales have a similar diet, the more contaminated southern population likely eats more contaminated fish from the industrialized areas of BC and Washington state (Ross et al. 2000).

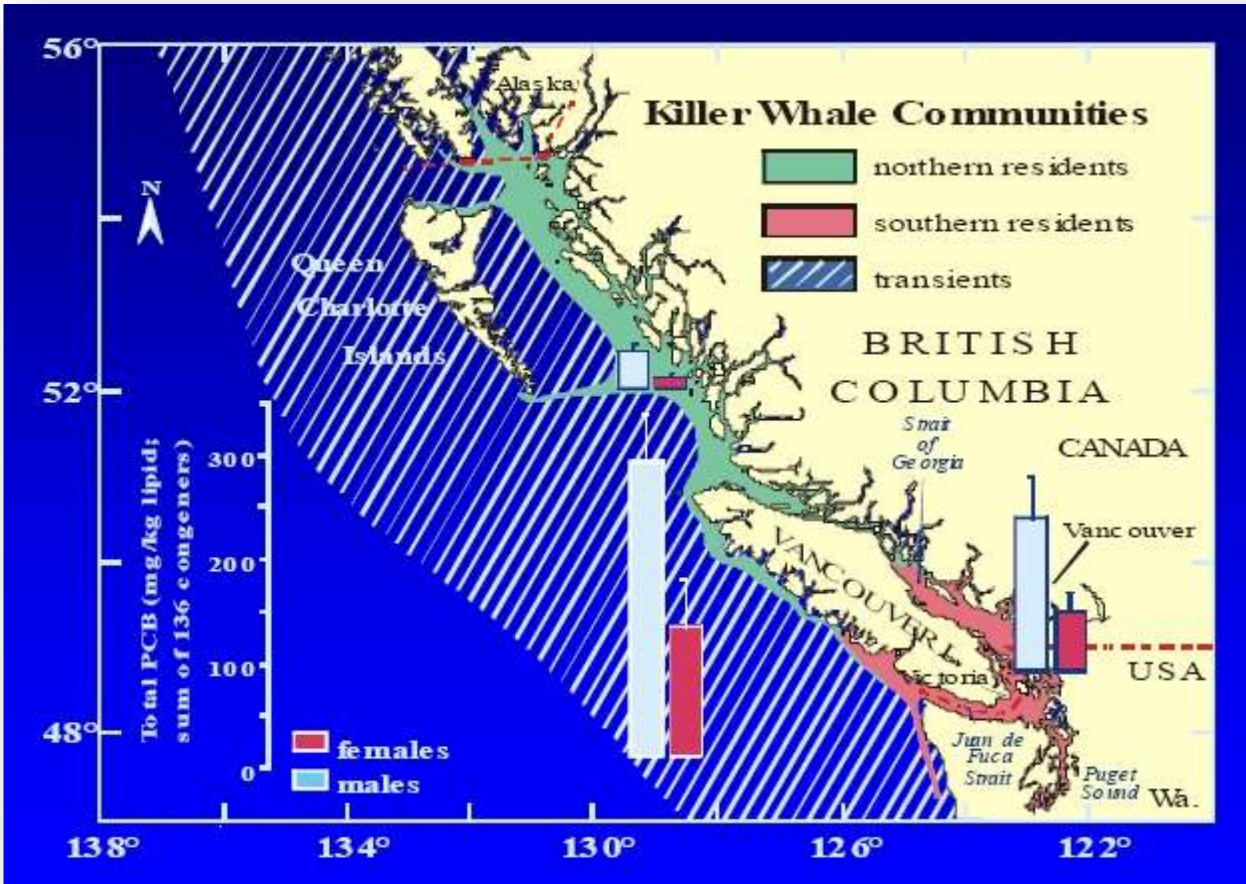

Figure 18. Killer Whale communities found in coastal waters off BC and Puget Sound, Washington (source: Ross 2005).

PCB concentrations in killer whales are roughly 100 times higher than PBDE concentrations (Rayne et al. 2004), which reflects the longer historical period of PCB usage relative to PBDEs (**Figure 19**). PCBs may also accumulate to a greater extent because PCB molecules are smaller than PBDE molecules, and small size favors more rapid uptake. The most common PBDE congener, BDE-47 (one of the more toxic forms), accounted for about 60–75% of the PBDEs found in killer whales (Rayne et al. 2004) and is widely distributed in environmental samples (Gill et al. 2004). In all three killer whale populations, males were more contaminated with PCBs (but not PBDEs) than females (**Figure 19**). Females shed some of their body burden of PCBs and related compounds through the birth and lactation of each calf, whereas males would continue to accumulate contaminants throughout their lives. The lack of difference between males and females for PBDEs may reflect a barrier in females that prevents ready transfer to their calves (Ross 2006).

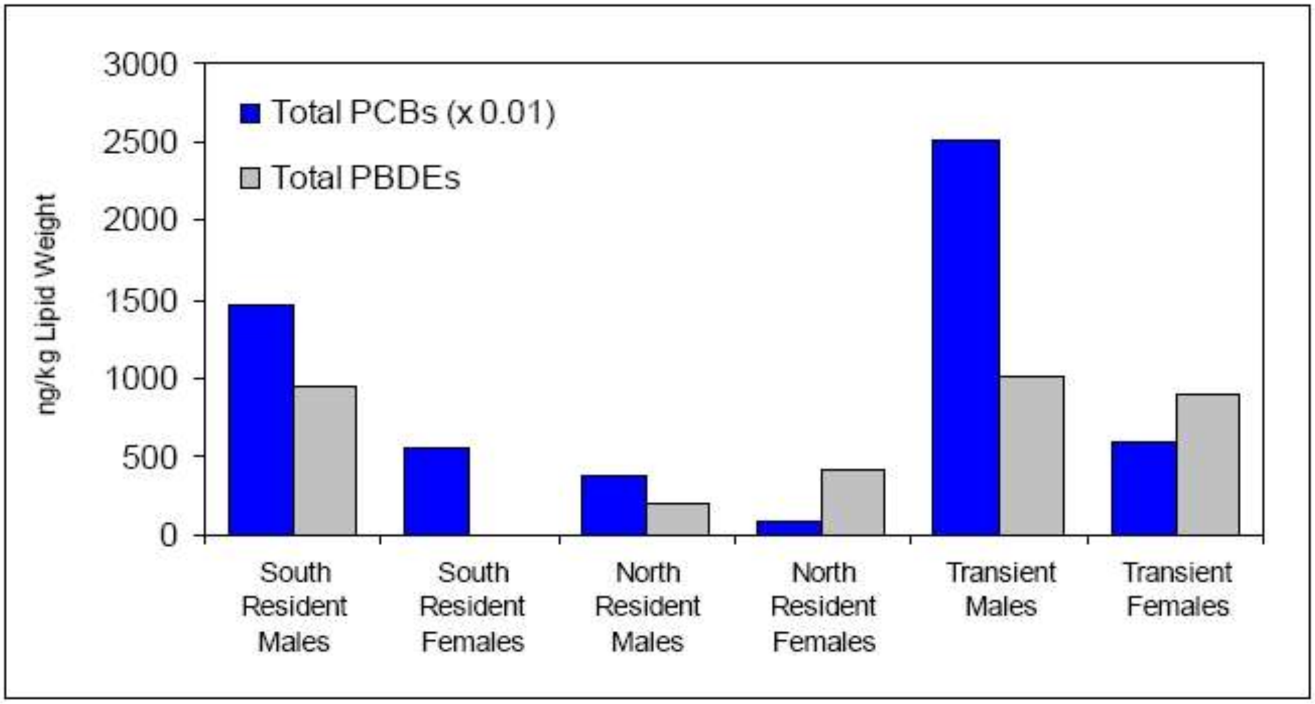

Figure 19. PCB and PBDE concentrations (ng/kg lipid weight) in male and female killer whales from three populations (southern and northern residents, transients) (sources: Rayne et al. 2004, Ross et al. 2000, Ross et al. 2004).

Although the health risk to whales from these contaminants is unknown, concentrations in most whales were higher than those likely to cause immunotoxicity in harbour seals (Ross et al. 2000). They are among the most contaminated marine mammals in the world (Ross et al. 2004). A high tissue concentration of PCBs was one reason for the recent classification of southern resident killer whales as Endangered (northern resident and transient populations are classified as Threatened) and the under Canada's Species at Risk Act. Recent research suggests that it may take up to 60 years before southern resident killer whales are likely to experience a real reduction in health risks associated with PCB exposure (Hickie et al. 2007).

Harbour seals (*Phoca vitulina*) are year-round residents on the coast, and occupy relatively small ranges of about 20 km^2 (Cottrell et al. 2002). This makes them good indicators of contamination at a local to regional scale. However, stocks of two of their preferred food fish, herring and hake, undertake local migrations, so there may be some contaminants coming from sources outside the harbour seals' immediate range (Ross et al. 2004).

Tissue samples from harbour seal pups were collected in 1996 from four locations in the Strait of Georgia (Victoria, Vancouver, Crofton, and Hornby Island) and from Queen Charlotte Sound. The concentration of POPs in harbour seals increases with age, especially in males. Therefore, by sampling only pups, researchers could ensure that subjects were all the same age (3 to 6 weeks). Virtually all of the contaminants carried by pups come from their mothers through the placenta and in milk (Ross et al. 2004).

Of the three groups of harbour seal pups tested for PCBs, those born in Puget Sound were the most contaminated and those from Queen Charlotte Sound the least contaminated (**Figure 20**)

(Ross et al. 2004). This is agreement with the finding that herring from the Southern Strait of Georgia have lower contaminant concentrations than herring from the central and southern portions of Puget Sound (O'Neill and West 2005). The regional differences in the contamination of the diet of adult harbour seals is reflected in the contamination of their pups.

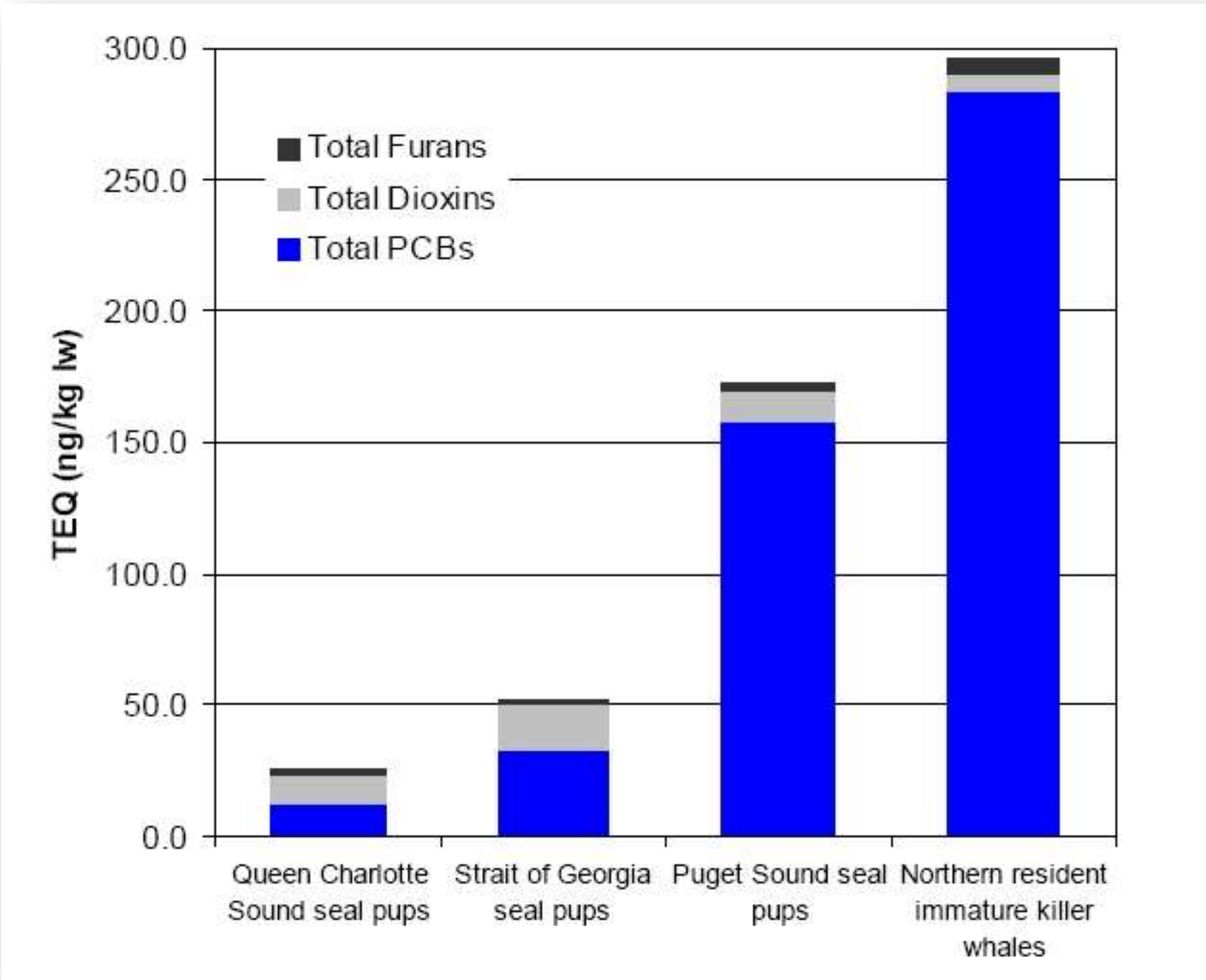

Figure 20. Total equivalent concentrations (TEQs) of PCBs, dioxins, and furans in harbour seal pups from Queen Charlotte Sound, Strait of Georgia, and Puget Sound and immature northern resident killer whales (ng/kg lipid weight) (source: Ross et al. 2000).

Marine invertebrates and fish are a significant pathway by which POPs can be ingested by higher level predators, such as seals. In order to approximate realistic dietary exposures of harbour seals to POPs, a food basket approach, using 20 species of prey, was used. This study showed that PBDEs are now ranked as the number three POP in the Strait of Georgia food web, after PCBs and DDT (Cullon et al. 2005).

Research has shown that a burden of mixed contaminants can impair the immune system in seals, possibly facilitating outbreaks of disease and mass mortality (de Swart et al. 1996). However, contaminant concentrations in Strait of Georgia seals are still below those likely to cause immunotoxicity (Ross et al. 2004). Exposure to contaminants has affected the Vitamin A and thyroid hormone physiology in harbour seals in the Strait of Georgia and Puget Sound (Mos et al. 2006, Mos et al. 2007, Simms et al. 2000, Tabuchi et al. 2006).

Fluorinated organic compounds have been detected in Arctic seals. However, there have been some voluntary reductions in the production and use of these compounds, and this appears to have resulted in a decrease in the amount of these compounds found in seals (CBC News 2006b). Other FOCs are in the process of being banned or restricted (CBC News 2006a).

High levels of organochlorine contaminants, probably from regional sources, have been found in sea otters from southern California (Kannan et al. 1998). They have been implicated as one possible cause of a population decline. High levels of PCBs and OC pesticides were also found in sea otters in the Aleutian Islands, presumably from atmospheric deposition (Estes et al. 1997). However, local sources of PCBs associated with military installations may also represent a regional contaminant source for Alaskan sea otters (Haggarty et al. 2003).

6.2.7. Impacts on Humans

PBDEs enter the human body by ingestion or inhalation. They are suspected of causing cancer, decreasing thyroid hormone levels, and disrupting endocrine systems (McDonald 2002), causing liver toxicity, immune system effects (Gill et al. 2004), hyperactivity, and reproductive effects (Kuriyama et al. 2005). Concentrations of PBDEs in animal tissue and human milk have been increasing steeply (Hites 2004, Rahman et al. 2001). Food represents the principal source of exposure for people, with breast milk accounting for 92% of the exposure for breast-fed infants (HC 2006, Ryan 2004).

In Canada, PBDEs have been found in human breast milk and blood, food, indoor and outdoor air, and water (HC 2004a, b, c, d). A 2004 Health Canada study showed that Canadian women had the second highest concentrations of PBDEs in their breast milk in the world after women in the USA (Ryan 2004). PBDEs in the breast milk of Vancouver women increased almost 10-fold between 1992 and 2002, from 3 ng/g to 20 ng/g (Ryan et al. 2002). PBDE concentrations in indoor air and household dust in Canadian (Wilford et al. 2004) and US (Stapleton et al. 2004) homes were found to be high enough to create a potential health risk to young children, whose hand-to-mouth activity exposes them to greater amounts of household dust than adults. The effect of these residues in people, if any, is largely unknown (BCMOE 2007f). No studies have conclusively linked present PBDE concentrations in humans to health effects (HC 2004d). The threshold for toxicity in animal studies is 100 to 1000 times greater than exposure estimates for the currently most-exposed humans (Laflamme 2005).

Recent studies have found detectable levels of PCBs, dioxins, and some persistent pesticides in wild and farmed BC salmon (Hites 2004). In 2002, Health Canada found low levels of PCBs in fish and seafood purchased in Vancouver, with average values not exceeding 17 ng/g. Farmed Atlantic salmon contained the highest average level (16.8 ng/g), approximately 2.5 times the level in the wild salmon samples (HC 2004b) In 2003, Health Canada found PBDE concentrations in retail samples of seafood up to 5.5 ng/g (parts per billion, ppb). Farmed salmon contained an average concentration of 2.2 ng/g and wild BC chinook averaged 2.9 ng/g PBDEs (HC 2004b). Health Canada has considered the risk to human health from reported levels of PBDEs in fish and seafood, available toxicological information, and estimated dietary fish and seafood consumption. They concluded that levels found in seafood to date are not a health concern for average Canadian consumers, and advised consumers that the known health benefits of eating fish and other seafood outweigh the risks from present contaminant levels (HC 2004b). However, because there is the potential for fish and shellfish to bioaccumulate dioxins and furans, people who eat large amounts of seafood may be at risk (Ross and Birnbaum 2003). Certain human consumer groups are particularly vulnerable, including subsistence-oriented peoples such as the Inuit and coastal First Nations (Kuhnlein and Chan 2000; Mos et al. 2004).

From an economic perspective, POPs can create an economic impact if they contaminate a wild resource (e.g., salmon or herring) which is being harvested for sustenance or to provide a source of income. In either case, closure of a fishery due to POP contamination could result in economic hardship. POP contamination can also be economically damaging to mariculture operations, where contamination would make the product unsafe for consumption and therefore unsellable.

6.3. Concerns in the North and Central Coast

Information on contaminant levels in wildlife in the PNCIMA regions is sparse. Data that do exist tend to be of limited temporal and spatial scale. Most monitoring data are focused around sites of concern such as pulp mills, mines and harbours (Haggarty et al. 2003). The remoteness of much of the PNCIMA does not ensure protection from highly persistent and mobile contaminants. The high levels of PCBs found in northern resident killer whales are testimony to the vulnerability of remote areas (Johannessen et al. 2007a). The prevailing winds ensure that contaminants released from Asia will reach the PNCIMA coastline within 5-8 days. A build-up of pollutants in snowpack, glaciers, coastal sediments and salmon-bearing streams may render ecosystem health vulnerable in the future (Johannessen et al. 2007b).

From the small number of studies that have been done in the PNCIMA region, we know the following:

- **Organochlorine levels in seabird eggs.** OC and PCB contamination levels in eggs from seabirds from the Queen Charlotte Islands and three central coast locations (Thomas Island on northern Vancouver Island and Moore and Whitmore Islands in Hecate Strait) were studied (Elliott et al. 1997). No difference in contamination levels among sites was observed, although there were interspecies differences. The most prevalent contaminants were DDE and PCBs. Fork-tailed storm petrels tended to have the highest residue levels, followed by Leach’s storm petrels and ancient murrelets. Cassin’s and Rhinoceros auklets had the lowest residue levels. Contamination levels appeared to be related to foraging mode and trophic level. Seabirds foraging in inshore or continental shelf areas (e.g. auklets) were exposed to lower levels of contaminants since DDT and PCB restrictions have led to a decrease in inputs of contaminants from regional sources. OC levels in bird species that foraged in offshore areas of the Pacific (e.g. petrels and ancient murrelets) did not decline appreciably between the 1960s and the late 1980s, reflecting the continued inputs from long-range atmospheric transport from Asian sources.

- **PCB, dioxins, and furans in harbour seals (*Phoca vitulina*).** When compared with Puget Sound (heavily industrialized) and Strait of Georgia (moderately industrialized), seals from the Queen Charlotte Strait (remote) had the lowest levels of contaminants. However, contaminants in the Queen Charlotte Strait seals were dominated by less chlorinated PCBs and PCDD/Fs. These “light” contaminants are more volatile than heavily chlorinated PCBs and PCDD/Fs congeners, and thus travel greater distances. The “light” contaminant signature in the seals from the Queen Charlotte Strait is indicative of long-range atmospheric transport of contaminants (Ross et al. 2004).

- **PCBs and PCDD/Fs in killer whales (*Orcinus orca*).** All three populations of killer whales in BC, transients, northern residents and southern residents, have high levels of PCBs. Both transients and northern resident home ranges include the PNCIMA region. Transients are more contaminated than northern residents due to their higher position in the food chain – transients consume marine mammals whereas residents mainly consume salmon. Contaminants in salmon may explain some of the contamination of the northern residents. Long-range atmospheric transport of contaminants also plays a significant role in the contamination of northern resident killer whales (Ross et al. 2000).

- **PBDE concentrations in Dungeness crabs and English sole**. Comparison of animals from the Strait of Georgia, Kitimat, and Prince Rupert showed that Dungeness crab had 4–420 ng/g lipid weight in tissues of their hepatopancreas and English sole collected from the same areas and time period had 22–310 ng/g lipid weight in the liver tissue **Figure 21**). Prince Rupert had the highest values for Dungeness crab, whereas the Strait of Georgia has the highest values for English sole (Ikonomou et al. 2002).

In summary, the PNCIMA faces the following threats (Johannessen et al. 2007b):

- ‘legacy’ POP contaminants that will continue to cause health effects in vulnerable species such as killer whales.
- POP contaminants that are considered ‘legacy’ in the Canada and the USA, but are still used in Asia.
- POP contaminants that are not yet regulated in Canada and/or the USA, such as polybrominated diphenylethers (PBDEs).
- Non-POP contaminants, such as currently used pesticides, that may adversely affect salmon in natal streams or other biota in coastal and estuarine areas.

6.4. Monitoring

To monitor for POPs, a water, sediment, or tissue sample is collected, preserved (usually by freezing), and shipped to a specialized laboratory for chemical analysis. The number and type of samples collected will depend on the particular issue being studied, the decisions that will be made using the data obtained from the samples, the overall understanding of the ecosystem that is desired, and the amount of time and money available for the sampling program. There are a number of possible approaches to monitoring, for example:

- **Sediment or water monitoring** – used to determine the level of contaminants in the physical environment. This information can be used to assess the degree of contamination of a particular environment and to determine the exposure of organisms to pollutants.
- **Resource monitoring** – used to determine the level of contaminants in a valuable resource (e.g. salmon, herring, kelp) that may be used either as a source of income or food. A tissue sample of the particular organism of interest is analyzed. Acceptable, legal limits of different pollutants may exist, and the amount of pollutant in the organism must be below these limits for consumption or sale.
- **Sentinel species monitoring** – used to determine changes in contaminant levels over time in a species which may have particular ecological or economic importance. Choice of sentinel species (biomonitors) should be cosmopolitan (widely distributed) species. Species found in BC that have been recommended as biomonitors include seaweeds (*Ulva* and *Fucus*), mussels (*Mytilus*), oysters (*Crassotea gigas*), polychaetes (*Nereis*), barnacles (*Balanus*), and amphipods (Rainbow 1995). The use of higher trophic level species, such as sea birds, birds of prey and marine mammals, has also been recommended (Elliott and Scheuhammer 1997, Elliott and Harris 2001, Ross et al. 2000). Dungeness crabs have been used as a biomonitor for dioxins and furans in BC. They are ideal for this purpose because they have a very limited ability to metabolize dioxins and furans. As a result, the levels of these contaminants in their tissues often mirror those in surface sediments (Yunker et al. 2002).
- **Ecosystem monitoring** – used to develop a greater breadth of understanding with respect to the sources, sinks, transport pathways, and metabolization of contaminants in an ecosystem. It is a broad scale monitoring program that incorporates sampling of organisms from all trophic levels, as well as sediment and water sampling (Macdonald et al. 2002).

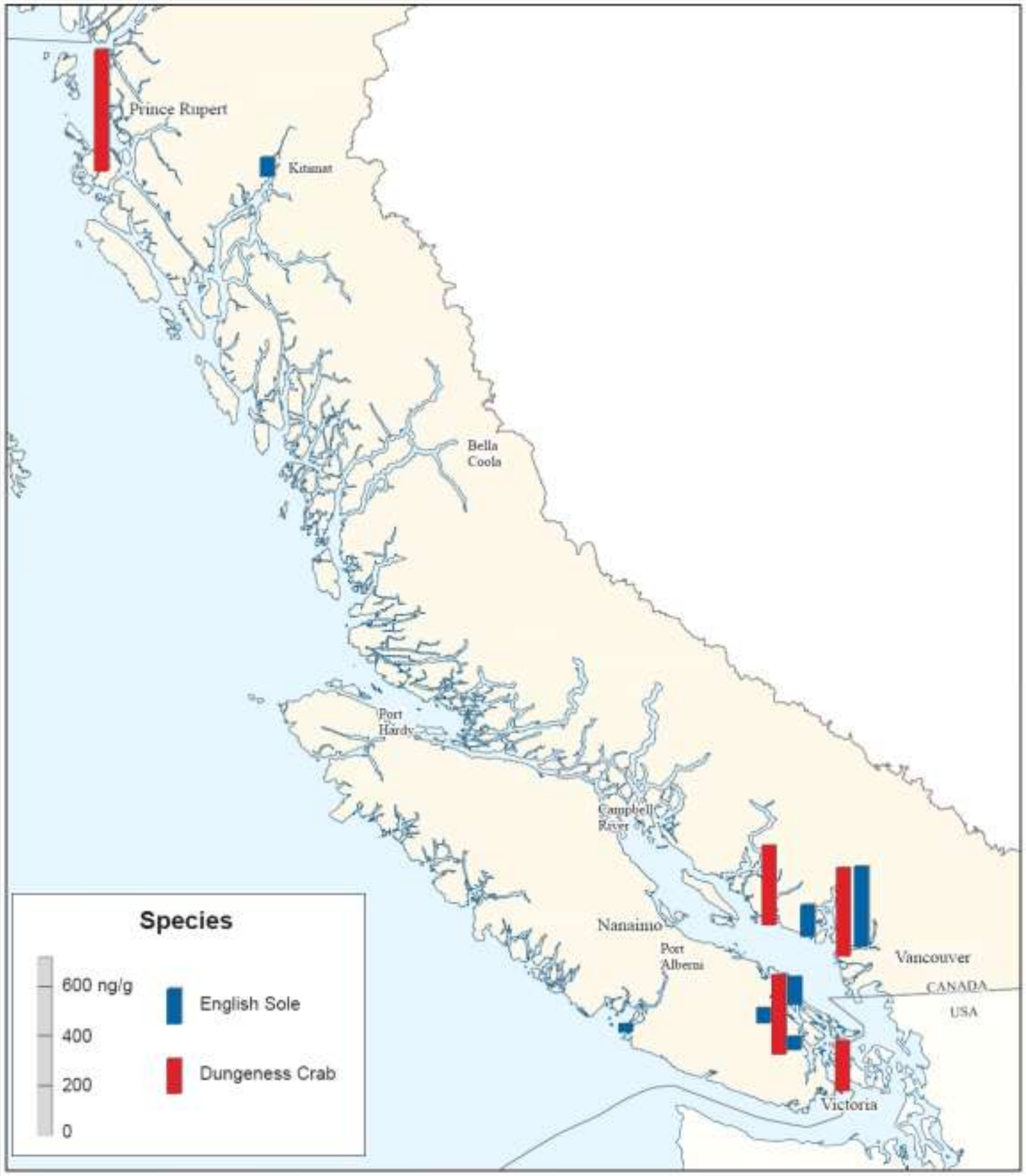

Figure 21. PBDE concentrations (ng/g lipid weight) in tissues of Dungeness crab and English sole in coastal samples (source: Ikonomou et al. 2002).

6.5. Mitigation

Mitigation measures for POPs involve two levels of action:

- Local pollution control for point source emitters of POPs. Mitigation measures for these point source polluters are discussed in other sections of this report.
- National and international actions towards preventing wanton release of contaminants that end up in remote aquatic food webs. 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 the PNCIMA region (Johannessen et al. 2007a).

7. Heavy Metal Pollutants

7.1. Pollution Sources

The term "heavy metals" is the general name given to common transition metals, such as copper, lead, and zinc. These metals are can be a cause of environmental pollution (heavy-metal pollution). Heavy metals are natural elements in the environment; however anthropogenic sources can increase certain metal concentrations. Common anthropogenic sources to the marine environment include mines and metal refineries, landfill leachate, sewage treatment plants, urban runoff and atmospheric deposition. It can often be difficult to determine if measured metal concentrations at a site are from natural or anthropogenic sources, particularly if the background levels of metal concentrations in the environment are not available (Haggarty et al. 2003). Like POPs, metals tend to enter the environment as point source pollutants, but may become widely distributed in the environment and end up as non-point source pollutants.

7.1.1. Mercury

Mercury occurs as elemental mercury, inorganic salts, and in organic forms (BCMOE 2006b). Mercury is used in gold mining activities, antifouling paints, laboratory instruments, and electrical equipment (Haggarty et al. 2003). Mercurial compounds are also used in scientific research and pharmaceuticals. Organic mercury compounds, such as methyl mercury, are used medically as fungicides and antibacterials (BCMOE 2006b). Like other heavy metals, mercury enters the marine environment from many sources, including coal-fired power stations, industrial processes, wastewater outfalls, mine effluents and discharges, and atmospheric emissions, as well as natural ore deposits. Municipal outfalls that contain mercury from dental and medical offices and light industry are probably the most important local source of mercury into coastal environments (Macdonald et al. 2002). In historic gold mining areas, mercury was used in the 19th and early 20th centuries, and heavily contaminated tailings are still present (Pacyna and Pacyna 2002). Mercury can also be released from flooded soils and vegetation in reservoirs, where bacteria use the organic carbon in soils to produce methyl mercury from natural concentrations of inorganic mercury (Brigham et al. 2002).

Elementary mercury is volatile, and can have long residence times in the atmosphere. As a result, it can be transported great distances (Haggarty et al. 2003). Mercury from metal smelting, coal-fired utilities and municipal waste incinerators is transported globally in the atmosphere. Best estimates suggest that human activities have doubled or tripled the amount of mercury in the atmosphere, with the atmospheric burden increasing by about 1.5% per year (Johannessen et al. 2005). Mercury is insoluble in water, adsorbs to particles, and settles out. Thus marine sediments can form a sink for mercury (Haggarty et al. 2003).

Mercury contamination is of international concern, with many countries, including Canada, taking stringent measures to regulate and reduce emissions. Mercury emissions from metal smelting in Canada have been significantly reduced since 1988, as have releases from chloralkali manufacturing, pesticides, paints, and batteries (BCMOE 2006b).

7.1.2. Copper

Copper is used in electrical equipment, in alloys, as a chemical catalyst, in antifouling paints, as a wood preservative, and in pesticides. In seawater, copper is usually present as an inorganic salt (copper carbonate or copper hydroxide); however it can also forms complexes with organic molecules. Most copper is adsorbed onto particles and becomes incorporated into the sediments (Clark 2001).

7.1.3. Cadmium

Cadmium is widely distributed in the earth's crust. It is usually associated with zinc, and is often released as a byproduct in zinc smelting. Since the 1950s, it has been used as a pigment stabilizer in plastics, in electroplating, in solders and alloys, and in Ni-Cd batteries. Sources of cadmium to the marine environment include atmospheric deposition from impurities in zinc, coal, iron, steel and phosphate processing, sewage sludge, and rinsing water of electroplating. Cadmium is not volatile, and tends to be associated with particles (Grant and Ross 2002). Most cadmium is deposited in sediments on the continental shelf; however its fate is not completely understood (Clark 2001). Long-range transport of cadmium has been observed in the North Pacific (Macdonald et al. 2002).

7.1.4. Lead

Elemental metallic lead is used in lead-acid batteries, ammunition (lead shot), as sheet and casting metal, in solder, alloys, and bearings (Laws 2000). Elemental lead is largely recycled and recovered. However, in some specific situations, elemental lead has created significant pollution problems. Lead shotgun pellets have caused increased levels of lead in some estuaries (Elliott and Harris 2001). Improper disposal of lead-acid batteries can be a serious issue in marinas. An organic lead compound, tetra-ethyl lead, is widely used in leaded gasoline, and this contributes the greatest source of lead to the atmosphere (Clark 2001). Leaded gasoline was phased out in Europe and North America in the 1990s, but it continues to be used in other parts of the world. Lead emissions are also released from smelters and refineries. Lead is generally detected in sediments near point sources including smelter, acid mine drainage areas, and urban and industrial sites (Grant and Ross 2002). Anthropogenic sources of lead to the environment are much greater than natural inputs (Clark 2001).

7.1.5. Other Metals

Arsenic, silver and nickel inputs have caused concern in some areas worldwide, however none appear to have been responsible for environmental damage or a threat to human health. All three are known to be highly toxic; however, contaminant levels are usually far below toxic concentrations (Clark 2001).

7.2. Environmental and Socio-Economic Impacts

Some metals, such as copper, zinc, and iron, are essential elements which are required by plants and animals for growth. Other metals, such as mercury and lead, are not. While all metals can be toxic at high concentrations, metals such as cadmium, mercury, copper and lead are toxic even at low concentrations (Haggarty et al. 2003). Non-essential metals (not required by organisms) tend to be toxic at lower concentrations than essential metals (required by organisms). If an organism cannot excrete a metal, it will accumulate in tissues, and may biomagnify in predators. The degree of toxicity, bioaccumulation and biomagnification depends on the particular metal, the chemical form of the metal (not all forms are bioavailable), and the biolochemistry of the organisms exposed to the metal (Haggarty et al. 2003).

7.2.1. Mercury

Unlike other metals, mercury bioaccumulates and biomagnifies in aquatic food webs, and can present a health risk to high-level consumers (BCMOE 2006b). Methylmercury is the most bioavailable and toxic form of mercury. It biomagnifies in invertebrates, fish, birds, and mammals. The highest concentrations occur in large, longer-lived animals, and in species at the top of the food chain (Bodaly and Fudge 1999). It is known to accumulate in long-lived fishes (i.e. tuna, swordfish, marlin, some sharks, and halibut). High concentrations of methylmercury are dangerous to human consumers, so limits on allowable amounts of methylmercury in food and recommendations for consumption limits exist (Haggarty et al. 2003).

Mercury's primary health effects are neurological. High exposure to mercury can also permanently damage the brain and kidneys, and cause birth defects in humans (Clarkson 1997) and wildlife (Wolfe et al. 1998). Children are particularly susceptible to the toxic effects of mercury. Methylmercury easily passes through the placental barrier, resulting in damage to the brain and neurological system of the fetus (BCMOE 2006b). The main source of human mercury poisoning is through eating mercury-contaminated fish (BCMOE 2006b).

7.2.2. Copper

Copper is an essential element, and is required in a number of biological processes, including serving as the blood pigment in crustaceans. However, it is the most toxic metal after mercury and silver. Fortunately, it does not generally biomagnify in food chains. Particulate-bound copper in the sediments may not be bioavailable, and thus serves as a copper sink (Clark 2001).

7.2.3. Cadmium

Some marine organisms accumulate large concentrations of cadmium, although no environmental effects have been reported (Haggarty et al. 2003). Various toxic effects such as reductions in growth, immune impairment, renal dysfunction, and cancer have been noted in mammals (Grant and Ross 2002). Cadmium does not appear to accumulate in food chains (Clark 2001).

Cadmium levels in oysters cultured in BC often exceed 1 ppm. The Canadian Food Inspection Agency, shellfish growers, and the Department of Fisheries and Oceans are concerned about these levels, as they exceed the 1 ppm import limit wet for bivalve molluscs by the European Union. It is believed that natural sources, including mineral deposits, local geology, sediment transport from watersheds or the head of fjords, and upwelling from deep ocean water, play a large role in the enrichment of biota with cadmium. However, anthropogenic causes, such as increased sedimentation from forestry, inorganic phosphate fertilizers used in agriculture and golf courses, and sewage and septic system sludge, may also contribute cadmium to local areas. Oysters accumulate cadmium through food items such as phytoplankton. Bioavailablity of cadmium increases in waters with lower salinity, such as the Strait of Georgia and inlets with estuarine circulation. Cadmium concentrations increase slightly in a northward trend along the BC coast, particularly around shellfish growing areas in fjords, upwelling areas, and areas with other local sources of cadmium. Ramifications of these elevated cadmium levels in BC oysters may include damage to public perception of the safety of cultured shellfish products, loss of export market, and general undermining of the industry (Kruzynski 2000, Kruzynski et al. 2002, Kruzynski 2004).

High levels of cadmium have been reported from seabirds in BC, such as Leach's storm-petrels in the Queen Charlotte Islands (306 ±78 mg/kg dry weight kidneys) (Elliott and Scheuhammer 1997).

7.2.4. Lead

Although many toxicological effects of lead exist, it is not believed to be particularly toxic to marine organisms (Clark 2001). As a result of inadvertent ingestion of lead shot, some waterfowl have shown increased levels of lead, and some bald eagles have contracted lead poisoning from scavenging contaminated waterfowl (Elliott and Harris 2001).

7.3. Concerns in the North and Central Coast

Very little information exists on the presence of naturally occurring or anthropogenically derived heavy metals in PNCIMA region. From the studies that have been done, we know the following:

- slightly elevated levels of cadmium and lead have been found in fish, shrimp, and prawns (Harding and Goyette 1989).
- elevated cadmium levels have been detected in seabirds and scoters (sea ducks), particularly around the Queen Charlotte Islands (Barjaktarovic et al. 2002, Elliott and Scheuhammer 1997).
- elevated levels of cadmium in oysters and scallops have been detected all along the BC coast. Specific sources of this contamination are not identified (Kruzynski 2000, Kruzynski et al. 2002, Kruzynski 2004).
- studies of mercury in bald eagles did not detect significant levels in the north coast area (Weech et al. 2003).

7.4. Monitoring

To monitor for heavy metals, a water, sediment, or tissue sample is collected, preserved (usually by freezing), and shipped to a specialized laboratory for chemical analysis. The number and type of samples collected will depend on the particular issue being studied, the decisions that will be made using the data obtained from the samples, the overall understanding of the ecosystem that is desired, and the amount of time and money available for the sampling program. Monitoring approaches are similar to those described for POPs (section 6.4).

7.5. Mitigation

Mitigation measures for heavy metals involve two levels of action:

- Local pollution control for point source emitters of heavy metals. Mitigation measures for these point source polluters are discussed in other sections of this report.
- Regional, national, or international actions towards preventing release of heavy metals that become globally distributed and end up in remote aquatic food webs.

8. Sewage Pollution

8.1. Pollution Sources

One of the major impacts people have on the environment is the discharge of raw or treated sewage (wastewater), directly or indirectly, into marine or estuarine environments. The main sources of wastewater are households (municipal sewage), industrial operations, commercial operations, and stormwater runoff (DFO 2001). By volume, municipal sewage and combined sewer overflows (which contain stormwater runoff) are one of the largest point sources of pollution to Canadian waters (BCMOE 2006b, 2007c). In Canada, it is estimated that 80% of marine pollution comes from terrestrial activities, including municipal, industrial, and agricultural runoff (DFO 2001).

Wastewater discharged from urban and industrial sources directly into the ocean contains various biological, chemical, and physical contaminants. One of the growing concerns regarding municipal wastewater is the chemical contaminants which it contains. Hundreds of chemicals, including metals (Cd, Hg, Cu, Pb), synthetic organic chemicals (PCBs, dioxins, furans, pesticides, nonylphenols, pesticide residues, pharmaceuticals), chlorine, solvents, paint thinner, oils, antifreeze, and bleaches are released into the marine environment through wastewater (BCMOE 2006b, 2007c, Haggarty et al. 2003). Sewage can contain the following contaminants (EC 2001, Waldichuk 1983):

- **Grit, debris, and suspended solids** - can discolor the water, make it unfit for recreational, domestic, and industrial use, and eventually smother and contaminate plant and animal life on the bottom of the receiving water body
- **Disease-causing pathogens** (e.g., bacteria and viruses) - can make the water unfit for drinking, swimming, and other recreational uses and can contaminate shellfish
- **Decaying organic wastes** - can use up the water's dissolved oxygen, contributing to the biochemical oxygen demand (a measure of the quantity of oxygen, in milligrams per liter, taken up in the biochemical oxidation of organic matter in the dark, in a specified time, and at a specified temperature; referred to as BOD) of the water, and threaten the survival of fish and other aquatic life
- **Nutrients** - can over-stimulate the growth of algae and other aquatic plants, giving rise to odors and other aesthetic problems, diminished biodiversity, and, in some cases, toxic contamination of shellfish
- **Chemical contaminants** - about 200 different identified chemicals, many of which may be either acutely or chronically toxic to aquatic organisms, and may pose a health risk to humans; many of these chemicals may have long-term environmental effects, as they are not easily broken down and tend to accumulate in aquatic or terrestrial organisms through the food chain
    - **Trace metals** - sources of trace metals in municipal sewage include street runoff, industrial wastes from small industries such as photographic processing, laboratories, hospitals, dental clinics, and other operations, and household wastes (Kay 1989, Waldichuk 1983).
    - **POPs** - municipal wastewater is also a source of toxic contaminants such as PCBs, dioxins, furans, PAHs, and chlorinated phenols (Haggarty et al. 2003). Since these POPs are released by a variety of sources in addition of municipal wastewater, it is difficult to determine the proportion of POPs that are attributable to sewage discharges (Pierce et al. 1998).
    - **Chlorine** - chlorine may be added to sewage effluent to act as a disinfectant to reduce bacterial and viral contamination. However, chlorine is toxic to many marine organisms. Chlorine also reacts with other organic substances to create organochlorine compounds that can be very toxic. The BC government discourages the use of chlorine as a disinfectant for effluent released into the marine environment (Haggarty et al. 2003). Where disinfection is required and chlorine is used, the regulation requires the residual chlorine is to be limited to

0.01 mg/L (Waste Management Act - 1999 Municipal Sewage Regulation (MSR) - Part 8: Effluent disinfection) (Associated Engineering (BC) Ltd 2003a).

- **Household cleaning products** - various contaminants are introduced into the marine environment when household cleaning products are washed down drains. Household cleaning products can contain bleach, solvents, surfactants, and nonylphenols (Haggarty et al. 2003). Many of these substances are carcinogens, reproductive toxins, endocrine disrupting chemicals, or may be toxic chemicals which react with other chemicals to form additional toxins (LEAS 2007a, b)
- **Pharmaceuticals and personal care products (PPCPs)** - pharmaceuticals and personal care products produced by humans can end up in wastewater. These include natural and artificial estrogens, antibiotics, antiseptics, analgesics, beta-blockers, steroids, and many other compounds (Johannessen and Ross 2002). A recent study by the US Geological Survey found that detergent metabolites, plasticizers, steroids, and non-prescription drugs were found in US streams. The most commonly detected substances included antibiotics, reproductive hormones, and various prescription drugs (Barnes et al. 2002). These products have been found in wastewater in Canada as well (Kleywegt et al. 2007). Many of the impacts of these products are unknown; however, acute toxicity and endocrine disruption have been documented for some products (Daughton and Ternes 1999, Hydromantis Inc. et al. 2005).

Table 9 gives some examples of specific biological, chemical, and physical contaminants found in wastewater.

Table 9. The biological, chemical, and physical constituents of wastewater effluents (EC 2001).

Type of wastewater constituent	Selected examples
Biological	Bacteria e.g., fecal coliforms (e.g., *Escherichia coli*, *Campylobacter*) e.g., *Salmonella* Viruses e.g., hepatitis A virus Protozoa e.g., *Giardia* e.g., *Cryptosporidium*
Chemical	Nutrients Nitrogen (e.g., nitrate, nitrite, ammonia) Phosphorus Organic chemicals Pesticides (e.g., toxaphene, DDT/DDE) Surfactants (e.g., nonylphenol) Chlorinated solvents (e.g., tetrachloroethylene, trichloroethylene) Polycyclic aromatic hydrocarbons (PAHs) Polychlorinated biphenyls (PCBs) Endocrine-disrupting substances (e.g., PCBs, dioxins, furans, contraceptives, nonylphenol) Inorganic chemicals Metals (mercury, cadmium, copper, iron, lead, nickel, zinc) Chloride and chlorine Cyanide Oil and grease Biochemical oxygen demand (e.g., organic matter)
Physical	Suspended solids Debris Grit

One of the important factors affecting the environmental impacts of wastewater is the ability of the aquatic environment receiving the wastewater to disperse, dilute, and assimilate sewage (Haggarty et al. 2003). Coastal environments generally have high flushing and mixing rates. As a result, over-enrichment from the input of nutrients is unlikely to occur in coastal environments, except in poorly flushed fjords or bays (Waldichuk 1983). The effects of wastewater on the environment also depend on factors such as salinity, volume of discharge, presence of sensitive species, and degree of wastewater treatment. The more sensitive the receiving environment, the greater the degree of treatment of the wastewater that will be required to remove nutrients and other contaminants (BCMOE 2006b).

8.2. Environmental and Socio-Economic Impacts

The release of untreated or inadequately treated wastewater may put people and wildlife at risk if drinking water becomes contaminated with micro-organisms or toxic substances. People are also put at risk from consuming fish and shellfish from contaminated waters. Fecal coliform bacteria indicate the presence of human or animal wastes, and the possible presence of other disease-causing organisms. Areas of shellfish beds are closed when they are found to be contaminated with fecal coliform bacteria. Fecal coliforms in the marine environment come from a variety of sources, including urban runoff, sewage discharge, and agricultural drainage. Sporadic outbreaks of fecal contamination also come from wildlife sources, such as deer and bear (BCMOE 2007c). Shellfish closures have often been the impetus for increased sewage treatment. For example, water quality requirements in Baynes Sound, a major shellfish farming area, led the municipalities of Courtney-Comox to install a secondary sewage treatment plant (Waldichuk 1983). Shellfish sites can be closed if the level of coliforms in the water exceeds 14 coliform bacteria in 100 ml or if poisonous or deleterious substances within the tissue of the shellfish exceed legally set levels. Shellfish harvesting is prohibited within 300 m of industrial, municipal, and sewage treatment plant outfalls or within 125 m of marinas (CFIA 2003). Shellfish closures can be a significant issue, particularly in light of the desire to expand shellfish aquaculture on the North and Central coast.

Elevated levels of trace metals have been found in sediments, water, and shellfish near municipal outfalls. Metal concentrations in sediments in Nanaimo have been increasing steadily since the installation of a sewage outfall. High levels of zinc, mercury and copper in molluscs occur around Victoria outfalls (Kay 1989).

Other environmental impacts caused by wastewater are eutrophication (process whereby water bodies, such as lakes, estuaries, or slow-moving streams receive excess nutrients that stimulate excessive plant growth), oxygen depletion, toxicity, and aesthetic issues for people (BCMOE 2006b). **Table 10** list some of the environmental and socio-economic impacts from the various components of sewage.

Table 10. Ecological and socioeconomic effects of municipal wastewater effluents (sources: Chambers et al. 1997, EC 2001).

Effluent component	**Observed effects**			
	Ecological effects			Socio-economic effects
	Water quality, habitat	Plants	Animals	Health, economy, recreation
Chemical Nutrients (phosphorus and nitrogen)	• increase in nutrient concentrations • depletion of oxygen due to decay of plant material • reduced water clarity	• changes in algal species composition • increase in submerged weed growth • increase in algal biomass and possible formation of toxic blooms	• changes in species composition due to changes in food supplies for herbivores • reduced productivity and survival of invertebrates and fish due to oxygen depletion • concentration of biotoxins by shellfish	• health risk from contamination of drinking water with nitrates • algae-related taste and odor problems in drinking water • health risk from consumption of shellfish contaminated with algal toxins • blockage of water intakes by filamentous algae and weeds • interference with passage of boats by submerged weeds • degradation of shorelines and impairment of recreational uses by nuisance algae • economic losses from biotoxin-related closures of shellfish growing areas
Toxic contaminants (bioaccumulative and nonbioaccumulative)	• increased concentrations of toxic contaminants in water and sediments	• acute or chronic toxicity (affecting reproduction, growth, survival), resulting in changes in species abundance and diversity • bioaccumulation of toxic contaminants	• acute or chronic toxicity (affecting reproduction, growth, survival), resulting in changes in species abundance and diversity • bioaccumulation of toxic contaminants • biomagnification of contaminants at higher food web levels	• health risk from consumption of contaminated fish and shellfish • health risk from contaminated drinking water • economic losses from closures of fish and shellfish growing areas contaminated with metals and/or organic compounds
Endocrine-disrupting chemicals			• deformities and embryo mortality in birds and fish • impaired reproduction and development in fish • depressed thyroid and immune functions in fish-eating birds • feminization of male fish and reptiles	• risks to human health from consumption of contaminated food (e.g., fish and shellfish) and water • economic and recreational losses due to restrictions on consumption

Effluent component	Observed effects			
	Ecological effects			Socio-economic effects
	Water quality, habitat	Plants	Animals	Health, economy, recreation
Physical Increased water flow (stormwater discharge)	• stream- or riverbed erosion leading to increased concentrations of suspended solids in the water • bank erosion leading to increased concentrations of suspended solids • flooding • habitat washout		• loss of habitat • washout • downstream drift of bottom-dwelling invertebrates	• economic and recreational losses due to reduced fish abundance
Suspended solids	• reduced water clarity • transport of adsorbed contaminants • sedimentation-related changes to water flow	• reduced photosynthesis and plant growth due to reduced water clarity	• blanketing of spawning grounds • reduced growth or survival of species • blockage of migration or dispersal routes by accumulated sediments	• economic and recreational losses due to reduced fish abundance
BOD	• reductions in dissolved oxygen in water column and sediments due to buildup of oxygen-consuming material		• fish kills, loss of species, reduced biodiversity	• economic and recreational losses due to reduced fish abundance
Heating of the receiving water	• ambient water temperature increase	• succession from coldwater to warm-water algal species	• succession from coldwater to warm-water fishery	• economic and recreational losses due to changes in fisheries
Floating debris	• reduced aesthetics		• entanglement leading to starvation, exhaustion, and infection from wounds • ingestion of debris leading to blocked digestive tract	• health risk from waste on beaches (e.g., medical waste) • loss of tourism revenue due to reduced aesthetic value • increased costs for beach and park maintenance
Biological Pathogens (bacteria, viruses, protozoa)	• increased concentrations of pathogens in water and sediments		• increased concentrations of pathogens in filter-feeding shellfish (bivalve molluscs)	• health risk from consumption of contaminated drinking water, fish, and shellfish • health risk from recreational exposure to contaminated water and sediments • restricted recreational use (swimming and fishing) • economic losses due to closures of fish and shellfish growing areas and beaches

8.3. Concerns in the North and Central Coast

The impact of sewage discharge is site specific and highly dependent on the characteristics of the outfall and the receiving environment. Factors such as rate of flushing, type of discharge (shallow, deep), level of treatment, and cumulative loadings can all have an effect on the degree of environmental impact (McDonald 2002). Although specific information on all of the communities is not available, **Table 11** shows the level of treatment for some of the communities in the PNCIMA. There are three general observations that can be made from this data:

- Almost all of the larger communities in the PNCIMA have some level of secondary treatment. Prince Rupert is an outstanding exception. Prince Rupert's sewerage system currently consists of ten separate catchment areas, each being defined by natural drainage boundaries. Four of the catchments in the core area are serviced by separated sanitary and storm sewer systems, with six of the catchments serviced by combined sewers. The eleventh catchment services a small area east of the core area that primarily uses individual septic tank systems at each dwelling, connected into a common sewer that discharges into Fern Passage. Each of the ten other sewerage areas has a dedicated marine outfall which discharges untreated wastewater into the Prince Rupert harbour. One sewerage system in the core urban area receives preliminary wastewater treatment through the use of comminutors, which are units that grind up sewage solids prior to discharge (Associated Engineering (BC) Ltd 2003b). The City of Prince Rupert is currently engaged in a planning process to address the lack of wastewater treatment; however this process will take a number of years, as it will involve significant repairs and upgrades to the current system, and is presently hampered by a lack of funds.
- Most of the small communities and rural areas rely on either septic systems or simple marine outfalls with little or no treatment. Small amounts of raw sewage, as well as untreated grey water, may be released into marine waters from septic systems (Haggarty et al. 2003). Many First Nations communities in BC are experiencing issues with respect to maintenance and repair of their current wastewater systems. 22% of BC First Nations communities have wastewater systems with minimal or no problems, 61% have wastewater systems requiring some repairs, and 17% have wastewater systems with potential health and safety concerns (INAC 2003).
- No communities in the PNCIMA have tertiary treatment.

Local inputs of sewage may become more serious problems as shellfish aquaculture in the PNCIMA expands. Subsidence harvesting may also be affected if natural shellfish beds are exposed to bacterial contamination.

Table 11. Levels of sewage treatment in some of the communities in the PNCIMA (sources: Associated Engineering (BC) Ltd 2003b, EC 2008, Haggarty et al. 2003). 1° = primary treatment, 2° = secondary treatment.

District/ Town	Population	Sewage Treatment
Alert Bay	555	2°
Bella Coola Indian Reserve	788	septic / untreated
Campbell River	29,370	2° (hi rate activated sludge)
Central Coast Regional District A	140	septic / untreated
Central Coast Regional District C	555	septic / untreated
Central Coast Regional District D	420	septic / untreated
Central Coast Regional District E	130	septic / untreated
Holberg Winter Harbour	169	septic/untreated septic/untreated
Kitimat	8,950	2°
Klemtu (Kitasoo) Indian Reserve	285	septic / untreated
Mount Waddington Regional District A	1,050	untreated/2°
Mount Waddington Regional District D	305	untreated
Port Alice	820	2°
Port Hardy	3,810	2° (contact stabilization)
Port McNeill	2,620	2°
Prince Rupert	12,755	untreated (10 outfalls, one with preliminary comminution)
Quadra Island	2,548	septic / untreated
Quatsino Coal Harbour	829	untreated 2°
Sayward	340	2° (aeration lagoon)
Sointula, Echo Bay	886	2° septic
Telegraph Cove Woss Beaver Cove	401	2° 2° (aeration lagoon) 2° (industrial residential septic)

8.4. Monitoring

The following characteristics of wastewater are often monitored to provide information on the efficiency of the wastewater treatment and the potential environmental impact of the wastewater (INAC 2000):

- **Temperature -** wastewater temperature is an important factor for the treatment process. Settling of solids is more effective at higher temperatures, whereas colder conditions reduce the biological activity that takes place in the treatment facility.
- **Biochemical oxygen demand** - BOD, or biochemical oxygen demand, is the amount of oxygen that is required to decompose the organic matter in wastewater. This indicates how much organic matter is in the wastewater, which in turn indicates the ‘strength’ of the sewage. The organic ‘strength’ of the sewage is one of the most important criteria used in the design of a wastewater treatment facility for determining the extent of treatment needed. By testing the BOD before and after treatment, the efficiency of the treatment process can be measured, and the impact of the treated sewage on receiving waters can be predicted.
- **Dissolved oxygen** – the bacteria used the wastewater treatment process need oxygen to decompose the organic matter. However, since the oxygen required by the bacteria usually exceeds the amount available in the wastewater, additional oxygen must be supplied by means of mechanical equipment such as aerators. Chemical test kits can be used to measure the amount of oxygen in the wastewater, and thus determine if aeration is necessary for the process to work effectively.
- **pH** - pH is a measure of the acidity or alkalinity of a liquid. The pH scale ranges from 0 to 14, with the acceptable range for wastewater typically being 6.5 to 8.5. Acidic water (pH

less than 7) will tend to corrode equipment while alkaline water (pH greater than 7) will deposit scale in pipelines. Effluent with extreme pH values may damage the receiving environment

- **Coliforms** - coliforms are a harmless type of bacteria found in the intestines of warm blooded animals. Their presence in wastewater, however, indicates the possibility that pathogenic or disease-causing bacteria might also be present. Testing for, and ensuring that the number of coliform bacteria in wastewater are kept to a minimum, greatly reduces the possibility of disease being spread. Chlorinating the wastewater eliminates most disease-causing bacteria. To test for coliform bacteria, samples of treated wastewater are collected and sent to qualified laboratories for analysis.
- **Settleable solids** - very fine material in wastewater will settle if the wastewater is still. The settleable solids test indicates how much of the fine material in a sample of wastewater will settle during a set time (usually 30 minutes). By performing the test on samples of untreated and treated wastewater, the operator can check how efficiently the treatment plant is removing settleable matter.

In British Columbia, the following parameters are monitored for discharges to surface waters (BCMOE 1999a, CCME 2004):

- Biochemical oxygen demand (BOD)
- Total suspended solids (TSS)
- Total phosphorus (for freshwater receiving environments only)
- Ammonia
- Coliforms

The Municipal Sewage Regulations state that the minimum treatment level for discharges into surface waters is secondary; however, an interim primary treatment level is still accepted for existing discharges (BCMOE 1999a). The effluent quality standards for the monitored parameters are given in **Table 12**.

Table 12. Effluent quality standards for discharges to water (data: BCMOE 1999a).

Parameter	Standard
BOD	45 mg/L
TSS	45 mg/L
pH	6.0 – 9.0
Total phosphorus	1.0 mg/L
Ammonia	depends on temperature and pH of receiving water
Coliforms	< 2.2/100 ml in receiving waters used for drinking < 14/100 ml in receiving waters bearing shellfish < 200/100 ml in receiving waters used for recreation

8.5. Mitigation

The environmental and socio-economic impacts of wastewater can be largely mitigated by the design of the sewage collection and treatment facility and the type of treatment carried out at that facility. The type of treatment necessary will depend on several factors:

- **Contaminants in the wastewater** – this will affected by the types of activities, industries, etc. that are taking place in the community.
- **Nature of the body of water receiving the wastewater** – for example:
    - Freshwater is more sensitive to eutrophication from nutrient enrichment than seawater. Algal growth in freshwater is generally limited by the amount of phosphate (an essential element required for plant growth) in the environment. In contrast, algal growth in marine environments is usually limited by the amount of nitrate (also an essential element required for plant growth). Many freshwater systems are oligotrophic (have low primary productivity [algal growth] as a result

of low nutrient content). The addition of small amounts of nutrients, particularly phosphate, from wastewater into the system can create massive algal blooms. However, coastal marine waters receive high levels of nutrients from natural terrestrial runoff, and support high primary productivity. Thus, addition of extra nutrients from wastewater has a relatively small impact as compared to freshwater systems.
    - Systems with low natural circulation are more sensitive to wastewater discharges than those with high water flows. Wastewater tends to become concentrated, or even trapped, in systems with inadequate circulation.
- **Presence of sensitive species** – some organisms are more sensitive to certain contaminants contained in wastewater than others. These species may require special protection.
- **Activities taking place in the receiving body** – certain activities, such as aquaculture, tourism, and recreation are not compatible with the presence of wastewater effluents.

Mitigation measures for wastewater effluents can take several possible approaches:

- **Source control** – this involves the development of source control bylaws in a community which restrict the types of substance which may be discharged into the wastewater system. This is often one of the most cost-effective methods of dealing with wastewater, as it can significantly reduce the type of effluent treatment required.
- **Reduction of wastewater volume** – many communities have combined sewer systems in which domestic and industrial wastewater are combined with storm runoff, thus significantly increasing the volume of effluent which requires treatment. During wet weather, the volume of the combined wastewater and storm water may exceed the capacity of the wastewater collection and treatment system. This excess volume, termed an overflow event, is usually discharged directly to the receiving environment without any treatment. In contrast, a sanitary sewer system separates the storm runoff from the wastewater. This significantly reduces the volume of wastewater that requires treatment, and prevents overflow events. The storm runoff, which may contain contaminants from roads (e.g., oils, grease, salt), usually requires much less treatment, and is often released directly into the receiving environment untreated.
- **Location of outfall** – the wastewater effluent outfall can be placed such that it minimizes the impact on the marine environment. This requires information on the current patterns and bathymetry in the area where the outfall is to be located, as well as information on nearby sensitive areas.
- **Treatment of wastewater** - the purpose of wastewater treatment is primarily to protect human health and to reduce stress on the receiving environment. Before sewage is discharged to the environment, it is treated to remove some impurities and to reduce the biological oxygen demand (BOD) and total suspended solids (TSS) (BCMOE 2007c). The greater the degree of treatment, the more the BOD, TSS, and other contaminant levels are reduced (Grant and Ross 2002). However, increased levels of treatment also mean increased costs of construction, operation, and maintenance of the wastewater treatment facility. The various treatment levels are defined as follows (BCMOE 2006b, 2007c, Haggarty et al. 2003, Hydromantis Inc. and University of Waterloo Dept. of Civil Engineering 2006, INAC 2000):
    - **Preliminary** - grit and solid material are screened out before the sewage is treated or released into the environment.
    - **Primary** - solids are separated from the liquids by settling. Floatable solids, oil, and grease are usually skimmed off the surface of the wastewater. Sludge is removed and disposed of elsewhere (usually terrestrially, but sometimes in the marine environment). The liquid effluent is discharged. Primary treatment removes approximately 40-50% of total suspended solids, 50% of metals, and a small proportion of organic contaminants.
    - **Secondary** - after primary treatment, further treatment may include supplying oxygen to the microorganisms already present in the effluent which assists in the biological breakdown and reduction of organic material in the effluent.

Secondary treatment removes 85-95% of the suspended solids, 75% of the metals, and 70-80% of the organic contaminants. Some typical secondary treatment systems are described below:

- **Trickling filter process** - a biological treatment process that uses coarse media (usually rock or plastic) contained in a tank that serves as a surface on which microbiological growth occurs. Wastewater trickles over the media and microorganisms remove the pollutants (BOD and TSS). Trickling filters are followed by settling tanks to remove microorganisms that wash off or pass through the trickling filter media.
- **Activated sludge process** – a biological sewage treatment process in which a mixture of sewage and activated sludge is agitated and aerated. Activated sludge separates from the treated sewage by settling, and is disposed of or returned to the process as needed. The treated wastewater overflows to the next treatment stage.
- **Integrated fixed-film activated sludge** - an innovative hybrid process used to reduce nitrogen in existing wastewater treatment plants. It involves introducing small free floating plastic cylinders into the activated sludge aeration tanks where they provide a large surface area to which biological growths attach, thereby increasing the treatment capacity of the plant.
- **Moving bed biofilm reactors** - a group of treatment technologies that consist of an aeration basin which contain floating plastic media that serve as biofilm carriers. Biodegradation is primarily achieved by the biofilm-associated organisms. This process encourages higher biomass concentrations, which promote nitrification and biodegradation of some organic substances.
- **Biological aerated filters** - aerated wastewater flows through a plastic or expanded clay media which acts as a both a filter and a bioreactor where breakdown of organic material occurs. Phosphorus is not removed by this system.
- **Lagoons** - sewage lagoons are man-made ponds or dyked depressions which rely on natural processes of mainly bacteria and algae to reduce organic matter to acceptable levels. Lagoons should be placed some distance from the community and oriented in such a fashion that winds do not carry odors towards the residences. The two types of sewage lagoons used are facultative and aerated.

o **Tertiary** – this involves further treatment to reduce TSS and BOD, and to remove nutrients and specific contaminants. The particular technologies used depend on the characteristics of the sewage. Tertiary treatments tend to be used where there are particularly sensitive ecosystems, where there are health concerns, or where the water is to be reused.

- **Chemically enhanced precipitation** - coagulants and precipitating agents (i.e. organic polymers, ferric iron, alum) can be added to wastewater in order to enhance the formation and separation of solids that can be more readily removed from the wastewater stream. This is commonly employed for phosphorous removal.
- **Sand filtration** – a filtration process in which suspended solids are removed from wastewater by passing the effluent through a sand bed. The solids collect on the surface as a surface mat and in the sand interstices. Sand filtration is often employed as a tertiary treatment process to enhance the removal of suspended solids. In some systems, it may be possible to remove ammonia and nitrate as well.
- **Membrane bioreactors** - a biological treatment process that incorporates a microfiltration membrane to support the growth of bacteria which purify the wastewater. Microfiltration is a filtration process that removes particles from wastewater by passage through a microporous

membrane (MF). Typical pore size of an MF membrane is 0.1 to 10 micrometers.

- **Membrane filtration -** treatment process which involves reverse osmosis, nanofiltration, or ultrafiltration. Reverse osmosis (RO) is the finest filtration process known, allowing the removal of particles as small as ions from solution. RO typically filters out charged salt ions and substances with molecular weights greater than 150. Nanofiltration is not as fine as RO, but requires less energy to filter out particles. Nanofiltration can remove divalent and multivalent cations (ions with more than one negative charge). Ultrafiltration is a membrane filtration process that is not as fine as nanofiltration. Ultrafiltration typically removes substances with molecular weights greater than 10,000 and particles in the size range of 0.01 to 0.1 microns. Membrane filtration is used as a tertiary treatment process to provide a high quality effluent that might be considered in water reuse scenarios. Reverse osmosis and nanofiltration can remove virtually all dissolved organics and pathogens.
- **Surface wetlands** - surface wetlands typically consist of a series of ponds that contain cultivated plants of some type. Surface wetlands can remove nutrients such as phosphorous and nitrogen by plant uptake. Suspended solids are typically removed by sedimentation and filtration processes. Dissolved organic substances may be removed through adsorption onto plant matter or by biodegradation that is carried out by bacteria that are present in biofilms that form on the plants.
- **Subsurface wetlands** - subsurface wetlands typically consist of a porous media (i.e. gravel) through which the wastewater is directed. Plants are often grown in the media to assist in transferring oxygen into the subsurface, promoting aerobic conditions. Biodegradation of organic contaminants is carried out by bacteria that form biofilms on the porous media. These wetlands remove suspended solids through sedimentation and filtration processes.

- **Disinfection** – wastewater effluents may undergo disinfection to reduce pathogenic organisms, mainly bacteria and viruses. Chemical disinfection in Canada is most commonly accomplished using either gaseous chlorine or sodium hypochlorite (bleach) solution. Without an additional dechlorination process, chlorinated effluents are generally toxic to the aquatic receiving environment. In recent years, ultraviolet (UV) light has become a popular disinfection because it leaves no toxic residual, it is safer to handle than chlorine gas, and it is more effective in inactivating parasites such as *Giardia* and *Cryptosporidium* than is chlorine.

Table 13 shows the percentage of the municipal population in BC which is serviced by each level of wastewater treatment. **Table 14** provides some examples of different levels of wastewater treatment and the efficiency of each treatment in removal of a variety of wastewater constituents. Some smaller communities and rural areas do not have sewage treatment facilities, and rely on private sewage treatment or septic systems. Septic systems are similar in degree of treatment to primary treatment, as they remove solids through settlement and release untreated liquid effluent. Poorly-maintained septic systems can contaminate shorelines (Macdonald et al. 2002). Seepage from septic tanks was once considered to represent a source of contamination for oyster leases near Comox (Waldichuk 1983).

Table 13. Population of BC served by each level of waste treatment facility (source: BCMOE 2007c).

Proportion of municipal population					
Year	Municipal population with treatment[1]	Preliminary	Primary	Secondary	Tertiary
1983	1,990,863	7%	64%	23%	6%
1986	2,007,356	7%	65%	23%	5%
1989	2,264,064	7%	63%	25%	5%
1991	2,422,783	6%	63%	24%	7%
1994	2,626,018	6%	62%	24%	8%
1996	2,865,142	8%	62%	23%	8%
1999	2,986,973	7%	29%	56%	8%
2004[2]	3,059,509	0	35%	56.4%	7.5%

Notes: [1]Total population served by wastewater treatment facilities; remaining population (approximately 20%) has on-site sewer systems regulated under the Ministry of Health. [2]Although the methodology for the municipal water and wastewater survey in 2004 (EC 2005a) was similar to previous surveys [1983-99 (EC 2008); 2001 (BCMWLAP 2001)], it does not show a figure for population with preliminary treatment (as currently in place for the core of Victoria).

Table 14. Removal of substances by wastewater treatment processes (sources: Helmer and Hespanhol 1997, Hydromantis Inc. and University of Waterloo Dept. of Civil Engineering 2006, Laws 2000)

	Substance											
Technology	BOD	Ammonia	Nitrate	Phosphate	Solids	Toxicity	Metals	Pesticides	PAH's	Hydro-carbons	PPCPs	Pathogens
Primary treatment												
Primary sedimentation	25-50%	25%		25%	50-100%		25-50%					
Secondary treatment												
Trickling filters	50-100%				50-100%		25-50%					25%
Activated sludge	50-100%	50-100%		50-100%	50-100%		25-100%					50-100%
Integrated fixed film activated sludge processes	90-100%	90-100%	50-100%		50-100%							
Moving bed biofilm reactors	50-100%	50-100%	50-100%									
Biological aerated filters	90-100%	50-100%	50-100%	20-50%	90-100%						50-100%	
Lagoon	95-100%	95-100%	0-50%	75-94%	95-100%		0-74%	50-100%	95-100%		50-100%	
Tertiary treatment												
Chemically enhanced precipitation		0-20%		50-100%	50-100%							90-100%
Sand filtration	50-100%	50-100%	50-100%		50-100%						0-20%	50-90%
Biological nutrient removal	50-100%	50-100%	50-100%	50-90%	50-100%		50-100%	0-100%			50-100%	0-50%
Membrane bioreactors	90-100%	90-100%	50-100%	50-90%	90-100%						50-100%	90-100%
Membrane filtration	50-100%	50-100%	50-100%	50-100%	50-100%		50-100%	50-100%	50-100%	50-100%	90-100%	50-100%
Surface wetlands	20-100%	0-50%		0-90%	20-100%		20-100%				0-50%	20-100%
Subsurface wetlands	50-100%	0-20%		0-90%	50-100%		50-100%	50-100%			90-100%	50-100%

9. Oil Pollution

9.1. Pollution Sources

Oil can enter the marine environment through a variety of sources, including natural marine seeps, chronic anthropogenic oil pollution, and catastrophic oil spills. **Table 15** shows the estimated inputs of petroleum hydrocarbons to the marine environment. Approximately 0.25 million tonnes per year are input by natural sources, whereas 2.1 million tonnes per year come from anthropogenic sources. 56% of the anthropogenic inputs come from municipal and industrial wastes and runoff. Only 5% comes from tanker accidents. However, many tanker accidents occur near land, and have a much greater impact on marine organisms, particularly in the intertidal zone, than discharges from sources such as bilge and fuel oils (Laws 2000).

Table 15. Estimated world input of petroleum hydrocarbons to the marine environment (source: Laws 2000).

Source	Amount (10^6 tonnes/year)	Total
Natural sources		0.25
Marine seeps	0.2	
Sediment erosion	0.05	
Anthropogenic sources		2.1
Offshore production	0.05	
Transportation		
Tanker operations	0.1	
Drydocking	0.03	
Marine terminals	0.02	
Bilge and fuel oils	0.3	
Tanker accidents	0.1	
Nontanker accidents	0.02	
Atmosphere	0.3	
Municipal and industrial wastes and runoff		
Municipal wastes	0.7	
Refineries	0.1	
Nonrefinery industrial	0.2	
Urban runoff	0.12	
River runoff	0.04	
Ocean dumping	0.02	
Total		**2.35**

The terms chronic and acute (or catastrophic) are used to describe both the type of oil pollution as well as the effects of a contaminant such as oil (see section 4.2). Acute oil spills often lead to acute effects, such as mortality of organisms that come in contact with the oil. Chronic impacts can include decreased health, growth, or reproduction, as well as genetic effects. Even though there are considerably more sources of chronic oil in the oceans, much less is known about the effects of chronic oil pollution than acute oil pollution (Haggarty et al. 2003).

Crude oil consists of a complex mixture of hydrocarbons, usually containing 4 to 26 carbon atoms arranged in straight chains, branched chains, cyclic chains, or aromatic compounds (benzene rings) (Clark 2001). The hydrocarbon mixture of each crude oil reflects the geological history of the area that it was extracted from (Clark 2001, Spies et al. 1996). Crude oils also include organic compounds containing nitrogen, oxygen, sulfur, vanadium, nickel, and iron (Laws 2000).

Hydrocarbons containing fewer than 5 carbon atoms are usually gases at room temperature, while those with 5-18 are liquids, and those with more than 18 are solids (Laws 2000). As a result of variations in length and structure, the diverse petroleum hydrocarbons differ in physical properties (e.g., solubility, vapor pressure, density, viscosity) and toxicity.

Temperature greatly affects the physical and chemical properties of the hydrocarbon components of oil. Therefore, oil spilled in Northern waters will react very differently from oil spilled in warm waters. When crude oil or petroleum products are released into the environment, they are subjected to a wide variety of weathering processes that change their composition (**Figure 22**). These include (Doerffer 1992):

- spreading and drift
- evaporation
- dissolution (dissolving) and advection (horizontal transport by ocean currents)
- dispersion (breaking up and scattering) of whole oil droplets into the water column
- photochemical oxidation
- water-in-oil emulsification
- microbial degradation
- adsorption (sticking) onto suspended particles
- ingestion by organisms
- sinking and sedimentation

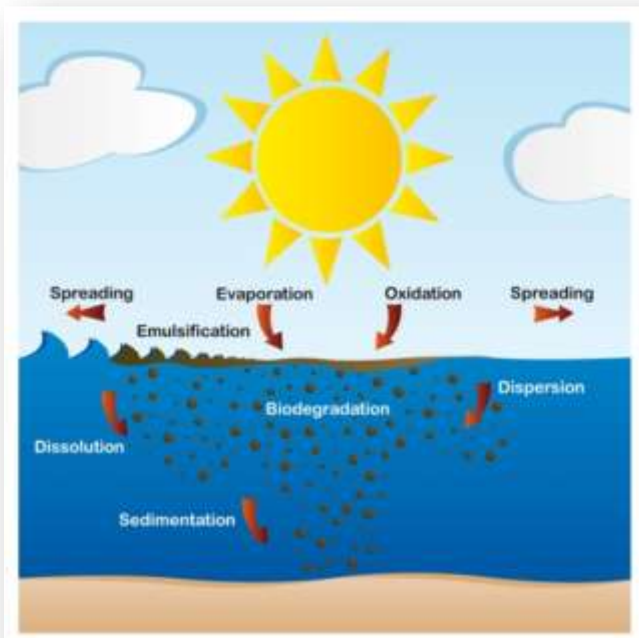

Figure 22. Fate of oil spilled at sea showing the main weathering processes (source: ITOPF 2007)

Low molecular weight constituents will evaporate into the atmosphere. Other components will dissolve in the underlying water column, or will be emulsified in small water droplets which are degraded by bacteria. High molecular weight fractions tend to form tar balls. The complex chemical composition of crude oil in conjunction with weathering processes and variable environmental properties (temperature, salinity, wind, waves) makes predicting the effects of oil on the environment very difficult (Haggarty et al. 2003).

9.2. Environmental and Socio-Economic Impacts

The soluble components of oil are generally the most toxic to marine organisms. These are termed the **water soluble fractions** (WSF), and cause immediate toxic effects to marine life. Low-molecular weight fractions from fresh oil are likely to cause acute toxicity and immediate mortality. High-molecular weight fractions, such as PAHs, persist in the environment and can bioaccumulate. As a result, they tend to cause chronic effects, and are probably more significant in the long-term. Volatile fumes from the very low molecular weight compounds can pose a risk to animals that breathe just above the surface of the water, such as marine mammals and seabirds (Haggarty et al. 2003). Oiled seals in the Exxon Valdez spill behaved lethargically, and may have suffered brain damage from inhalation of volatile fumes (Sloan 1999).

The sublethal effects caused by oil pollution can have very serious environmental impacts. Sublethal physiological and behavioural effects on organisms may result in population-level changes that are likely to have lasting effects in the environment. Sublethal effects can be carcinogenic or cytogenic (interfering with cell development), or can negatively impact reproduction, growth, respiration, excretion, chemoreception (sense of taste and smell), feeding, movement, responses to stimuli, and susceptibility to disease (Haggarty et al. 2003). However, exposure to chronic oil pollution, and the resultant sublethal effects are often difficult to measure.

9.2.1. Habitat Sensitivity

The most significant factor influencing the degree of impact that oil will have on the environment is the habitat type. Different habitats come into contact with oil at different rates, and contain different species, each with their own oil tolerance or sensitivity. Intertidal habitats are more sensitive than subtidal habitats. Benthic habitats are generally more affected than pelagic habitats (Sloan 1999). The sensitivity of intertidal habitats has been rated and ranked with respect to vulnerability, the chance oiling, persistence of oil, and the sensitivity of associated biota (**Table 16**) (Haggarty et al. 2003).

Table 16. Vulnerability index of shores (source: Clark 2001). 1 = least vulnerability; 10=most vulnerable.

Vulnerability index	Shoreline Type
1	Exposed rocky headlands
2	Eroding wave-cut platforms
3	Fine-grain sand beaches
4	Coarse-grained beaches
5	Exposed, compacted tidal flats
6	Mixed sand and gravel beaches
7	Gravel beaches
8	Sheltered rocky coasts
9	Sheltered tidal flats
10	Saltmarshes and mangroves

Oil deposited in the intertidal environment remains largely in the high intertidal zone, where it penetrates into the cobbles and soft sediments. Widespread effects have been observed in many intertidal habitats. Fewer invertebrates, mussels, barnacles, limpets, and rock weed have been found in oiled habitats when compared to non-oiled habitats (Spies et al. 1996). In addition to immediate mortality caused by an oil spill, recolonization of affected shorelines by invertebrates and algae is also inhibited by the oil coatings on rocks (Duncan and Hooten 1996). Recovery of some intertidal habitats can be much slower than others. Bivalves exposed to residual oil remaining 10 years after the *Exxon Valdez* oil spill continued to show signs of physiological stress relative to bivalves from un-oiled sites (Downs et al. 2002) indicate that. Contaminated mussels were identified as a source of hydrocarbons to juvenile sea otters (Sloan 1999).

Subtidal environments are generally less affected by oil spills than intertidal ones, as they do not as readily come into contact with the oil. However, oil can be transported to the subtidal environment by adsorption to sinking particles or by being ingested and transported by plankton such as copepods (Sloan 1999). Two subtidal benthic invertebrates, the leather star and the helmet crab, showed decreased densities following the *Exxon Valdez* oils spill (Spies et al. 1996).

9.2.2. Impacts on Birds

Seabirds are one of the groups most at risk from oil spills. Birds coated with oil are physically impaired, and die from drowning, hypothermia, or the inability to fly or forage. Birds also ingest oil when attempting to preen coated feathers. Physiological effects of ingested oil include greatly lowered red blood cell counts (anemia) that reduce the bird's ability to recover from stress, reduced body weight, and liver damage (Haggarty et al. 2003). In the *Exxon Valdez* oil spill, negative impacts were observed in marine bird populations for nearly a decade following the spill. Species that dive for their food were more negatively affected than species that feed at the surface (Irons et al. 2000).

Bald eagles also appear to be affected by oil spills. Eagles may be killed during the initial spreading of the oil when they come into contact with the surface of the water during feeding. They may also suffer chronic effects as a result of ingestion of oil, either through preening or eating contaminated prey. Surveys in the *Exxon Valdez* oil spill area indicated a decline in nesting success during the year of the spill; however, by 1992, the population had recovered (Spies et al. 1996).

9.2.3. Impacts on Marine Mammals

Marine mammals are another group that is acutely affected by spilled oil. Sea otters are particularly susceptible, and suffer severe mortalities from oiling as a result of hypothermia and toxic effects. Damage to tissues in the lungs, stomach, liver, and kidneys have been observed in oil sea otters. In the *Exxon Valdez* oil spill, sublethal effects were reported until 1993, at which time it was believed that populations were recovering. These sublethal effects were probably caused by damage to the liver and kidneys as a result of continued exposure to oil from prey, especially for juvenile otters feeding on mussels (Loughlin et al. 1996).

Both harbour seals and Steller sea lions have been found swimming in oil, and don't appear to make any attempt to avoid it. Harbour seals also continue to use oiled haul-outs after an oil spill. Seals exposed to oil probably die from a combination of toxic fumes and stress resulting from ingestion of oil. Seals in oiled areas have elevated levels of petroleum hydrocarbons and PAHs in their bodies. Chronic contamination can continue for at least a year after the spill (Loughlin et al. 1996).

Mortality in whales has been observed after oils spills. During the *Exxon Valdez* oil spill, several whales from AB pod were recorded missing. Six additional whales went missing afterwards (Loughlin et al. 1996). Inhalation of vapors at the water's surface and ingestion of hydrocarbons during feeding are the most likely pathways of exposure to toxic substances during an oil spill (NMFS 2008). Transient killer whales may be especially vulnerable after consuming prey debilitated by oil (Matkin et al. 1997). Killer whales do not appear to avoid oil-sheened waters (Matkin et al. 1994). Acute exposure to petroleum products can cause changes in behavior and reduced activity, inflammation of the mucous membranes, lung congestion, pneumonia, liver disorders, and neurological damage (Geraci and St. Aubin 1990). Oil spills are also potentially destructive to prey populations, and therefore may adversely affect killer whales by reducing food availability (NMFS 2008).

9.2.4. Impacts on Fish

The extent to which fish are affected by oil depends on their life histories and their likelihood of coming into contact with the oil. Zones of potential impact from oil spills include the water surface, intertidal habitats, and sediments. Any life history stage of a particular fish species which depends on these zones may be vulnerable to oil impacts (Sloan 1999). Adult fish can ingest oil or absorb oil hydrocarbons through their skin and gills. Eggs and larvae can also be affected. Acute effects in fish include death or debilitation due to damage of the central nervous system, osmoregulatory dysfunction (loss of ability to regulate the concentration of the body's fluids), metabolic dysfunction, and tissue damage. Increased stress levels due to exposure to oil can also increase susceptibility to disease, and reduced the ability to feed or avoid predators. Oil can cause damage to organs, including the liver, gills, gut, brain and ovaries. Heavy oil fractions (i.e. PAHs) are also known to bioaccumulate in fish, especially when the ability to metabolize these compounds is exceeded (Haggarty et al. 2003).

The life histories of both pink salmon and herring put them at risk to impacts by oils spills. Large schools of herring congregate in nearshore areas to spawn and lay their eggs on lower intertidal and subtidal vegetation. The attached eggs incubate for approximately three weeks before hatching. Pink salmon spawn in creeks near the upper intertidal zone, and fry emerge into the intertidal areas in April or May (Haggarty et al. 2003). Oil impacts in the intertidal zone will have serious negative effects on both of these species. Additionally, both species are commercially fished, leading to further socio-economic impacts.

Other intertidal, subtidal, and nearshore benthic fish species that have shown signs of oil impacts are Dolly Varden trout, gunnels, greenlings, rock sole, yellowfin sole, and flathead sole (Haggarty et al. 2003, Jewett et al. 2002). Walleye pollock, a bathypelagic fish that feeds in the water column, has also shown increased levels of oil metabolites following a spill (Collier et al. 1996). Ten years after the Exxon Valdez oil spill, there was still evidence of chronic contamination in some fishes (Jewett et al. 2002).

9.2.5. Chronic oil pollution

Low levels of chronic oil pollution contribute more hydrocarbons to the marine environment than do acute spills. Chronic effects of oil pollution are often measured at the cellular level using biomarkers (biomolecules that are associated with metabolic changes caused by the pollutant). However, the effects of chronic oil pollution on individuals and populations are poorly understood (Haggarty et al. 2003). Chronic, low-level pollution from ship operations may have a greater impact on bird populations than catastrophic spills (O’Hara 2007, Sloan 1999).

The effects of chronic oil pollution (especially persistent compounds such as PAHs) on different species depend on a number of factors, including feeding habits, life histories, uptake pathways (i.e. through ingestion as with mussels or across gills as with fish), and the species’ ability to enzymatically degrade the pollutants. Thus, in order to assess the risks of chronic oil pollution, it is necessary to consider the bioavailability of the pollutants (amount of the pollutants which are available for uptake by a particular organism), the toxicity of the pollutants, and the fate of the metabolites of the pollutants (some metabolites are more toxic than the parent compounds) (Baussant et al. 2001a, Baussant et al. 2001b).

9.2.6. Impacts on Humans

Some possible impacts to humans from oil spills are (Global Marine Oil Pollution Information Gateway 2002):

- **Fisheries and aquaculture**
    - Valuable fishing and shellfish areas may be closed due to the risks of the catch being tainted by oil. Concentrations of petroleum contaminants in fish and crab tissue, as well as contamination of shellfish, could pose a significant potential for adverse human health effects.
    - The fisheries sector could suffer a heavy loss if consumers are either stopped from using or unwilling to buy fish and shellfish from the region affected by the spill.
    - Boats and gear may be directly damaged by an oil spill. Floating and fixed equipment extending above the sea surface are most likely to be damaged.
- **Tourism and recreation**
    - Contamination of coastal beaches and resorts could restrict recreational activities as such as swimming, boating, fishing, or diving.
    - Hotel and restaurant owners, boat rental agencies, diving tour operators, and fishing tour operators may suffer significant economic losses.
- **Industry**
    - Industries depending on clean water from the marine environment can be negatively affected if there is risk of getting oil into their water intakes.
- **Human health**
    - Human health could be adversely affected by oil either when inhaling oil vapors, touching oil products, or eating contaminated sea food.

9.3. Concerns in the North and Central Coast

Sources of oil pollution in the PNCIMA include natural seepages, vessel traffic, sewage, atmospheric input, and run-off from land. The specifics of each of these issues are discussed in other sections of this report.

9.4. Monitoring

Monitoring for oil pollution involves several stages, as shown in **Table 17**.

Table 17. Description of monitoring according to the stage of the incident (source: AMSA 2003).

Response Stage	Description of Monitoring
Stage 1 Pre Spill	This includes true baseline monitoring and may be long term and large scale. "Control" sites can be well established. Study design can be modified and refined over time. Generally, such monitoring is undertaken in areas of high risk or on resources that are sensitive to spills or are of protection or conservation priority.
Stage 2 Post Spill – Pre Impact	Monitoring done at this stage is reactive, and must often be designed and implemented at short notice to collect a "snapshot" of pre-impact conditions. Establishment of reliable "control" sites is difficult.
Stage 3 Post Impact – Pre Cleanup	Monitoring of oil-impacted shorelines, waters or resources. Examples include monitoring of oil behavior and persistence in un-cleaned shorelines or monitoring of immediate damage due to oil (not cleanup).
Stage 4 Cleanup	Monitoring that occurs throughout a cleanup activity. For example, monitoring the success or the effect of cleanup on shorelines, water quality or biological resources.
Stage 5 Post Cleanup - Pre Response Termination	Monitoring of resources, water or shorelines after cleanup activities have ceased but before the response has been terminated. These are usually short-term programs. This would include final assessments of cleaned shorelines, perhaps as an agreed precondition to terminating a response.
Stage 6 Post Response	This includes all monitoring that occurs after the formal end of a response. Such studies may be short, medium or long-term.

Types of monitoring activities may include (AMSA 2003):

- spill surveillance using airplanes or satellites to track the movements of the spill
- identification of the source of the oil
- determination of oil character
- identification of sensitive areas or resources which may be impacted by the spill
- assessment of water quality during the spill
- assessment of the impacts on organisms living in the water column
- assessment of the effects on fisheries
- shoreline assessment
- determination of the amount of oil in or on the shoreline sediments
- assessment of the effects on marine mammals
- assessment of the effects on other intertidal and subtidal organisms

9.5. Mitigation

Mitigation measures for marine oil pollution involve two levels of action:

- Local pollution control for point source emitters of oil. Mitigation measures for these point source polluters are discussed in other sections of this report.
- Regional, national, and international actions towards decreasing the possible risk of catastrophic oil spills by preventing the transport of oil through sensitive areas.

Once oil has been spilled, the only actions left are essentially those of remediation. Only 14% of the 10.8 million gallons spilled during the *Exxon Valdez* oil spill was recovered (Wolfe et al. 1994). The Marine Oil Spill Response Information System (OSRIS) is a computer-based, shoreline sensitivity project using a geographic information system (GIS) containing data on shoreline geomorphologies and marine uses. It was developed by the BC government following the *Nestucca* (1988) and *Exxon Valdez* (1989) oil spills. OSRIS can calculate sensitivity to oil spills as well as help to determine the best remediation action to take (BCMOE 2002, Haggarty et al. 2003).

10. Ports and Marinas

10.1. Pollution Sources

Ports, harbours, and marinas face numerous contamination challenges. Although tankers largely avoid the PNCIMA 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 the major ports of Prince Rupert and Kitimat (Johannessen et al. 2007a). Fishing vessel density is high throughout the year as fish are brought in for processing, and vessels are refueled, serviced, or moored, although fishing vessel traffic has decreased on the North Coast in recent years (**Table 19**). Recreational vessels are also regular users of ports, harbours, and marinas in the PNCIMA. Common contaminants found at these facilities include wood preservatives and anti-sapstains, antifouling compounds, and persistent pollutants such as PAHs and pentachlorophenol (PCP) (Johannessen et al. 2007a).

10.1.1. Major Ports

The PNCIMA has two major industrial ports, Prince Rupert and Kitimat, and a smaller port at Stewart:

- **Prince Rupert** - 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. Partially in response to this decline, a new cruise ship dock was completed in 2004. In 2005, the Fairview terminal was demolished and replaced with a high volume container terminal to accommodate the increasing import of goods from Asia (Johannessen et al. 2007a). The terminal is being constructed in two phases (**Figure 23** and **Figure 24**). Phase I involved the creation of a 400 m long berth out into deep water (minimum depth of 16 m) and increased the dock area to approximately 58 acres. Phase I opened for operation on September 12, 2007 (Prince Rupert Port Authority 2007a). Phase II will extend the dock to 800 m and will increase the dock area to 165 acres.
- **Kitimat** - is a privately owned industrial port with no federal port authority (Chamber of Shipping 2007, Northwest Corridor Development Corporation 2007). It is the deepest and widest of the north coast ports (Chamber of Shipping 2007) 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 (Johannessen et al. 2007a). **Figure 25** show the layout of the existing industrial port at Kitimat. The following projects are proposed or underway at the Port of Kitimat (Port of Kitimat 2008):
    - **Alcan Smelting expansion/rebuild** – proposed development an increased smelting capacity of approximately 400,000 tonnes per year including modernization/rebuild of the existing smelter. Power will be generated at Kemano. Facilities must be in place by January 2010 to meet the BC/Alcan Settlement Agreement Replacement Electricity Supply Agreement.
    - **Cascadia Materials Inc.** – proposed construction of a deep-sea marine terminal for aggregate mining, sorting, and shipping. Shipping was expected to commence in 2006/2007.
    - **Kitimat LNG Inc./Galveston Inc.** – Galveston LNG, a company backed by European and U.S. investors, is proposing to build a liquefied natural gas (LNG) receiving, regasification, and export terminal in Bish Cove, 14 km south of Kitimat (Environmental Assessment Office 2006, Kitimat LNG Inc. 2006). The project received Federal and Provincial approval in July 2006. Construction is slated to begin in 2008, pending LNG supply contracts, and the terminal is expected to be operational in 2011 (Port of Kitimat 2007).

- **Pacific Trail Pipeline Ltd.** – proposed construction of a 470 km pipeline loop to the existing Pacific Northern Gas (PNG) pipeline system. This pipeline is contingent on the Kitimat LNG Project for gas supply. Construction is expected to begin in 2008, with a commissioning target of 2010-2011.
- **Enbridge Gateway Pipeline** – Enbridge Inc., operator of the world's longest liquid crude pipeline system, has entered into a proposal to build a pipeline that would make Kitimat the destination for the export of crude oil and the import of condensate. Enbridge has proposed the construction of two 1200 km pipelines (one for bitumen [crude] export and one for condensate import) from Edmonton to a deepwater terminal and tank farm at Kitimat. Project completion is targeted for 2012-2014.
- **Pembina Condensate Pipeline Project** – proposed construction of a 470 km condensate import pipeline from Kitimat to Summit Lake. The environmental assessment of this project commenced in October 2006; however, the project is presently in hiatus as a result of commercial certainty.
- **Kinder Morgan Pipeline Project** - proposed construction of a 950 km bitumen export pipeline from the TMX Trans-Mountain pipeline system to Kitimat. Public consultation has not yet begun.
- **Methanex** – proposed modifications to the marine terminal, rail access, and storage tanks. No specifics on the project are available. Methanex's permitting for deep-sea shipping is governed by Transport Canada Marine Acts and Regulations.
- **Eurocan Co-Generation Power Project** – completed project to reuse waste heat and steam from the Eurocan paper mill and hog-fuel input operations to drive turbines and generate 20-25 megawatts of power. Construction was completed in 2006, and power plant was in full operation.
- **Katabatic Power Project** – development of a 3000 MW wind farm on a 40,000 ha Banks Island property near Kitimat. Pending regulatory approvals, construction will begin in 2009, with commissioning in 2009-2010.

- **Stewart** - is a smaller port located close to the Alaska border. 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 (Chamber of Shipping 2007).
- **Campbell River** - the Wei Wai Kum Terminal is the first Aboriginal-themed cruise ship terminal. The terminal is located on the eastern shore of Vancouver Island on Campbell River Indian Band lands, two km north of downtown. It is adjacent to Discovery Harbour Marina. The terminal has one berth with a maximum ship length of 310 m. The cruise ship terminal had its first year of operation in 2007. By 2010, it is estimated that over 60,000 cruise passengers will be visiting Campbell River each year as a result of the terminal development. The average annual economic impact for the region is estimated at $11.4 million, including the creation of over 200 full time jobs (CruiseBC 2007, INAC 2007).

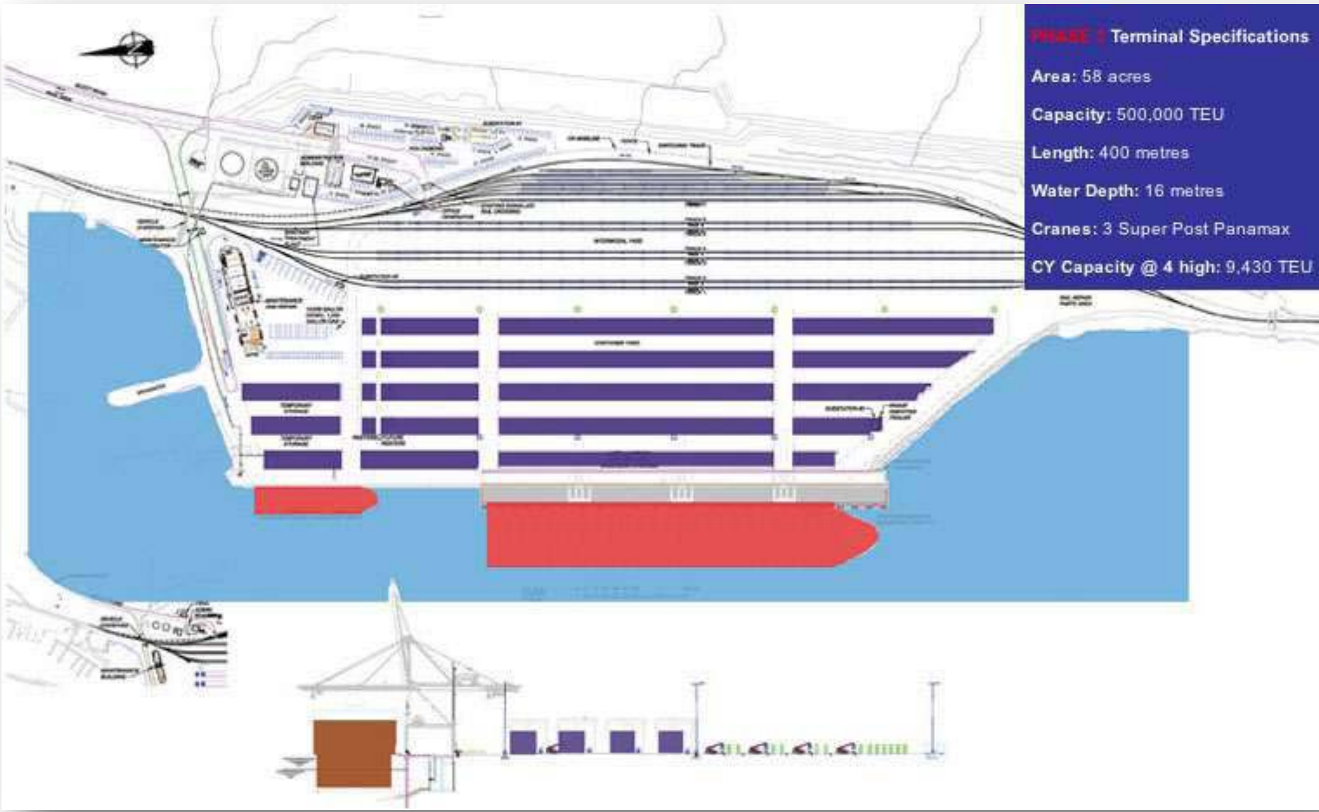

Figure 23. Phase 1 of the new Fairview high volume container terminal (Prince Rupert Port Authority 2007b)

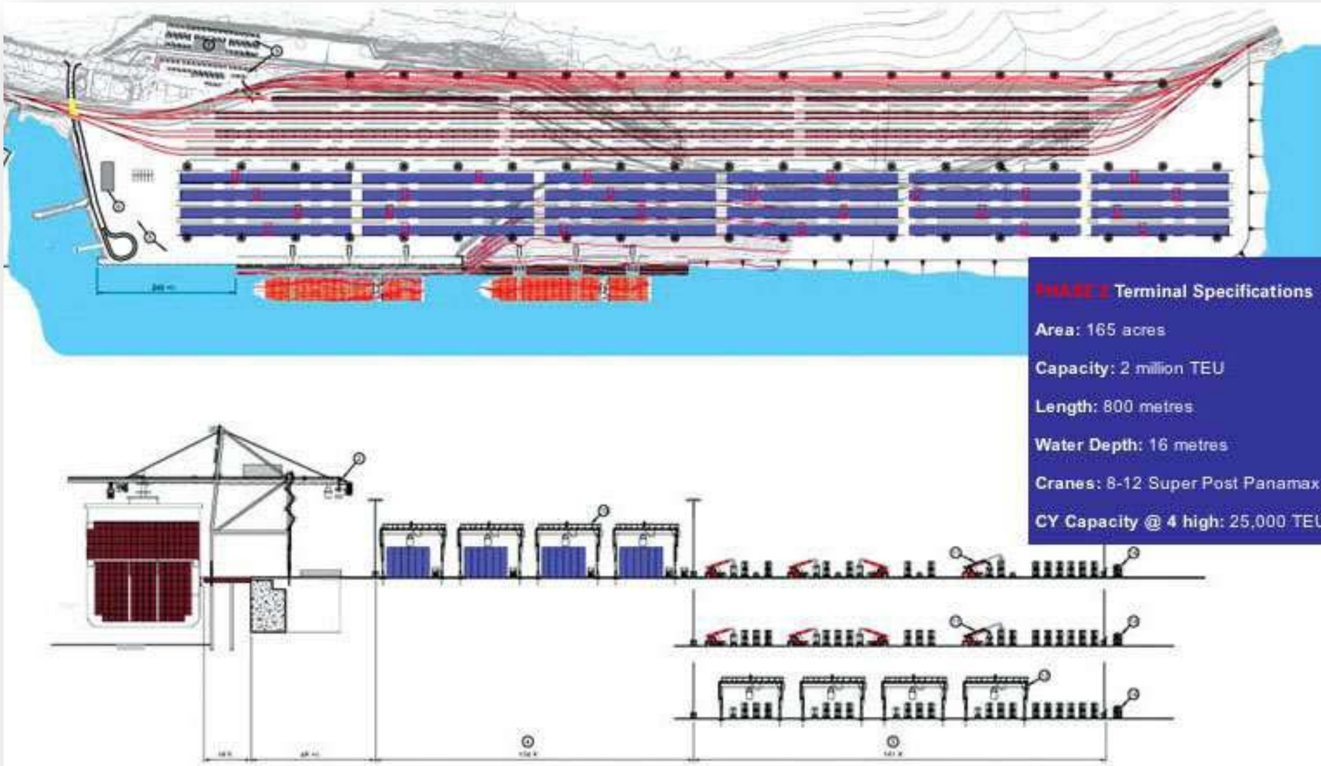

Figure 24. Phase 2 of the new Fairview high volume container terminal (Prince Rupert Port Authority 2007b).

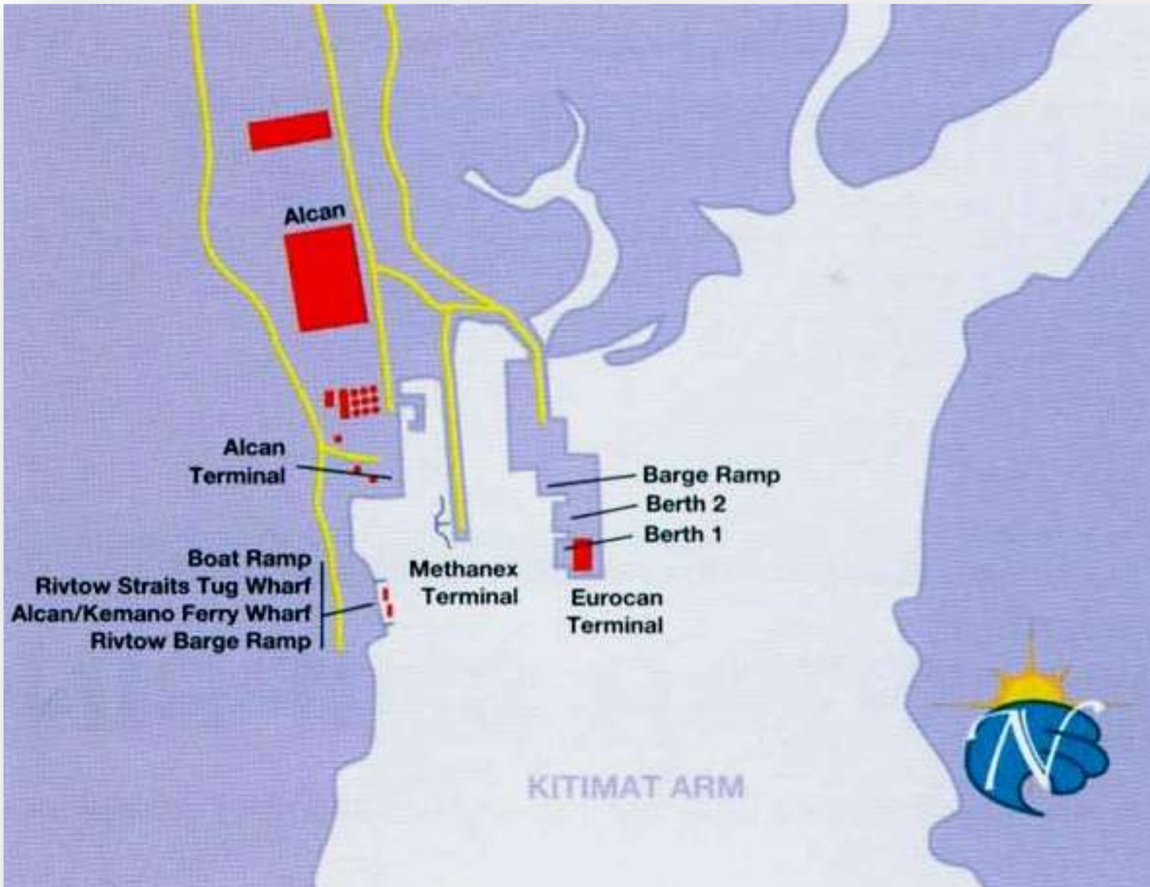

Figure 25. Layout of the existing industrial port at Kitimat (Johannessen et al. 2007a).

10.1.2. Harbours and Marinas

The PNCIMA has 46 small craft harbours, some run by DFO or Transport Canada, and some by private harbour authorities, as well as numerous marinas, boat launches, and anchorages (**Figure 26**, **Figure 27**, and **Figure 28**). Boats and ships are concentrated in harbours and marinas. Smaller vessels no longer contribute to TBT contamination, but problems associated with sewage discharge, PAHs from engine leaks and combustion, and chemicals associated with boat maintenance still exist at some of these locations (Johannessen et al. 2007b). High levels of pollutants (e.g. PAHs, TBT, PCP) have been found in the sediments of harbours and marinas. Even small marinas can have high levels of contaminants. Oil and gas pollution is expected to be higher at marinas with fuel docks, since many fuel spills occur when boaters are fueling up (EPA 2001). Areas that are exposed to chronic discharges of petroleum hydrocarbons experience contamination from PAHs. PAH concentrations in harbour sediments were found to be 260 times higher than in non-harbour sites (Kay 1989). Harbours may have increased levels of dioxins and furans from wood treatment facilities and combustion (Yunker et al. 2002). Harbours and marinas are also a source of wood preservatives, such as creosote, since treated wood is used as a primary building material (Haggarty et al. 2003).

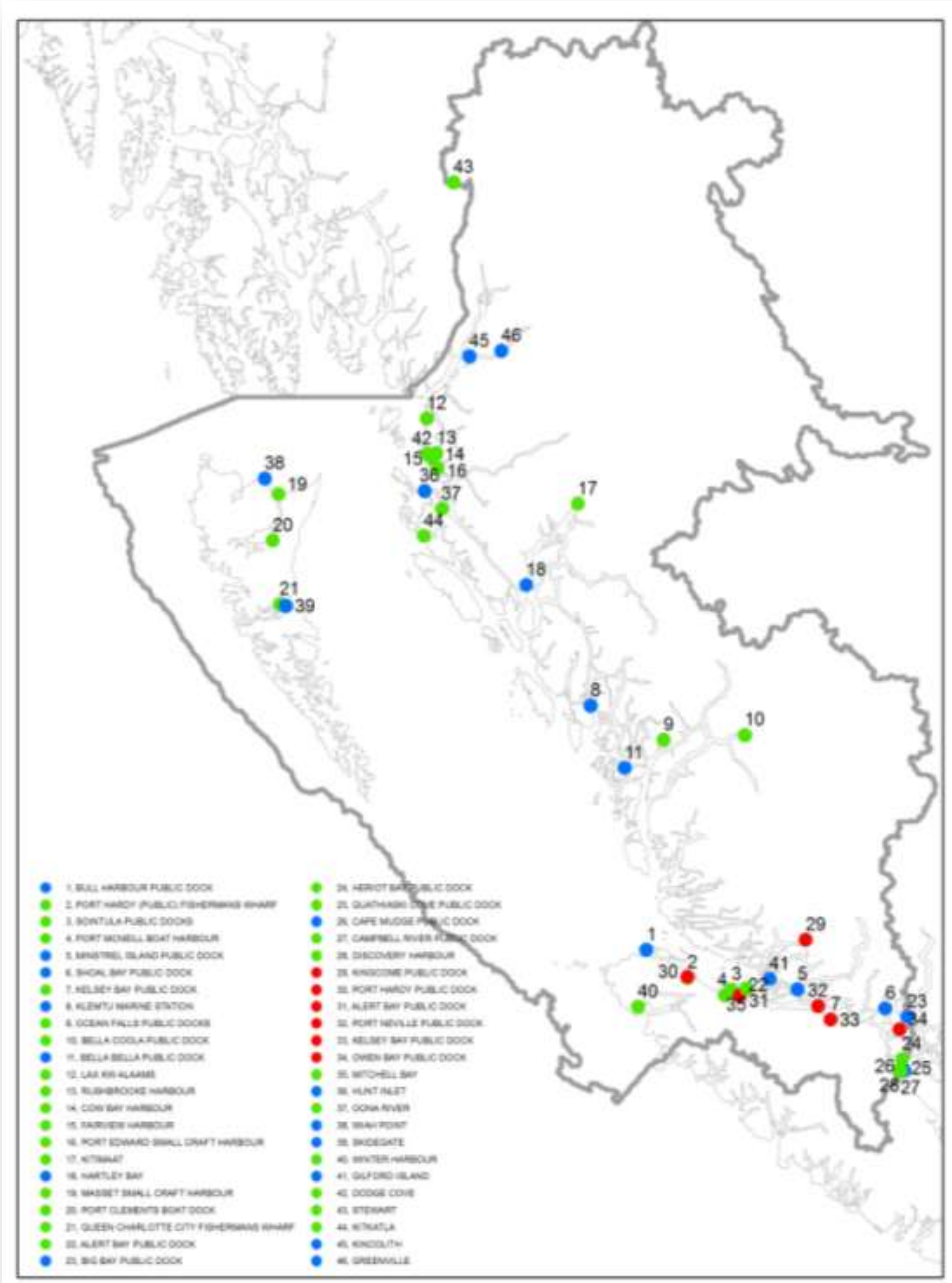

Figure 26. Public small craft harbours operated in the PNCIMA by DFO (blue), harbor authorities (green), and transport Canada (red) (data: BCILMB 2008).

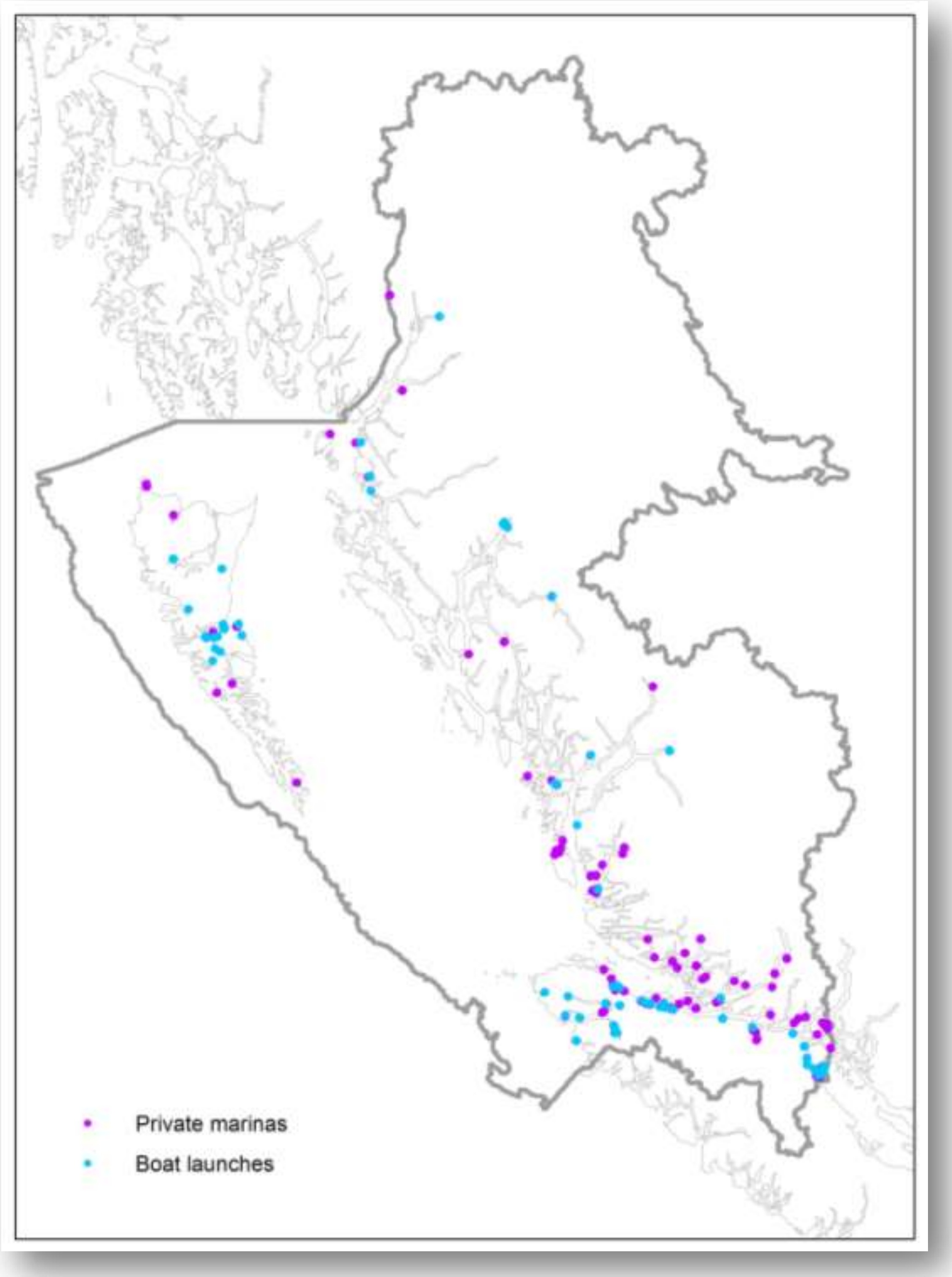

Figure 27. Boat launches and private marinas in the PNCIMA (data: BCILMB 2008).

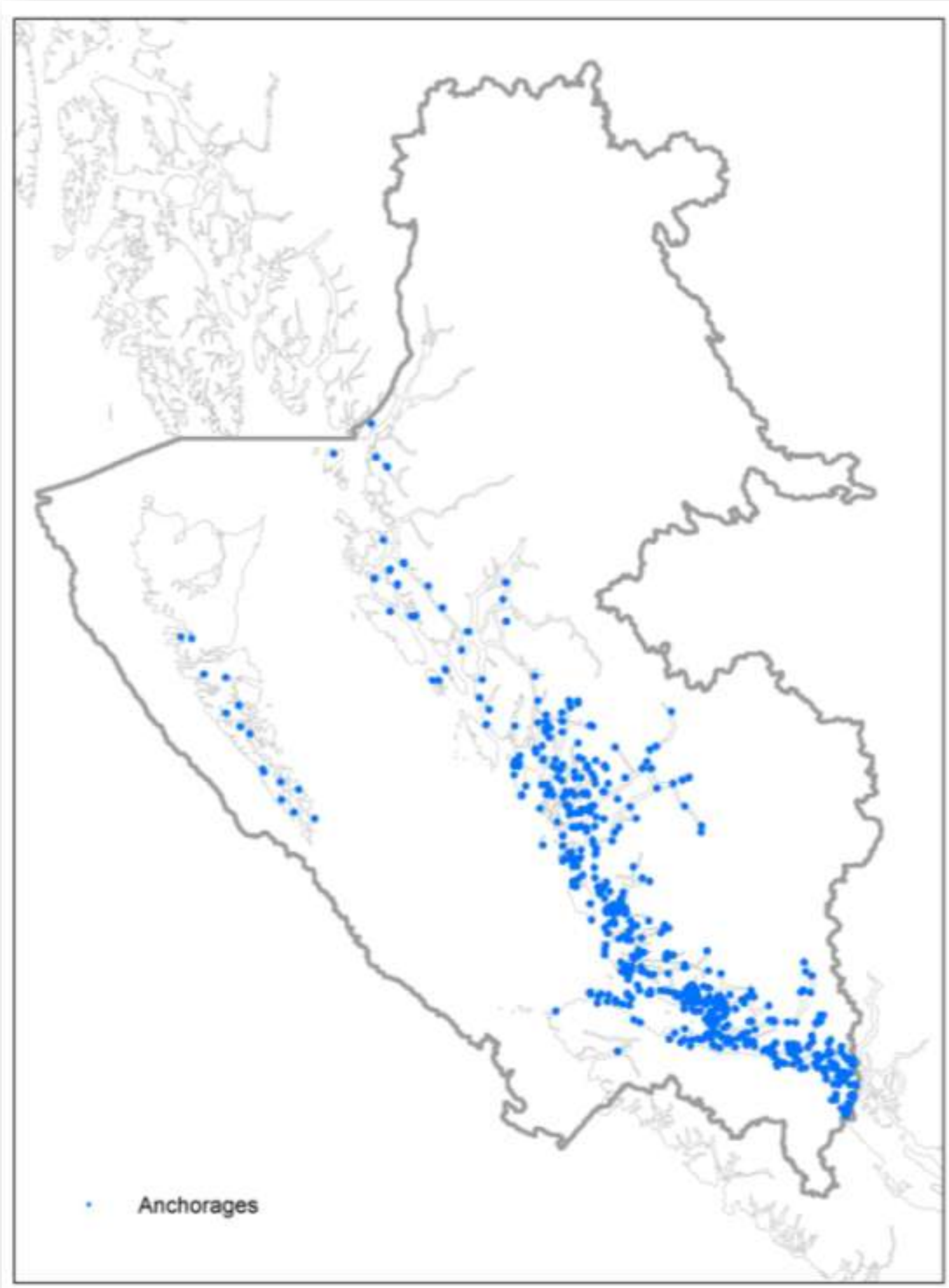

Figure 28. Anchorages in the PNCIMA (data: BCILMB 2008).

10.1.3. Wood Preservative and Anti-Sapstains

Wood preservatives are pesticides (used to kill rot-causing fungus) which are used to prolong the life of wood products used in construction materials such as pilings, piers, docks, fence posts and railway ties. In the past, the most significant source of wood preservative contamination was from the plants that produced these products. However, improved practices have resulted in an estimated 90% decrease in the discharge of contaminated effluent (Johannessen and Ross 2002). There are no wood preservation plants in the PNCIMA. At present, the main source of wood preservatives in the environment is non-point source runoff and the use of wood preservatives in direct contact with the aquatic environment, such as pilings (Johannessen and Ross 2002). Harbours and marinas in the PNCIMA are likely to be the main users of preserved wood products. Other marine operations, such as aquaculture facilities, log booms, private docks, and shore stabilization efforts, will also contribute to wood preservative contaminants (Haggarty et al. 2003).

Creosote and chromated copper arsenate (CCA) are the two most prevalent wood preservatives used in BC (**Figure 29**). Other preservatives include pentachlorophenol (PCP), ammoniacal copper arsenate (ACA), and ammonical copper zinc arsenate (ACZA). While creosote comprised 66.4% of total pesticide sales and use in the province in 1999, none was sold or used in the North Coast region during that year. The only wood preservative with documented use on the North Coast in 1999 was CCA (ENKON Environmental Limited 2001). This pesticide is used on docks, pilings, bulkheads, and piers, where it can form a source of contaminants to the marine environment (Cox 1991, Johannessen and Ross 2002).

Creosote is a complex mixture containing over 90% cyclic aromatic compounds, including PAHs (85%), phenolics (10%) and oxygen, sulfur and nitrogen heterocyclics (5%) (Johannessen and Ross 2002). Only a small fraction of creosote is dissolved by contact with water. However, when creosote is exposed to the sun, it becomes soft and can drip into the marine environment (Hutton and Samis 2000).

There is widespread use of pentachlorophenol (PCP) as a wood preservative in the marine environment in BC (Kay 1989), although its use appears to be declining (**Figure 29**). PCP is a complex group of chlorinated hydrocarbons of varying carbon chain lengths that is used in over 2,000 commercial products. Its complexity and widespread usage makes sources of PCP in the environment difficult to pinpoint.

The use of ACA or ACZA as wood preservatives in BC is very low (**Figure 29**).

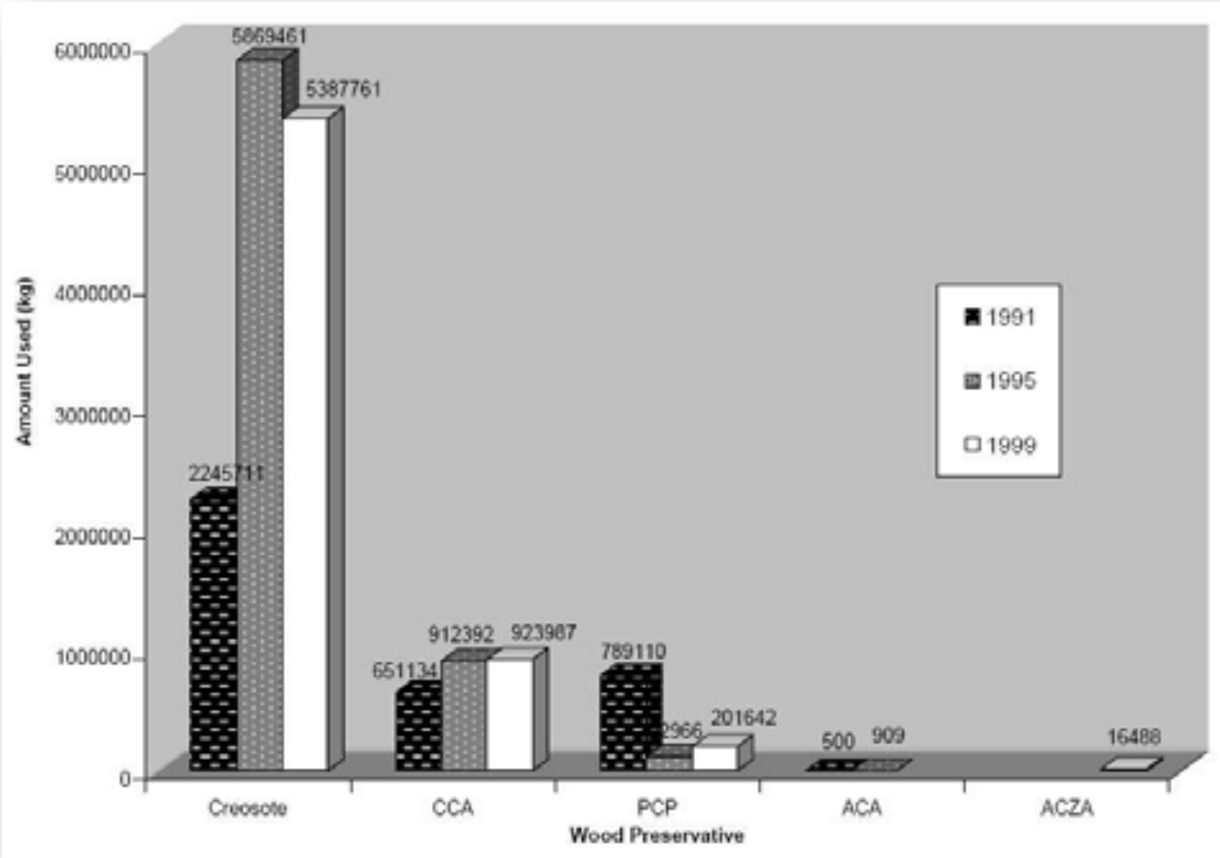

Figure 29. Wood preservative used in BC in 1991, 1995 and 1999 (data: ENKON Environmental Limited 1999, Johannessen and Ross 2002).

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).

10.1.4. Antifouling Paints

Antifouling paints containing copper and tributyltin (TBT) are used to prevent marine organisms from colonizing the hulls of boats, ships and wooden structures. These compounds build up in harbours and marinas, especially near ship repair facilities (Haggarty et al. 2003). The most common antifouling compound, TBT, has been used in Canada and around the world as a biocide on the hulls of boats since the 1970s. TBT has been described as “the most toxic substance ever deliberately introduced into natural waters” (Stewart and Thompson 1994).

In 1989, as a result of the environmental problems caused by TBT, Canada and several other countries imposed a ban on the use of TBT-containing paints for vessels less than 25 m in length, except for aluminum-hulled boats which were unable to use copper oxide based paints due to corrosion issues. TBT was still permitted for use on vessels greater than 25 m in length, if the release rate of the paint was less than 4 µg TBT/cm^2/day. In 2002, Canada completely banned the use of TBT, as two copper thiocyanate antifouling paint products were available on the market which were suitable for aluminum hulls and did not cause corrosion (HC 2002, International Coatings Ltd. 2003, PMRA 2002). In December 2004, the last US producer of TBT-based paint requested voluntary cancellation of its product registration. An international resolution has been put forward to phase out TBT-based paints with a full prohibition to be in place by 2008 (IMO 2001). Canadian regulations also require that all registered antifouling paints containing copper must have a release rate of less than 40 µg copper/cm²/day (International Coatings Ltd. 2003).

Most harbours in the PNCIMA are frequented by boats under 25 m that must comply with the anti-TBT regulations. Large ships traveling in the North and Central Coast region, including cruise ships and ferries, have phased out the use of TBT, and are now using copper-based antifouling paints (Haggarty et al. 2003, Science Advisory Panel 2002). The Canadian Navy is also in the process of phasing out TBT in favor of copper-based antifoulants (Haggarty et al. 2003). Several studies have evaluated the effectiveness of the anti-TBT regulations in BC waters. A comparison of TBT levels in sediments of recreational versus industrial harbours indicated that the TBT ban effectively reduced TBT levels in recreational harbours. However, industrial harbours with traffic from ships greater than 25 m, such as Vancouver Harbour, show no reduction in TBT levels (Pierce et al. 1998).

TBT still accumulates and persists in marine sediment. Currently, TBT continues to enter the environment as a result of the use of TBT paints on boats over 25 m (even though new, anti-leaching formulations are required), leaching from old paint chips, and illegal use of remaining stocks of TBT paints on smaller boats. TBT has been found in sediments from a range of locations, including sites with intensive shipping activity to remote coastlines to deep, sedimentary basins. Apparently, TBT contamination is still extremely widespread despite the improvements that have been made over the past decade (Stewart and Thompson 1994, Stewart and Thompson 1997).

10.1.5. Other Chemical Contaminants

Harbours are sites of spills from fuel docks, releases of bilge water, and engine exhaust, all of which contribute sources of polycyclic aromatic hydrocarbons (PAHs). Sediment samples at harbours and marinas have been shown to be contaminated with high levels of pollutants of PAHs and PCP (Haggarty et al. 2003). BC harbours have PAH concentrations that are up to 260 times those detected at 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).

10.1.6. Sewage

Sewage discharge from vessels can create localized biochemical oxygen demand (BOD), but is frequently insignificant relative to sewage from adjacent terrestrial sources (Johannessen et al. 2007b).

10.1.7. Ballast Water

Ballast water released into harbours may be the most important vector for the introduction of some invasive species. (Johannessen et al. 2007b). 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, illegal discharge of ballast water by container ships can be very difficult to monitor (Johannessen et al. 2007a).

10.2. Environmental and Socio-Economic Impacts

10.2.1. Major Ports

The impacts of major ports depend largely on the types of industries which are active at each port. The specifics of the issues associated with each of these industries are discussed in other sections of this report.

10.2.2. Harbours and Marinas

The many small anchorages, boat launches, and marinas in the PNCIMA are not likely to have broad scale impacts on the environment, 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.

10.2.3. Wood Preservatives and Anti-Sapstains

Wood preservatives have been shown to be highly toxic to fish 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 (EC 1998). Some environmental concerns for specific wood preservatives are give below:

- **Creosote** - the toxicity of the water soluble fraction of creosote is much higher than would be expected just based on the PAH content of creosote. Nitrogen heterocyclics make up 70% of the soluble fraction of creosote, and are much more toxic and bioavailable to organisms in the water column. Other chemicals such as phenols, cresols, and xylenols are also likely to add to the toxicity of creosote (Padma et al. 1998).
- **Chromated copper arsenate (CCA)** – toxicity is a serious concern as copper, chromium, and arsenic are all toxic heavy metals, and the synergistic toxicity of copper and chromium together is believed to make CCA more toxic than the sum of its components (Cox 1991, Johannessen and Ross 2002). Currently, there are insufficient data to quantify the leaching rates of CCA into the environment (Hingston et al. 2000).
- **Pentachlorophenol (PCP)** - PCP is highly persistent, can be transported great distances in the atmosphere, has high lipid solubility and has been observed to bioconcentrate as much as 139,000 times in biota (Grant and Ross 2002). PCP concentrations in the livers of copper rockfish living near sources of PCP contamination in BC, including a salmon farm, were found to be elevated (Levings 1994).
- **Ammoniacal copper arsenate (ACA) and ammonical copper zinc arsenate (ACZA)** - no information on the effects of ACA or ACZA is available, although the component metals are known to be toxic (Haggarty et al. 2003).

The toxicity of the anti-sapstain DDAC results from its ability to disrupt cell membranes, causing damage to exposed areas in animals (such as gills and digestive tracts) (Henderson 1992, Wood et al. 1996). It is not surprising then, that DDAC is toxic to aquatic organisms, both fish and invertebrates (Farrell et al. 1998). However, very little is known regarding the toxicity of DDAC in the marine environment and further studies need to be done (Szenasy 1999).

10.2.4. Antifouling Paints

Tributyltin (TBT) is toxic to many aquatic organisms, including fish, molluscs (especially whelks, oysters, and clams), and other benthic animals. It slows growth, causes abnormal shell development, kills larvae, and can cause endocrine disruption. TBT contamination has been shown to disrupt reproduction in molluscs, most notably in neogastropod snails such as whelks.

At extremely low concentrations of TBT (4-10 ng/L), female whelks displayed masculine traits such as the development of a penis and vas deference (termed imposex). This prevents reproduction. The condition is irreversible, and manifested itself in rapid population declines or even complete extirpation of the affected species from heavily contaminated areas (EPA 2002, Pierce et al. 1998, Tester et al. 1996).

Since the ban on TBT is not yet international, there will still continue to be some new TBT inputs as ships with TBT-based hull paint enter BC waters (BCMOE 2006b). Significant concentrations of TBT are likely to remain in the sediment for 20 to 30 years (Maguire 2000, Stewart and Thompson 1997).

Whelks have been commonly used as bioindicators of TBT contamination. Population measurements, as well as rates of imposex, have been used to monitor the effectiveness of the TBT ban (Reitsema et al. 2002, Tester et al. 1996). These studies have found a recovery in whelk populations in harbours with small boats (less than 25 m), but not in industrial harbours. Populations of whelks are still absent from Vancouver Harbour. In some areas of BC (e.g., Burrard Inlet), TBT contamination had eradicated the whelk populations by 1989, and juvenile whelks failed to mature in other areas (Bright and Ellis 1990). At the Ogden Point breakwater in Victoria, all female whelks sampled in 2000 showed reproductive effects caused by TBT, which was 11 years after most uses were banned (Reitsema et al. 2002).

Other shellfish, such as mussels and oysters, and flatfish have also shown TBT contamination in BC (Stewart and Thompson 1994).

10.2.5. Other Chemical Contaminants

PAHs in harbour sediments have been shown to be carcinogenic in animals and humans. Certain marine organisms, especially molluscs, accumulate PAHs since they do not rapidly excrete or metabolize them (Haggarty et al. 2003). More information regarding the impacts of PAHs is provided in section 6.2 of this report.

10.2.6. Sewage

The impacts of sewage on the marine environment are discussed in section 9.2 of this report.

10.2.7. Ballast Water

Ballast water is one of the main pathways for introduction of invasive alien marine species into BC waters (BCMWLAP 2004). Some examples of organisms which have been found in ballast water are (BCMWLAP 2004, Cohen 1998):

- **Asian clam** – the Asian clam can single-handedly alter an ecosystem. It is a highly-efficient filter feeder, ingesting bacteria and small zooplankton as well as phytoplankton. It can severely deplete phytoplankton populations, reducing or altering the food available to some of the organisms higher in the food chain. It may also reduce native zooplankton populations and make an ecosystem more vulnerable to subsequent invasions by other alien species.
- **New Zealand sea slug**
- **Black Sea jellyfish**
- **Asian zooplankton**
- **Chinese mitten crab** (possibly)
- **European zebra mussel** - the zebra mussel can become a major problem by clogging water systems for cities, factories and power plants, by fouling boat hulls and by accumulating in immense numbers on recreational beaches.

- **Atlantic comb jelly** – the Atlantic comb jelly virtually eliminated the crustacean zooplankton from the Black Sea, contributing to the decline of the region's fisheries.
- **Japanese sea star** – this sea star has devastated shellfisheries in Tasmania.
- **Toxic dinoflagellates** – these dinoflagellates produce neurotoxins that accumulate in shellfish, causing illness and sometimes death in the people that eat them. Large numbers of these organisms in the water may cause the water to become discolored, and hence these events are referred to as toxic red tides. In some regions, toxic dinoflagellates were introduced in the sediments transported with ballast water.
- **Cholera** - an epidemic strain of cholera from South America was apparently discharged with ballast water into waters on the Gulf Coast of the United States, where it was discovered in fish and shellfish.
- **Fecal coliforms**
- **Japanese mahogany clam**

Aquatic invasive species (AIS) may also be introduced by hull fouling on vessels arriving at ports. The clubbed tunicate, violet tunicate, golden star tunicate, and vase tunicate have been discovered in waters in and around the Maritime Provinces. These organisms the may be introduced into new aquatic ecosystems through ballast water, hull fouling and transport on fishing gear. The clubbed tunicate was initially established in an estuary of eastern Prince Edward Island (PEI) in 1998. This invasive species is causing significant problems for the mussel aquaculture industry by overgrowing mussels, reducing yields and increasing costs of harvesting and processing mussels. The spread and establishment of the clubbed tunicate into other mussel growing areas of PEI, Nova Scotia, New Brunswick and Quebec could have devastating effects (DFO 2005).

Alien species can dramatically alter an ecosystem's flora and fauna. In some areas, such as the San Francisco Estuary, exotics now account for more than 90 percent of the species, individuals or biomass in several habitats (Cohen 1998).

10.3. Concerns in the North and Central Coast

10.3.1. Port Expansions

The activities at the various ports throughout the PNCIMA could cause environmental and socio-economic impacts:

- **Port of Prince Rupert -** the significant expansion of the Port of Prince Rupert 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 a result, inputs of compounds like CCA and antisapstains will continue to be an issue. Also, since the majority of ships visiting the new terminal will be international vessels over 25 m in length, inputs of TBT will most likely increase at the port (Johannessen et al. 2007a).
- **Port of Kitimat** - at the Port of Kitimat, many of the proposed projects could increase the risk of environmental contamination (Johannessen et al. 2007b).
- **Port of Stewart** - possible contaminant issues would likely be very localized at this smaller port.(Johannessen et al. 2007a).
- **Wei Wai Kum Terminal** – issues at this port will focus around cruise ship activities. These impacts of these activities are discussed in section 11.2 of this report.

10.3.2. Wood Preservatives and Anti-sapstains

Pentachlorophenol (PCP) in particular has been found in elevated levels in many parts of the BC coastal environment, including Campbell River's harbour, and is thought to originate from wood preservatives. PCP has also been found in remote locations in Clayquot sound and the Queen

Charlotte Islands, indicating widespread contamination from wood preservatives in BC (Yunker et al. 2002).

10.3.3. Antifouling Paints

The TBT ban has been largely effective in protecting biota in the smaller harbours of the PNCIMA. Sampling sites from Campbell River and Quadra Island, at the southern end of the Central Coast have shown significant decreases in frequency of imposex in whelk samples collected from 1987-89, 1994, and 2000 (Reitsema et al. 2002, Tester et al. 1996). However, one site, Cape Mudge on Quadra Island, did show 100% frequency of imposex in one species, while no other species previously sampled at that site could be found in the 2000 survey. The sampling location was directly adjacent to a slipway that may have been a source of TBT (Reitsema et al. 2002). Also, large ports will still experience TBT contamination as a result of traffic by international vessels over 25 m. Thus, although TBT contamination in most of BC has been reduced since 1989, it has not been eliminated.

10.3.4. Other Chemical Contaminants

More information on persistent organic pollutants in the North and Central Coast region is provided in section 6.3 of this report.

10.3.5. Sewage

More information on sewage pollution in the North and Central Coast region is provided in section 8.3 of this report.

10.3.6. Ballast Water

In 2005, the amounts of ballast water released in the PNCIMA were (Lo et al. 2007):

- Port of Stewart: < 140,000 megatons
- Port of Prince Rupert: 140,000-560,000 megatons
- Port of Kitimat: < 140,000 megatons

Although Canadian law states that ballast water taken on outside Canadian waters must not be discharged in waters under Canadian jurisdiction unless the ship conducts an exchange before entering Canadian waters in an area situated at least 200 nautical miles from shore where the water depth is at least 2000 m (TC 2006), this is difficult to enforce. Even if the legally required ballast water exchange has taken place, it is still possible than sediments and potentially invasive species have not been completely flushed from the ballast tanks. As a result, any ballast water released in the PNCIMA, unless strictly monitored, could potentially be a source of alien invasive species.

10.4. Monitoring

Pollution monitoring in ports, harbours, and marinas involves several aspects:

- **Establishing a baseline** – if possible, sediment and water samples should be collected before a facility is build, and analyzed for a variety of contaminants (POPs, TBT, coliforms, etc.). Studies of marine flora and fauna composition and diversity should also be done so that changes in the ecosystem can be monitored when the facility becomes operational.
- **Ongoing monitoring** – regular sampling and ecosystem studies should be carried out during the lifetime of a facility to allow changes to be observed, and if necessary, mitigation measures to be put in place

- **Compliance monitoring** – the amounts of pollutants which various industries, facilities, and ships are allowed to discharge into the marine environment are legally regulated. However, if these laws are not monitored and enforced, pollution discharges can and will occur.

10.5. Mitigation

10.5.1. DFO Initiatives for Small Craft Harbours

At harbours managed by the Small Craft Harbours division of DFO, several initiatives are underway with the goal of lessening the impact of pollutants from these harbours on the marine environment. While both washrooms and pump out stations exist at many harbours, washrooms are now preferentially installed over pump out stations in order to reduce organic contaminants released into the water. There is also a major capital project underway in Prince Rupert that will build systems to intercept storm water from boat repair sites, thus achieving zero discharge from these sites. The Small Craft Harbours division is actively discouraging boat grids for hull maintenance, and is 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 (Johannessen et al. 2007a).

10.5.2. Mitigation Measures for Introduced Species

Mitigation measures for alien introduced species can only take place after the presence of these species has been detected. Detection of introduced species relies on:

- ongoing monitoring for introductions
- regular inventories and surveys of key sites for invasive species

Once an AIS has been detected, biodiversity can be restored through the application of methods used to control the invasive species. If possible, the invasive alien species should be eradicated. If this effort is unsuccessful, then a mix of control methods (e.g., manual, chemical and/or biological methods) should be used to try to control the spread of the organism. The focus of such effort should be to reduce stresses to at-risk species and ecosystems while decreasing the negative effects of biodiversity loss (BCMWLAP 2004).

10.5.3. Mitigation Measures for Other Contaminants

Many mitigation measures are specific to the particular type of pollutant being released. The specifics of these mitigation measures for issues such as sewage, POPs, and various industrial contaminants, are discussed in other sections of this report.

11. Pollution Associated with Marine Traffic

11.1. Pollution Sources

11.1.1. Vessel Traffic

On the North and Central Coast, both residents and visitors rely on marine vessels for shipping (moving cargo) and for transportation (moving people). These vessels include oil tankers, container and cargo ships, barges, ferries, cruise ships, and fishing and recreational vessels (Haggarty et al. 2003). The annual vessel movements by vessel type for BC are shown in **Table 18**. Passenger vessels (ferries and cruise ships) accounted for approximately 56% of the total vessel traffic. Tugs towing or propelling barges accounted for 29% of the marine traffic on the coast, and oil, gas, and chemical tankers accounted for around 1% of traffic (BCMOE 2007c). **Table 19** shows the vessel traffic statistics specifically for the Prince Rupert Area of Responsibility, which corresponds closely to the PNCIMA. Ferries are the greatest source of vessel traffic in the PNCIMA, although tug traffic is also very frequent. The PNCIMA experiences a significant amount of vessel traffic around the large ports of Kitimat and Prince Rupert (**Figure 30**).

Table 18. Annual vessel movements by vessel type from 1996-97 to 2003-04 for the coast of BC (sources: BCMOE 2006b, MCTS 2008).

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

Table 19. Vessel traffic statistics (VTS) for the Prince Rupert Area of Responsibility from 2003-2006. VTS represent inbound, outbound, and transiting vessels (source: Johannessen et al. 2007a).

Movements by Vessel Type	2003-2004	2004-2005	2005-2006	Location of the Prince Rupert Area of Responsibility
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 > 20 m	667	783	702	
Other vessels < 20 m	56	49	82	
Ferries	3163	15115	15013	
Total Vessel movements	**21140**	**33192**	**30479**	

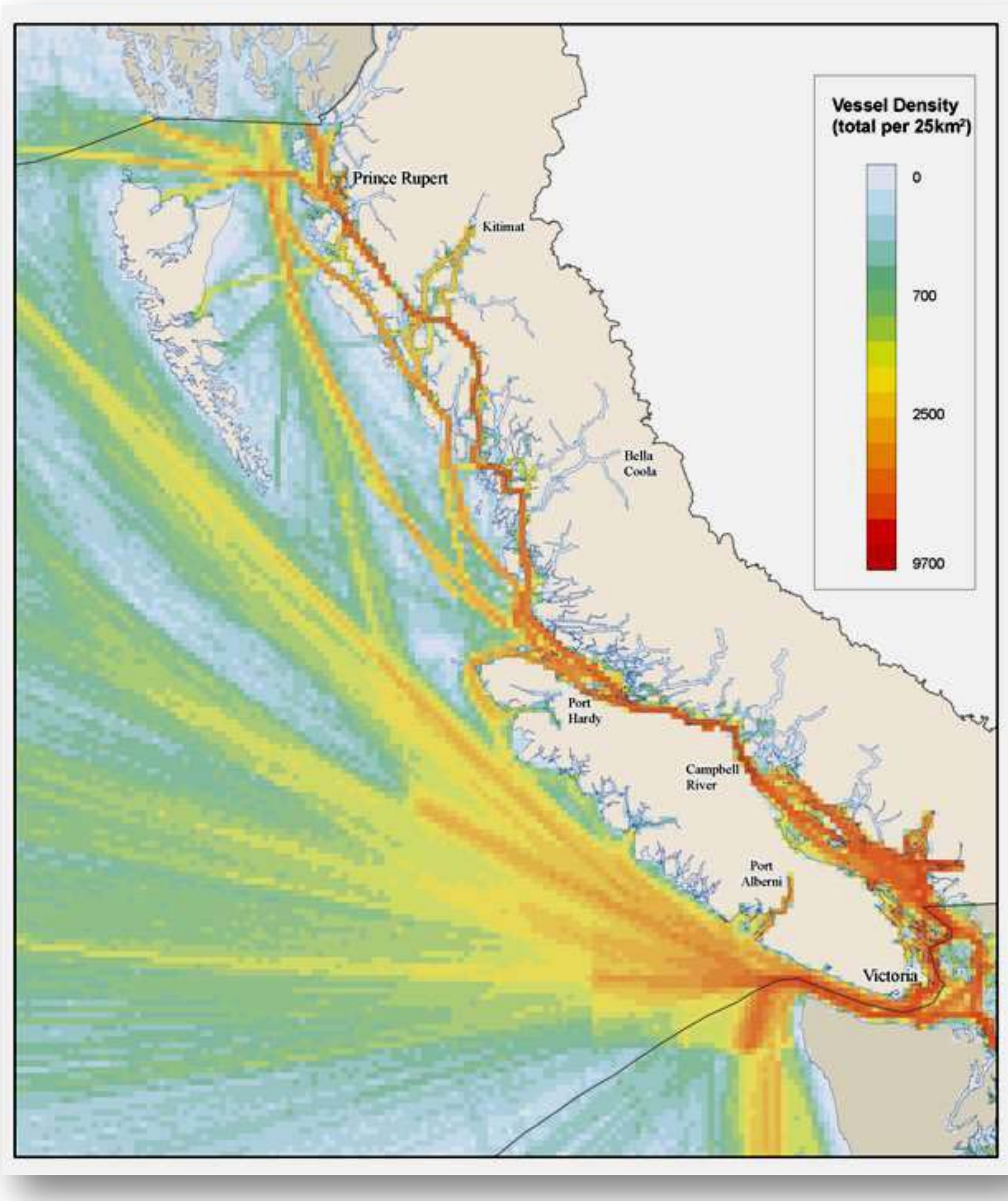

Figure 30. Map of marine vessel traffic density on the BC coast in 2003 (source: BCMOE 2003).

Vessel traffic can contribute to marine pollution in a variety of ways, such as (BCMOE 2007c, Haggarty et al. 2003):

- sewage discharge
- discharge of grey water
- dumping of ship board solid wastes
- bilge cleaning
- accidents and spills
- noise from motors and activity which can disturb wildlife, particularly marine mammals and birds
- recreational use of marine parks, ecological zones, and other areas which can disturb wildlife and habitats
- emission of pollutants from marine vessel motors which can contribute to regional and local air pollution
- introduction of exotic and invasive species that are carried on the hulls and in ballast water of international ship traffic
- chemical pollution from antifouling paints, wood preservatives, and chemical treatment of ballast water

Ship-based pollution is often greatest in areas where boats are most concentrated, such as in harbours and marinas (Haggarty et al. 2003).

The impact of shipping, in terms of number and type of ships, can vary seasonally on some routes. The Marine Communications and Traffic Service (MCTS) annual summary data show that overall shipping traffic is greater in summer than in winter, and varies according to vessel type. The distribution of bulk carrier, cargo, and tanker traffic does not change much seasonally, but fishing vessel traffic is seasonal because it depends on fishery openings. Cruise ship traffic is also seasonal, with the heaviest traffic during the summer, especially on the west coast of Vancouver Island, through Queen Charlotte Sound and Hecate Strait, and along the Inside Passage (BCMOE 2006b, O'Hara 2007).

11.1.2. Ferries

BC Ferries operates seven routes in the PNCIMA (**Figure 31**):

- **Route 10** - Inside Passage: Port Hardy to Prince Rupert
- **Route 11** - Hecate Strait: Prince Rupert to Queen Charlotte Islands (via Skidegate)
- **Route 23** - Discovery Passage: Campbell River to Quadra Island (via Quathiaski Cove)
- **Route 24** - Sutil Channel: Quadra Island (via Heriot Bay) to Cortes Island (via Whaletown)
- **Route 25** - Broughton Strait: Port McNeill to Alert Bay (on Cormorant Island) and Sointula (on Malcolm Island)
- **Route 26** - Skidegate Inlet: Skidegate (on Graham Island) to Alliford Bay (on Moresby Island)
- **Route 40** - Discovery Coast: Port Hardy to Bella Coola (with stops at Bella Bella, Shearwater, Ocean Falls and Klemtu)
- **Route xx** – Inside Passage-Mid Coast Connections

There is year-round ferry service on routes 10, 11, 23, 24, 25, and 26. Route 40 is only run during the summer (Haggarty et al. 2003). **Table 20** gives the names and capacities of the different ships operating on each of these routes.

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. No chlorine is used. Effluent reportedly surpasses all environmental regulations. As a result, 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 (Johannessen et al. 2007a).

Figure 31. BC Ferries routes in the PNCIMA (modified: BC Ferries 2008b).

Table 20. BC Ferries vessels servicing the PNCIMA (data: BC Ferries 2008a).

Vessel Name	Route	Vehicle Capacity	Passenger and Crew Capacity
Northern Adventure	10, 11, 40	101	600
Queen of Prince Rupert	11	80	544
Quadra Queen II	25	30	300
M.V. Nimpkish	xx	16	133

11.1.3. Cruise Ships

Each year, numerous cruise ships take passengers on scenic tours through BC's Inside Passage en route to Alaska. In doing so, they travel through the PNCIMA. Cruise ships travelling along 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 (Johannessen et al. 2007a). Typical routes for cruise ships are shown in **Figure 32**. The cruise ship industry has played an increasingly important role in BC's economy during the last two decades. In 1995, 283 cruise ships visited at the three main ports of call in BC (Vancouver, Victoria, and Prince Rupert). In 2002, there was a high of 462 visits, which dropped somewhat to 381 in 2004 (**Figure 33**). Over the same time, however, total passenger visits doubled, showing that the size and capacity of visiting ships has increased. The number of ports of call within BC is increasing, and the cruise ship industry is planning to initiate BC-only cruises that will also include smaller ports along the BC coast (BC Stats 2003).

The cruise ship industry contributes greatly to BC's economy, bringing in approximately $765,000,000 annually in direct cruise-related spending by cruise lines, passengers, and crew members. In 2007, employment was generated for 6,910 people ($233,000,000 in wages) in BC (CruiseBC 2008). Most economic benefits are felt in Vancouver. Vancouver handled nearly half the Canadian total of passengers (960,500), while other BC cruise ports included Victoria (324,000 passengers), Prince Rupert (98,300 passengers), Nanaimo (30,400 passengers), and Campbell River (2,300 passengers) (Vancouver Sun 2008).

The port of Prince Rupert is the major destination and stopover point for cruise ships on the North Coast. The new Northland cruise terminal has the capacity to berth cruise ships up to 330 m in length, while the smaller Atlin cruise terminal can handle vessels up to 100 m in length (Prince Rupert Port Authority 2008a). The Northland terminal attracted 50 cruise ships and 94,000 passengers in 2005, 32 ships and 62,845 passengers in 2006, and 60 ships and 100,000 passengers in 2007. The port expects 65 large cruise ships for 2008 (Prince Rupert Port Authority 2005, 2008b). Visitation rates have increased at the Port at Prince Rupert in part due to the growing popularity of Seattle as a starting point for Alaskan cruises. 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 Seattle to Alaska must stop somewhere in BC (Dobson et al. 2002).

Cruise ships carry an average of 2,000 crew and passengers, and generate more waste and sewage than a small town (Nowlan and Kwan 2001). Cruise lines have been recently criticized internationally and in British Columbia for their environmental record with respect to pollution (Gorecki and Wallace 2003). A report by the US General Accounting Office (United States General Accounting Office 2000) confirmed 104 cases (mostly in the Caribbean) of illegal discharges of oil, garbage and hazardous wastes between 1993 and 1998, with over $30,000,000 US paid in fines. Most of the violations were considered accidental; however, 13% of the incidents involved intentional dumping, and some companies admitted to having routinely dumped harmful wastes into the environment (Nowlan and Kwan 2001). Some of these violations occurred in Alaska, and prompted the establishment of a scientific advisory board to perform a review of potential impacts of cruise ship pollution in Alaska. The panel released its findings in November of 2002 (Science Advisory Panel 2002). Little documentation exists on cruise ship impacts in British Columbia. Violations reported in Alaskan waters may also occur in BC's waters, as the same ships travel between Seattle and Alaska (BCMOE 2006b). The International Council of Cruise Lines has also adopted waste management practices and procedures that all of its members must comply with (International Council of Cruise Lines 2001). In recent years, the cruise ship industry has been developing new environmental policies and waste treatment technologies (minimization, re-use, and recycling) that go beyond international standards (Dobson et al. 2002). Transport Canada released a revised set of guidelines in 2005 for the prevention of pollution by cruise ships (TC 2005). It is not known, however, how many cruise ships currently plying BC waters meet these more rigorous levels of waste management (BCMOE 2006b).

Waste from cruise ships is categorized into eight types (Haggarty et al. 2003):

- **Sewage** (**blackwater**) - sewage from cruise ships is more concentrated than municipal sewage since less water is used to dilute wastes on ships than is on land.
- **Grey water** - wastewater from sinks, showers, galleys, and laundry.
- **Oil pollution** - bilge water often contains oil and fuel from on-board spills and wastes from engines and machinery.
- **Hazardous wastes** - dry cleaning sludge (containing perchlorethylene), waste from photo and x-ray processing laboratories (e.g. silver), paint waste and solvents, print shop wastes, deodorizers, disinfectants (e.g. chlorine), and batteries.
- **Solid waste -** plastic, paper, wood, cardboard, food waste, cans and glass. Much of the paper and food waste is incinerated on board.
- **Air pollution -** ship combustion and incineration which contribute to greenhouse gases and smog constituents.
- **Ballast water** - may contain oil, chemicals, and introduced species.
- **Vessel coating** - antifouling paints containing toxic chemicals or metals.

Figure 32. Typical cruise ship routes through the PNCIMA (data: BCMEMPR 2008c).

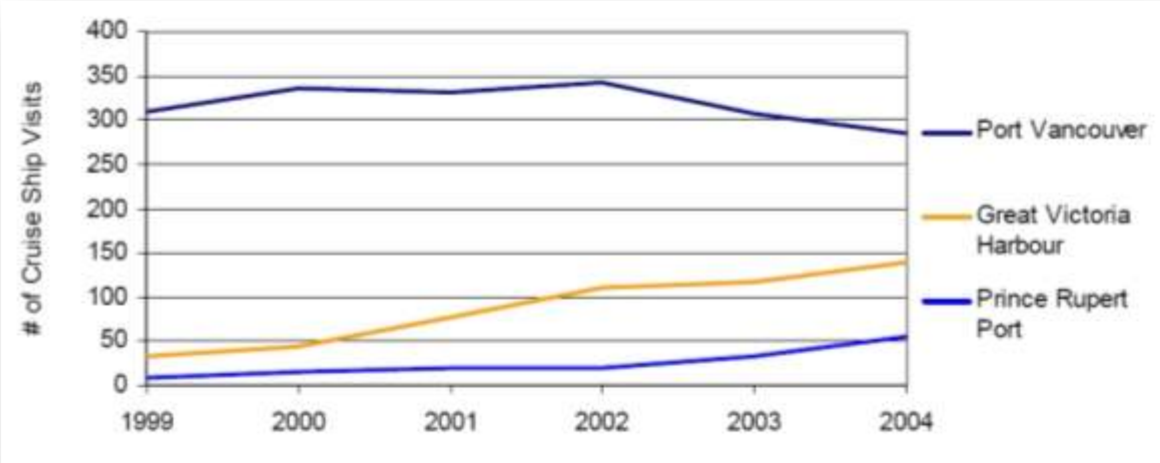

Figure 33. Cruise ship visits to three BC ports, 1999 to 2004 (source: BCMOE 2006b).

11.1.4. Whale Watching Tours

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. Increased interest in whale watching means that there are more boats on the water, which may further increase contaminant issues, such as leaching of antifouling compounds and fuel residues (Johannessen et al. 2007a).

11.1.5. Sewage

The new regulations in the Canada Shipping Act 2001 now prevent the release of untreated sewage close to shore (**Table 21**). There are 17 new no-discharge zones in BC (TC 2007b). None of these no-discharge zones are in the PNCIMA. Sensitive areas in the PNCIMA, such as the sponge reefs and protected areas should be considered for no-discharge zones (Haggarty et al. 2003).

Except for small motor boats without a head, most vessels generate sewage. Small recreational vessels, such as the numerous sports fishing boats frequenting the PNCIMA, may not have sewage treatment systems or holding tanks (Haggarty et al. 2003). Even if holding tanks are present, raw sewage is often released into the marine environment, as there are only eight pump-out stations in the PNCIMA (TBuck Suzuki 2007):

- Sandspit Harbour Marina (Sandspit)
- Ocean Falls Public Dock (Ocean Falls)
- Port Hardy Harbour Authority (Port Hardy)
- Port McNeil Harbour Authority (Port McNeil)
- Sointula Harbour Authority (Sointula)
- Harbour Authority of Sayward (Sayward)
- Browns Bay Marina (Browns Bay; close to Campbell River)
- Campbell River Harbour Authority (Fisherman's Wharf in Campbell River)

Most marinas and harbours have no dumping policies. Except in areas of high boat traffic, such as heavily visited recreational sites, sewage released from boats is likely to be adequately diluted, and impacts will be relatively low. However, cumulative impacts of wastes can lead to significant amounts of pollution in some areas.

Table 21. Regulations for sewage discharge from the Canada Shipping Act 2001 (TC 2007b). MSD = marine sanitation device (means any equipment installed on board a ship designed to receive and treat sewage).

Type of treatment	Discharge allowed in a "no-discharge" zone?	Discharge allowed in any other areas within Canadian Territorial waters?
MSD producing effluent with ≤ 14 fecal coliforms/100 ml	Y	Y
MSD producing effluent with ≤ 250 fecal coliforms/100 ml	N	Y
MSD with grinding and disinfection; vessel more than 400 tons with greater than 15 people	N	Y, but more than 3 nautical miles from shore
No treatment; vessel more than 400 tons with greater than15 people	N	Y, but more than 12 nautical miles from shore
MSD with grinding and disinfection; vessel less than 400 tons with fewer than 15 people	N	Y, but more than 1 nautical mile from shore
No treatment; vessel less than 400 tons with fewer than 15 people	N	Y, but more than 3 nautical miles from shore

Many of the same problems associated with municipal sewage effluent also exist with cruise ship releases. In a typical week-long cruise, a ship generates an estimated 800,000 liters of black water. During peak season, the combined releases of all cruise ships in BC waters are estimated to be 9.5 million liters of sewage per day, an amount equivalent to that produced by the city of Juneau, Alaska (approx. 25,000 people) (Nowlan and Kwan 2001).

Most large ships operating in Alaska treat black water using a US Coast Guard approved Marine Sanitary Device (MSD). Alternatively, Alaskan regulations allow untreated black water to be discharged when the ships are more than 12 nautical miles from land. The MSD units use the following treatment systems: (1) biological treatment, (2) macerator-chlorination, or (3) advanced treatment. The Alaskan government requires that the black water systems of passenger vessels be monitored twice per year. Analysis of the samples collected for monitoring has found that the advanced treatment systems are very effective at removing solids and fecal coliform bacteria. However, these systems produce a concentrated sludge which requires disposal. Macerator-chlorinating systems are used to reduce fecal coliforms on vessels with less than 1000 passengers and crew. None of the ships using either macerator-chlorinating systems or conventional biological treatment systems produce effluents which are within the limits that would allow them to discharge black water within 3 nautical miles from shore. Analysis of the black water samples from large ships (ships which sleep over 250 passengers) showed that none of the conventional biological treatment systems were functioning properly. In some cases, macerator-chlorinating systems had high chlorine residuals and high chemical oxygen demand. High residual chlorine is particularly problematic since it is toxic to marine life (Science Advisory Panel 2002).

Black water, like land-based sewage, contains many pharmaceuticals with poorly characterized environmental effects (Section 8.1). A variety of medications, such as antibiotics, hormones, steroids, and anti-hypertensive drugs (reduce blood pressure) can be taken either orally or applied topically to skin. They enter the black water system as excreted metabolites (Science Advisory Panel 2002).

A significant difference between effluents from cruise ships and municipal outfalls is that cruise ships are not stationary. Consequently, localized impacts associated with cruise ship effluents may be more diffuse and less severe. Although dilution is certainly not the solution to pollution, the vigorous mixing action of a moving ship can effectively dilute sewage (Science Advisory Panel 2002). Alaskan regulations require that black water be discharged at least one nautical mile from shore at speeds of at least 6 knots (Nowlan and Kwan 2001). The calculated dilution factor for a typical large cruise ship moving at 6 knots and discharging wastewater at 200 m^3/hr is 50,000 times (Science Advisory Panel 2002). As a result, sewage released from a moving ship probably has significantly less environmental impact than when released from a stationary ship. The new Canada Shipping Act 2001 regulations take this into account, and require sewage to be released at speeds of at least 4 knots (TC 2007b).

11.1.6. Grey Water

Grey water includes wastewater from sinks, showers, galleys, and laundry facilities, and can add up to four million liters of discharge per ship (based on a seven day cruise). Grey water is not usually treated; however, it may be mixed with black water, which is then treated. Grey water may contain organics, petroleum hydrocarbons, oils, greases, metals, suspended solids, nutrients, coliform bacteria, and personal care products (Nowlan and Kwan 2001). Transport Canada released guidelines for cruise ship operators which 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 6 knots, is not in port, and is at least four nautical miles from shore (TC 2005).

Wastewater sampling has shown that black and grey water are quite similar in quality. Both may contain high levels of fecal coliforms and suspended solids, trace metals (copper, zinc), plasticizers, and possibly medications. Drugs can enter the grey water system via showers and sinks. Some ships add chlorine to grey water to reduce bacteria (Science Advisory Panel 2002).

11.1.7. Oil Spills

Most concerns regarding oil spills in the PNCIMA are related to oil tanker traffic. In the report on science issues related to offshore oil and gas activities in BC prepared by The Royal Society of Canada, the following statement is made:

> *"In 1972 the Government of Canada imposed a moratorium on crude oil tanker traffic through Dixon Entrance, Hecate Strait and Queen Charlotte Sound due to concerns over potential environmental impacts. The moratorium was subsequently extended to include all oil and gas activities. This was followed in 1981 by a similar prohibition by the Government of British Columbia."* (The Royal Society of Canada 2004)

The actual existence of this "tanker moratorium" is under significant debate, and the legal implications of tanker traffic entering the Inside Passage are unclear.

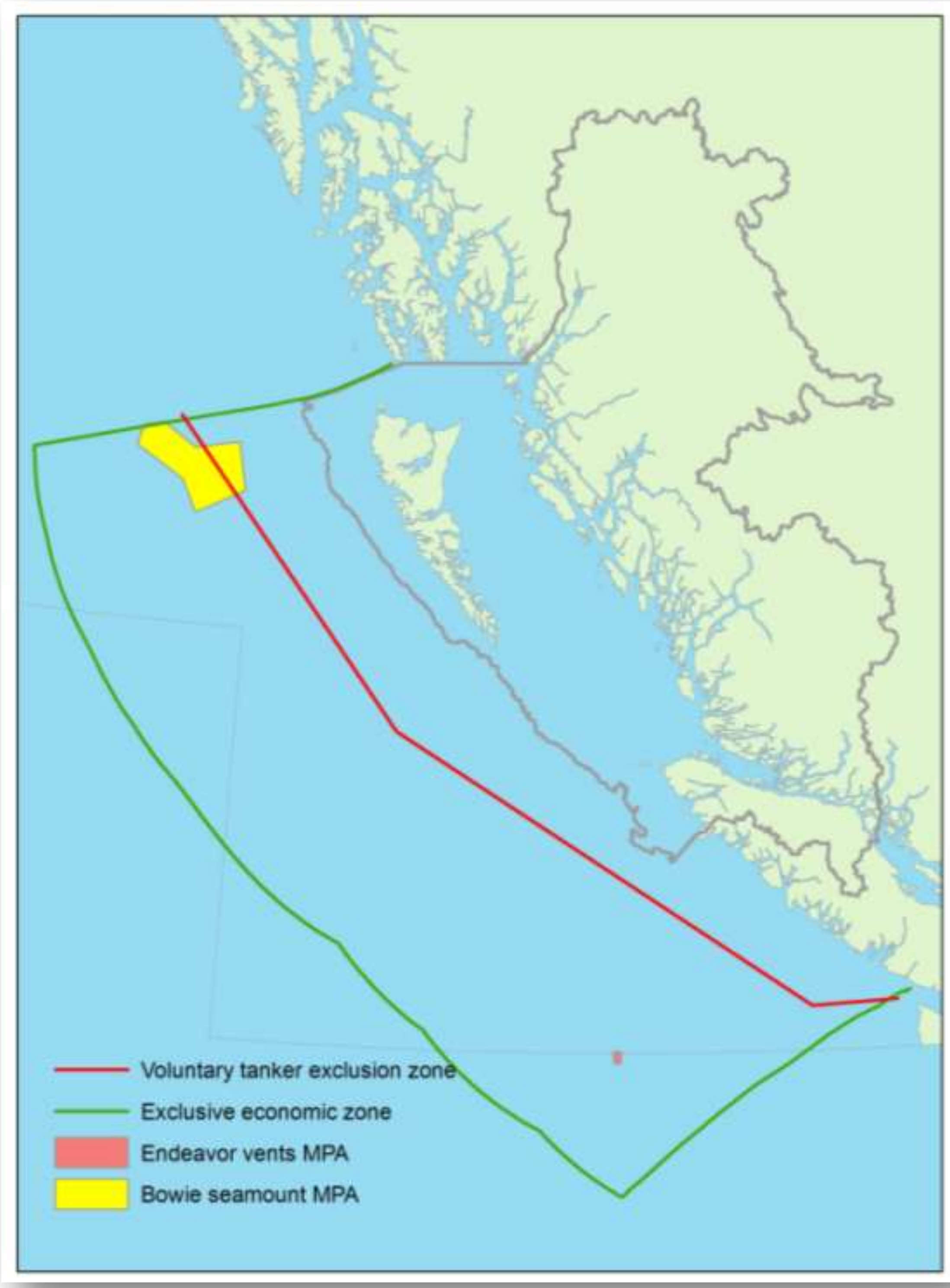

Figure 34. Location of the marine protected areas, voluntary tanker exclusion zone, and exclusive economic zone in relationship to the PNCIMA (data: BCMEMPR 2008c, DFO 2007a, Government of Canada 2008).

In 1977, environmental concerns over tanker traffic generated by the newly-established Trans-Alaska Pipeline System (TAPS) resulted in the creation of a voluntary tanker routing system off the Canadian West Coast. The system was designed to keep tankers at least 100 miles (160 km) offshore of the Queen Charlotte Islands, with distance offshore decreasing as the vessel transited south to areas where rescue tugs were more readily available (**Figure 34**). In 1982, the initial voluntary tanker routing system was terminated. Subsequently, in 1985, a temporary Tanker Exclusion Zone (TEZ) was established off the Canadian West Coast as an interim measure. Following a 1988 tanker drift study, all parties agreed to make the TEZ permanent with a boundary that was far enough offshore to almost eliminate the possibility that a disabled tanker could ground prior to the arrival of assistance (USCG 1996). The Bowie Seamount lies just west of the TEZ off of the Queen Charlotte Islands, and rises to within 25 m of the sea surface (**Figure 34**). Although it represents a grounding risk, tanker companies recognize it as a navigational risk and stay well clear of it (Pacific States/British Columbia Oil Spill Task Force 2002). Thus, while there is a risk of oil spills occurring in the PNCIMA as a result of tankers and other ships traveling through the region, the TEZ reduces this risk significantly by keeping most oil tankers out of the Inside Passage and well offshore.

In 1989, British Columbia and the US Pacific States of Alaska, Washington, Oregon, California and Hawaii signed a memorandum of cooperation to form the Pacific States/British Columbia Oil Spill Task Force. In response to the need to protect marine resources, this task force analyzed vessel routing, modeled several risk scenarios, and developed recommendations based on these scenarios. In 2002, they released a report for the West Coast Offshore Traffic Risk Management Project (Pacific States/British Columbia Oil Spill Task Force 2002). The following factors affecting risk of oil spills were evaluated (Haggarty et al. 2003):

- Distance Offshore
  - Risk of grounding decreases as boats move offshore
- Risk of Collision
  - Increases with traffic density at approaches to ports
  - Increases with increased offshore traffic density
- Tug Availability
  - Risk of drift groundings decreases with rescue vessel availability and capability
  - Increases with prevailing weather conditions (scenarios were modeled for 3 seasons)
- Historical Casualty
  - Increased risk for vessel types with relatively higher casualty rates.

Since risk decreases as vessels move offshore, the task force recommended that tankers laden with crude oil or persistent petroleum products that were travelling along the coast anywhere between Cook Inlet and San Diego, in regions where Areas to Be Avoided (ATBAs), Traffic Separation Schemes (TSSs), or Tanker Exclusion Zones (TEZs) were not already in place, should voluntarily stay a minimum distance of 50 nautical miles offshore (Pacific States/British Columbia Oil Spill Task Force 2002).

The Marine Communication and Traffic Services (MCTS) compiles pollution reports on pollution originating from oil handling facilities or vessels using the VTS (Vessel Traffic Service) system. Pollution discharges are reported to MCTS from a variety of sources; however, the majority of pollution reports are recorded as a result of a vessel incident (i.e., vessels in difficulty) that resulted in pollution. In addition, pollution from such sources as bilge pumping and spills at docks may be observed and reported by Transport Canada aircraft surveillance, floatplane pilots, or individuals on shore. **Figure 35** shows the number of pollution incident reports by VTS zone in BC from 1999 to 2004 (BCMOE 2006b).

About half (52%) of the nation's reported spills occur on the BC coast, which is where half of all vessel movements in Canada occur (DFO 2004b).

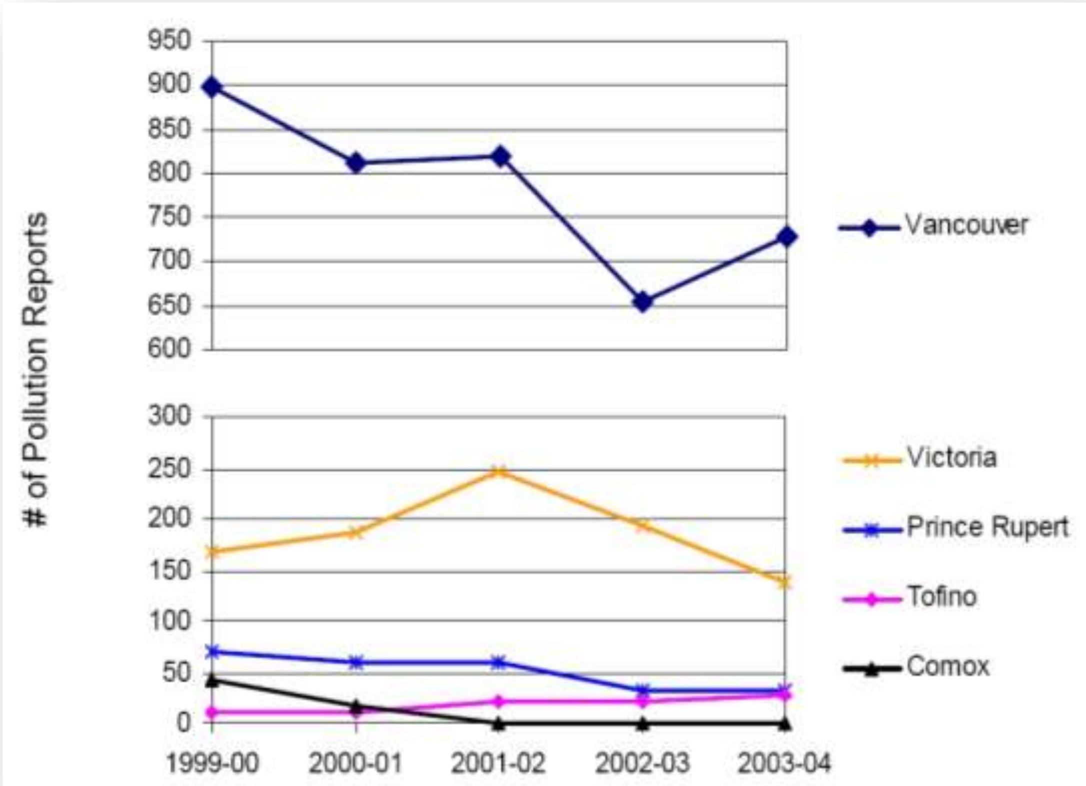

Figure 35. Pollution incident reports per year from shipping by VTS zone, 1999–2004 (MCTS 2008).

11.1.8. Oily Bilge Water

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. In addition, each discharge must be recorded (Nowlan and Kwan 2001, TC 2005).

11.1.9. Hazardous Wastes

Cruise ships produce many toxic chemicals. Standards adopted by the International Council of Cruise Lines require its members to treat photo processing wastes, dry-cleaning fluids, photocopying and printing cartridges and ink, unused pharmaceuticals, fluorescent and mercury vapor lamp bulbs, and batteries as hazardous materials that must have proper disposal on land land. They also encourage their members to switch to non-toxic alternatives, and to reduce consumption of hazardous materials (International Council of Cruise Lines 2001). Full disclosure from ships after generation and disposal of hazardous wastes is not required in Canada, thus illegal dumping of hazardous materials may still be an issue (Nowlan and Kwan 2001).

11.1.10. Solid Wastes

A typical cruise generates an estimated fifty tons of garbage on a one-week voyage (Nowlan and Kwan 2001). Regulations in the Canada Shipping Act state that solid waste cannot be dumped in Canadian waters south of 60th parallel N, which encompasses the PNCIMA. The *Oceans Act* also prohibits dumping in fishing zones.

Solid waste, which may contain hazardous materials such as batteries, is sometimes incinerated on board the ship, and may contribute to air pollution and the production of dioxins. Cruise lines investigated by the Scientific Advisory Panel were conscientious to carefully sort garbage for hazardous materials and recyclables prior to incineration (Science Advisory Panel 2002).

11.1.11. Air Pollution

Both ship exhaust and on-board incinerators are sources of air pollution from cruise ships, and contribute green house gases (CO_2 and CO) and PAHs to the environment. In the year 2000, cruise ships emitted almost 300,000 tons of greenhouse gases (not including emissions from incineration). Cruise ship emissions are also high in smog-causing nitrogen oxide and sulfur dioxide. Most cruise ships run on diesel bunker fuel that is 90% higher in sulfur than the gasoline used to power cars (Haggarty et al. 2003). Toxic substances such as plastics may be accidentally or intentionally incinerated on board, releasing dioxins, furans and heavy metals (Gorecki and Wallace 2003).

Canadian law prohibits the discharge of emissions beyond a maximum level and the unnecessary discharge of soot within 1000 m of land (Nowlan and Kwan 2001). They also require that ships report annually the sulfur contents and quantity of all fuel deliveries for any fuel used while operating in Canadian waters (TC 2005).

11.1.12. Ballast Water

Ballast water is taken on for ship's stability, and is a major pathway for introduced species. One method of dealing with introduced species in ballast water is to treat the water with chemicals. However, many of the chemicals may lead to chlorine residuals (Haggarty et al. 2003). Ballast water may also contain oil and other chemicals.

Canadian law requires all vessels to exchange or treat their ballast water prior to discharge in waters under Canadian jurisdiction with the exception of vessels that have been specifically exempted (TC 2007a).

11.1.13. Vessel Coating

Ship hulls are usually painted with an antifouling paint. This paint inhibits the growth of marine life on the hull. Most cruise ship hulls are steel, although some smaller vessels and support boats may be manufactured of aluminum. Steel hulls are typically coated with copper-based antifouling paints, which tend to leach copper and zinc. Alaska banned the use of TBT (tri-butyl tin) based antifouling paint on cruise ships and other large vessels in 2000, and prohibited vessels painted with TBT from entering State waters as of January 2001 (Science Advisory Panel 2002). Canada banned all uses of TBT in November 2002 (PMRA 2002).

11.1.14. Vessel Wakes

Wake is the path of moving waves that a boat leaves behind it. All boats create some wake. Large wakes can damage boats and injure passengers. Wakes can be a factor in shoreline erosion. Sediment may be washed into the water, along with trees and other plants whose roots have lost their support. A 12.5 cm high wake does limited damage to the shoreline. A 25 cm high wake is 5 times more destructive, and a 62.5 cm high wake is 30 times more destructive. Small motorboats with non-displacement hulls may create a 12.5 cm wake at planning speed, while crafts with displacement hulls can create wakes of 62.5 cm or higher. Boats operating at speeds under 10 km/h (a speed that is considered reasonable when operating close to sensitive shores) generally create waves of about 12.5 cm (DFO 2004a, Oregon State Marine Board 2003)

The size of the wake created by a vessel depends on a number of factors, including speed and hull design. Many vessels are designed to operate at specific speeds:

- **Displacement speed** – this is usually the slowest speed for most motor boats. It also creates the least wake. The boat operates with the bow down in the water
- **Transition speed** – as you increase the power while attempting to get on plane, the bow rises, causing the stern to plow through the water. This speed creates the largest wake.
- **Planing speed** – at planing speed, the bow drops back down and only a little of the hull contacts the water. This speed creates less wake than transition speed, but more than displacement. Many large craft are not designed to reach this speed.

The size of the channel can have an effect on the degree of erosion caused by wakes. In larger channels, boat wakes have relatively little impact as they make up only 2% to 5% of the annual energy dissipated against the banks. The opposite is true in smaller channels where wake accounts for between 95% and 98% of the energy (Hill et al. 2002). Thus, recreational boating in small channels can have a considerable impact (DFO 2004a).

11.1.15. Noise Pollution from Vessels

The ocean is filled with sound. Underwater sound is generated by a variety of natural sources, such as breaking waves, rain, and marine life. It is also generated by a variety of anthropogenic sources, such as ships and military sonars. The background sound in the ocean is called ambient noise. The primary sources of ambient noise can be categorized by the frequency of the sound (**Figure 36**). In the frequency range of 20-500 Hz, ambient noise is primarily due to noise generated by distant shipping. The amount of noise is greater in regions with heavy shipping traffic. There tend to be fewer ships in the southern hemisphere, and low-frequency ambient noise levels are substantially lower as a result (University of Rhode Island 2003). Noise generated by shipping has increased as the number of ships on the high seas has increased (Andrew et al. 2002). Sounds generated by human activities cover a wide range of frequencies, from a few Hz up to several hundred kHz, and a wide range of source levels. The source levels for some sounds generated by human activities are given in **Table 22**.

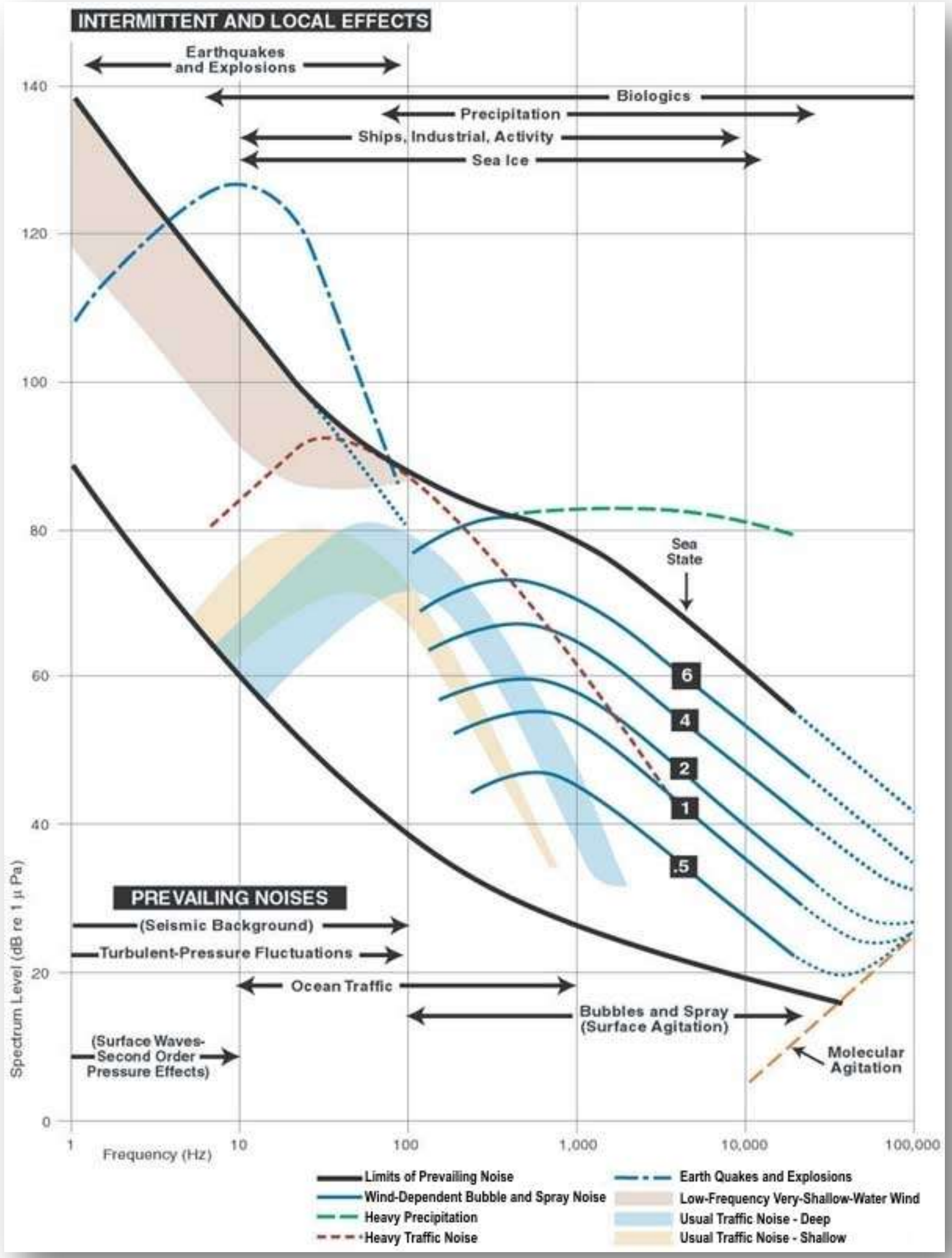

Figure 36. Typical sound levels of ocean background noises at different frequencies (source: University of Rhode Island 2003, Wenz 1962)

Table 22. Source levels for some sounds generated by human activities (source: University of Rhode Island 2003)

Sound Source	Source Level (underwater dB at 1 m)
Tug and barge	171
Supply ship	181
Large tanker	186
Icebreaking	193
Airgun array (32 guns)	259
U. S. Navy tactical mid-frequency sonar	235

11.2. Environmental and Socio-Economic Impacts

The environmental and socio-economic impacts of wastewater, heavy metals, oil, and persistent organic pollutants, all of which are contributed to by marine vessel traffic, have already been discussed in this report. The section that follows will look at several of the other important impacts created by pollution associated with marine traffic.

11.2.1. Impacts on Whales

Several researchers have documented behavioral 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). There is also concern that noise from heavy marine traffic may be interfering with killer whales' ability to locate prey and communicate with each other (Killer Whale Recovery Team 2005). Although ship collisions with whales are rare on the BC coast, increasing marine traffic in shipping lanes that cross whale migration and feeding areas may increase the risk of collision (EC 2004b).

11.2.2. Shoreline Erosion

Shoreline erosion has many consequences on the aquatic environment, including habitat destruction, an increase in sedimentation and in turbidity of the water, and the release of nutrients (phosphorous and nitrogen) that promote algal blooms. As well, shoreline erosion can result in the loss of land and affect shoreline property values (DFO 2004a). Other examples of environmental and socio-economic impacts of boat wakes are (Oregon State Marine Board 2003):

- Human safety
  - Wake may endanger inexperienced swimmers or wading anglers.
  - Wake may rock, swamp, or capsize other boats. Passengers may be thrown off balance or overboard, leading to serous injury.
- Recreation
  - Sediment from shoreline erosion may cloud the water, making it uninviting for swimming, boating, or fishing.
- Property damage
  - Wake may damage docked boats by thrusting them up against their moorings.
  - Trees that have fallen into the water could be washed up against docks or other structures.
  - Shoreline property owners may lose a small part of their land to erosion.
- Environmental
  - Sediment can be churned up by boat wake and settle to the bottom, silting in fish spawning habitat and smothering aquatic vegetation, an important food source for many fish and animal species.
  - Large wakes may disturb nesting birds along the shore.

11.2.3. Noise Pollution from Vessels

Marine animals use sound in a variety of ways, either passively or actively. Passive use of sound occurs when an animal responds to sounds in the environment. These uses include (Stocker 2002):

- Detection of predators.
- Location and detection of prey.
- Positioning in a school, raft or colony.
- Navigation.
- Sensing changes in the environment, such as earth quakes, tides, and currents.

Active use of sound occurs when an animal creates a sound. These uses include (Stocker 2002):

- Communication between members of the same species during breeding.
- Communication between members of the same species for cooperative feeding.
- Communication in territorial and social relationships.
- Echolocation.
- Stunning and catching prey.
- Alarm calls used warn others of the approach of enemies.
- Long distance navigation and mapping.
- Use of sound as a defense against predators.

Anthropogenic noise can affect marine organisms in a variety of ways, including (Stocker 2002):

- Tissue damage in extreme cases (e.g., very loud sounds).
- Interference with normal sound production and reception, resulting in impacts on feeding, breeding, community bonding, schooling synchronization, and other acoustically-mediated behavior.
- False triggering of behavioral responses causing an animal to expend energy unnecessarily. Large expenditures of energy that do not produce any positive benefits for an organism can make that organism unfit and less likely to survive.
- Producing stress. Responses to stress can weaken organisms or damage community interactions.

11.2.4. Impacts of Chronic Oiling on Birds

Chronic spills are less visible than major spills, such as the 1989 *Exxon Valdez* oil spill in Prince William Sound, Alaska, but they have persistent, cumulative impacts on marine organisms (BCMOE 2006b). Chronic oiling may be caused by natural seepages, sewage, atmospheric input, runoff from land, or marine vessel traffic. However, of all sources of oil pollution, ships are more likely to release oil in areas where it can 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 appear to cause greater mortality than more dispersed forms of oil pollution (Johannessen et al. 2007a). The degree of impact that chronic oiling can have varies seasonally due to the timing of certain wildlife activities, such as seabird nesting, salmon migration, and coastal wintering of some bird species (O'Hara 2007).

When a seabird passes through an oil slick, the oil coats its plumage. The bird may try to remove the oil by preening, thus ingesting some of the oil, which may lead to toxic effects. The oil also interferes with the water-resistant characteristics of the plumage, leading to hypothermia and loss of buoyancy (O'Hara 2007). The volume of oil spilled is not a good predictor of the seabird mortality that will occur as a result of a spill. Other factors, such as seabird density, wind velocity, wave action, and distance to shore may be equally important in determining the mortality from a spill (Burger 1993).

Chronic oil pollution is thought to have a greater impact on bird populations than catastrophic oil spills (Sloan 1999). Research based on 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 the area as a result of chronic oiling (Wiese and Robertson 2004). Estimates are not available for the Pacific coast, but the National Aerial Surveillance Program has found a higher rate of oil spill observations off the west coast (calculated per flight kilometer) than off the east coast of Canada between 1997–2001 (DFO 2004b). 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 in some regions of BC's exclusive economic zone (**Figure 34**) may be similar to those estimated for the small area off the Avalon Peninsula (BCMOE 2006b, O'Hara 2007). Data from the Beached Bird Survey attribute some seabird mortality to oiling in a few areas such as along the west coast of Vancouver Island (Bird Studies Canada 2004).

11.2.5. Ballast Water

International shipping traffic increases the risk of introducing exotic and invasive species carried on ship hulls and in ballast water. More than 3000 species of animals and plants are estimated to be transported around the world daily in ballast water (NRC 1996). Further information on the environmental impacts of ballast water is given in section 10.2.7 of this report.

11.3. Concerns in the North and Central Coast

11.3.1. Oil Spills

One major oil spill has affected the Central Coast in the past. On December 23, 1988, the fuel barge *Nestucca* collided with its tender and spilled about 875,000 L of oil off Grays Harbour, Washington. By December 31st, the oil had moved north and stranded at Carmanah Point on southwest Vancouver Island. By January 17th, it had spread as far as Cape Scott, and ten days later was reported near Bella Bella. Because of circulation patterns, tides, and winds, little oil penetrated the fjords and inlets, and oiling was largely confined to the exposed outer shorelines. Oil persisted longest in sheltered muddy bays (Addison 1998).

Most of the biological impacts occurred in areas where oil accumulated. Approximately 1,000 oiled and dead birds were collected from Vancouver Island, and one sea otter was known to have died as a result of oil exposure. Although widespread, the impact of the spill was relatively low. No effects on other mammals or fish were reported. Some fisheries were closed due to gear fouling. However, herring roe and salmon aquaculture in the area suffered no impacts. Following the *Nestucca* spill, the crab fishery in Clayoquot was shut down for several weeks because the crabs were unmarketable due to oil spots on their claws. The crabs had apparently been eating dead oiled birds on the bottom (Harding and Englar 1989). No follow-up studies of possible long-term effects of the spill have been conducted (Addison 1998).

Oil tankers are not the only vessels which can potentially cause an oil spill. Any large vessel carries enough fuel to cause significant environmental impacts should that vessel become damaged. While travelling from Prince Rupert to Port Hardy, the BC Ferries Vessel *Queen of the North* sank after running aground on Gil Island in Wright Sound, 135 kilometers south of Prince Rupert. The vessel was loaded with 225,000 liters of diesel fuel, 15,000 liters of light oil, 3,200 liters of hydraulic fluid and 3,200 liters of stern tube oil (BCMOE 2006a). Significant quantities of diesel fuel were released during the sinking; however the total volume released remains unknown. The Wright Sound area is rich in marine life. It is a major vessel transportation route, and part of the Inside Passage. The coastal waters are important for First Nations' fisheries and economies. Fortunately, the spill caused relatively minimal impacts on wildlife, as the initial large release of product – mostly diesel - quickly evaporated and dispersed as a result of the high winds and warm periods shortly after the spill. During the clean up phase of the spill, booms were established at numerous sites, including where fuel was upwelling from the sunken vessel.

Over 1500 meters of containment boom was set up in four sensitive areas. A shoreline cleanup and assessment team (SCAT) examined impacted shoreline. The on-going chronic discharges created by the oil still contained within the sunken ferry remain an environmental concern. A long-term environmental monitoring plan was formulated that involved members from both the Hartley Bay and Kitkatla First Nations (BCMOE 2006a).

With the planned expansion of the port at Prince Rupert (IC 2005) and increased industrial activity at the Kitimat port (Johannessen et al. 2007a), traffic volume in the PNCIMA can be expected to increase in future, thus creating a greater risk of environmental impacts from oil spills. During the period January 2006 to June 2007, 14 condensate tankers delivered to the Methanex terminal in Kitimat (Montgomery 2007). If all the currently proposed expansions at the Port of Kitimat proceed, an estimated 466 tankers could be arriving at the port annually (**Table 23**). The proposed tanker routes through the Inside Passage to Kitimat are shown in **Figure 37**.

Table 23. Maximum annual tanker traffic for proposed port expansions at Kitimat (source: Clifton 2007)

Facility	Tanker traffic
Enbridge	180 oil tankers; 72 condensate tankers
Methanex	40 condensate tankers
Pembina	84 condensate tankers
Kitimat LNG	90 LNG tankers
Total	**466 tankers**

11.3.2. Chronic Oiling on Birds

Seabirds congregate both on the open ocean and adjacent to their breeding colonies. In the summer, the Scott Islands are home to more than two million breeding seabirds. During this time, the tugboat traffic that passes by the Scott Islands is a concern, as the breeding seabirds are particularly susceptible to major and minor spill events anywhere in the Scott Islands area (EC 2004a). Canada's National Aerial Surveillance Program, which regularly conducts marine oil pollution patrols, has found that tugs may be the source of many of the small-scale oil spills off the coast of BC (O'Hara 2007).

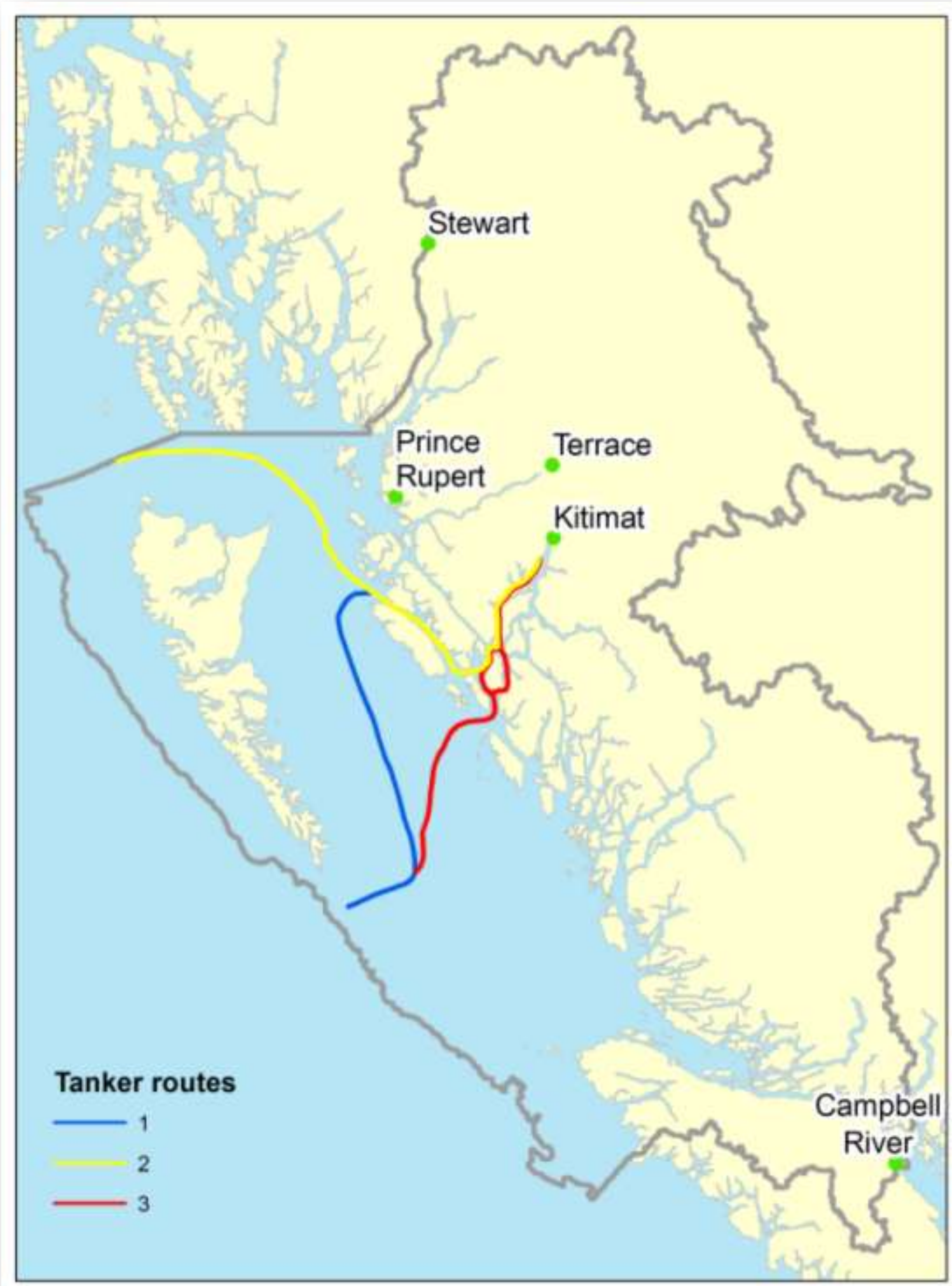

Figure 37. Proposed oil tanker routes through the Inside Passage to Kitimat (modified: Living Oceans Society 2007)

11.4. Monitoring

Pollution monitoring for vessel traffic consists of two parts:

- **Surveillance monitoring** – monitoring the movements of vessels and any damage they cause or pollution they release. This may involve using airplanes or satellites to track the movements of the large ships or oil spills.
- **Compliance monitoring** – the amounts of pollutants which ships are allowed to discharge into the marine environment are legally regulated. However, if these laws are not monitored and enforced, pollution discharges can and will occur.

11.5. Mitigation

The mitigation measures for sewage, oil spills, hazardous wastes, and ballast water have already been discussed in this report. The section that follows will look at mitigation measures for several of the other important impacts created by pollution associated with marine traffic.

11.5.1. Whale Watching Tours

In response to the impacts on marine life as a result of whale watching tours, the Department of Fisheries and Oceans has issued the following guidelines (DFO 2008c):

- **Be cautious and courteous**. Approach areas of known or suspected marine wildlife activity with extreme caution. Look in all directions before planning your approach or departure.
- **Slow down**. Reduce speed to less than 7 knots when within 400 meters of the nearest whale (**Figure 38**). Avoid abrupt course changes.
- **Keep clear** of the whales' path. If whales are approaching you, cautiously move out of the way.
- **Do not** approach whales from the front or from behind. Always approach and depart whales from the side, moving in a direction parallel to the direction of the whales (**Figure 38**).
- **Do not** approach or position your vessel closer than 100 meters to any whale (**Figure 38**).
- If your vessel is not in compliance with the 100 meters approach guideline, reduce your speed and cautiously move away from the whales
- **Stay** on the **offshore** side of the whales when they are traveling close to shore.
- **Limit** your viewing time to a recommended maximum of 30 minutes. This will minimize the cumulative impact of many vessels and give consideration to other viewers.
- **Do not** swim with, touch or feed marine wildlife.

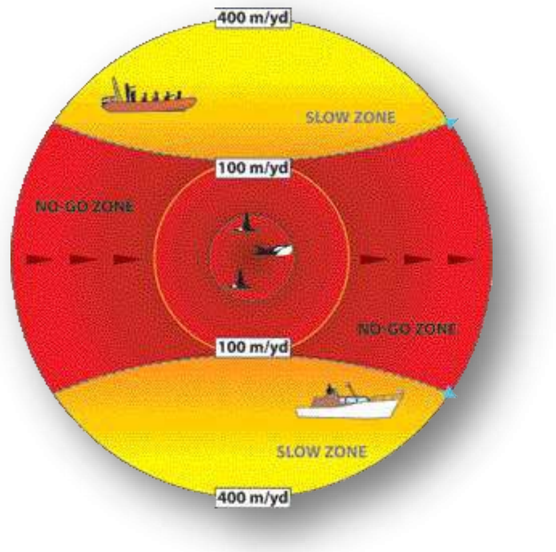

Figure 38. Whale watching zones (source: DFO 2008c).

11.5.2. Vessel Wakes

Boaters can reduce the impact of their boat's wake on sensitive shorelines by checking the wake being produced, particularly when they navigate near the shore (DFO 2004a). If a significant wake is being produced, then the speed of the boat needs to be reduced.

The hull designs of some large vessel can create wakes that are over a meter in height. The operators of these vessels need to be made aware of the damage that their wake can cause, and may need to operate at reduced speeds near sensitive habitats, human structures, or aquaculture sites.

11.5.3. Noise Pollution from Vessels

Some suggestions for mitigation of noise pollution from vessels are given in **Table 24**.

Table 24. Possible mitigation measures for sound pollution generated by vessels (modified: Stocker 2005).

Activity	Mitigation
Propeller noise	Quieter propeller technologies such as “vortex” drives, variable pitch drives and diesel electric and hydraulic “turret drives”
Hull radiated mechanical noise	Mounting equipment on resilient and sound attenuating mounting systems
Hull friction	Periodic hull cleaning; new hull designs and coatings
Seismic exploration using airgun blasting	Improved sensors and sensor information processing; refined targeting with electromagnetic and aerial thermal mapping
Active sonar	More sensitive receiving sensors; improved resolving algorithms; replace with satellite magnetic, thermal, radar, and laser scanning technologies

11.5.4. Small Vessel Mitigation Measures

The following is a list of possible actions that a small vessel owner can take to prevent marine pollution (BCMOE 2007d):

- Install a holding tank to avoid dumping sewage directly into designated waters.
- Use shore based holding tank pump-out stations.
- Use shoreside toilet facilities as much as possible.
- If no pump-out facilities are available, only release sewage in open waters which are not designated and that have good tidal flushing action. Do not release sewage near marinas or in bays, inlets and other sensitive areas such as shellfish leases.
- Create the demand for permanent or mobile pump-out facilities by letting marinas know that the service is needed and will be used.
- Do not throw trash overboard. Use shoreside recycling and garbage bins.
- Use biodegradable, phosphate-free cleaners instead of harmful chemical cleaners to clean the inside and outside of the boat. *All soaps are biodegradable (contain straight-chain hydrocarbons which can be broken down by bacteria); however, some synthetic detergents are not biodegradable (contain branched-chain hydrocarbons which cannot be broken down by bacteria). Today, most soaps and detergents are phosphate-free. Phosphate is not a significant problem in marine waters, where algal growth is usually limited by a lack of nitrogen; however, in fresh waters, algal growth is phosphorus-limited, and the addition of phosphate in wastewater can stimulate overgrowth of the algae.*
- Conduct major maintenance chores on land.
- When doing boat maintenance, use drop cloths to catch scrapings, paint chips, debris and drips and dispose of materials properly.
- Consider alternatives to copper-containing antifouling paints (silicone elastomers, photo-active coatings, wax-based products, polymers, teflon-based coatings, hard epoxy coatings, fluoropolymers, polyurethane, ceramic coatings (Georgia Strait Alliance 2008)).
- Keep motors well maintained and tuned to prevent fuel and lubricant leaks.
- Consider installing 4-stroke engines which are less polluting than 2-stroke engines. Use electric motors where practical.
- Use absorbent bilge pads to soak up minor oil and fuel leaks or spills.
- Report any spills to the Provincial Spill Reporting program at 1-800-OILS-911.
- Recycle used lubricating oil and leftover paints.

12. Pollution Associated with Offshore Oil and Gas Development

In BC, exploration for offshore oil and gas below the seabed began around 1958 (The Royal Society of Canada 2004). There are five sedimentary basins located off the BC coast that could contain reserves of oil and gas: (1) the Queen Charlotte Basin; (2) the Hecate Basin; (3) the Winona Basin; (4) the Georgia Basin; and (5) the Tofino Basin. Together, the Queen Charlotte Basin and the Hecate Basin underlie most of the PNCIMA (**Figure 39**). The Queen Charlotte Basin has the best prospects for oil and gas (Hannigan et al. 2001, Woodsworth 1991). In the late 1960s, interest grew in the oil and gas potential of the Queen Charlotte Basin. Eighteen exploratory wells (fourteen by Shell and Petro-Can) were drilled, and a number of seismic lines were run to investigate the potential (**Figure 39**).

Speculative estimates on the oil and gas potential of the Queen Charlotte Basin are 1.5 billion m^3 oil and 730 billion m^3 natural gas. Recoverable reserves, however, are more along the lines of 400 million m^3 oil and 550 billion m^3 natural gas. By comparison, the estimates for recoverable oil and gas reserves from the Queen Charlotte Basin amount to approximately 10% of Canada's current oil and gas production. The regions with the greatest oil and gas potential are, in order of importance, southern Hecate Strait, Queen Charlotte Sound, eastern Graham Island, northern Hecate Strait, and Dixon Entrance. No oil and gas potential is expected in the regions of western Graham Island, Moresby Island, Skidegate Channel, or on the continental shelf west of the Queen Charlotte Islands (Strong et al. 2002). Shell Canada, Chevron, Petro-Canada, Exxon Mobile, and Canadian Forest Oil all hold tenures in the PNCIMA (**Figure 40**).

At present, there are both federal and provincial 'moratoria' on exploration and development of offshore hydrocarbon resources in British Columbia. These 'moratoria' exist largely as a legacy of a variety of announcements going back over four decades. British Columbia has restricted offshore oil and gas activity since 1959, with the exception of a brief period from 1965 to 1966. The Province has issued three separate Orders in Council (1959, 1966 and 1981), reserving the seabed floor off the Queen Charlotte Islands and Vancouver Island to the Provincial Crown (Strong et al. 2002). In 1972, the Government of Canada apparently issued a federal Order in Council which established a moratorium on crude oil tanker traffic through Dixon Entrance, Hecate Strait and Queen Charlotte Sound as a result of concerns over potential environmental impacts. This federal moratorium was subsequently extended to include all oil and gas activities (The Royal Society of Canada 2004). However, extensive searching, apparently by many people, has not turned up any 1972 Order in Council, despite the fact that its existence is asserted in authoritative journals (Strong et al. 2002). In 1982, British Columbia issued an Order in Council which defined a provincial Inland Marine Zone, and established regulations which banned drilling in it. This was followed up by a Provincial announcement in 1989 that there would be no drilling for at least five years. In 1994, a new Order in Council and a new regulation removed any prohibitions on offshore drilling; however, the Provincial moratorium has not been formally lifted (Strong et al. 2002).

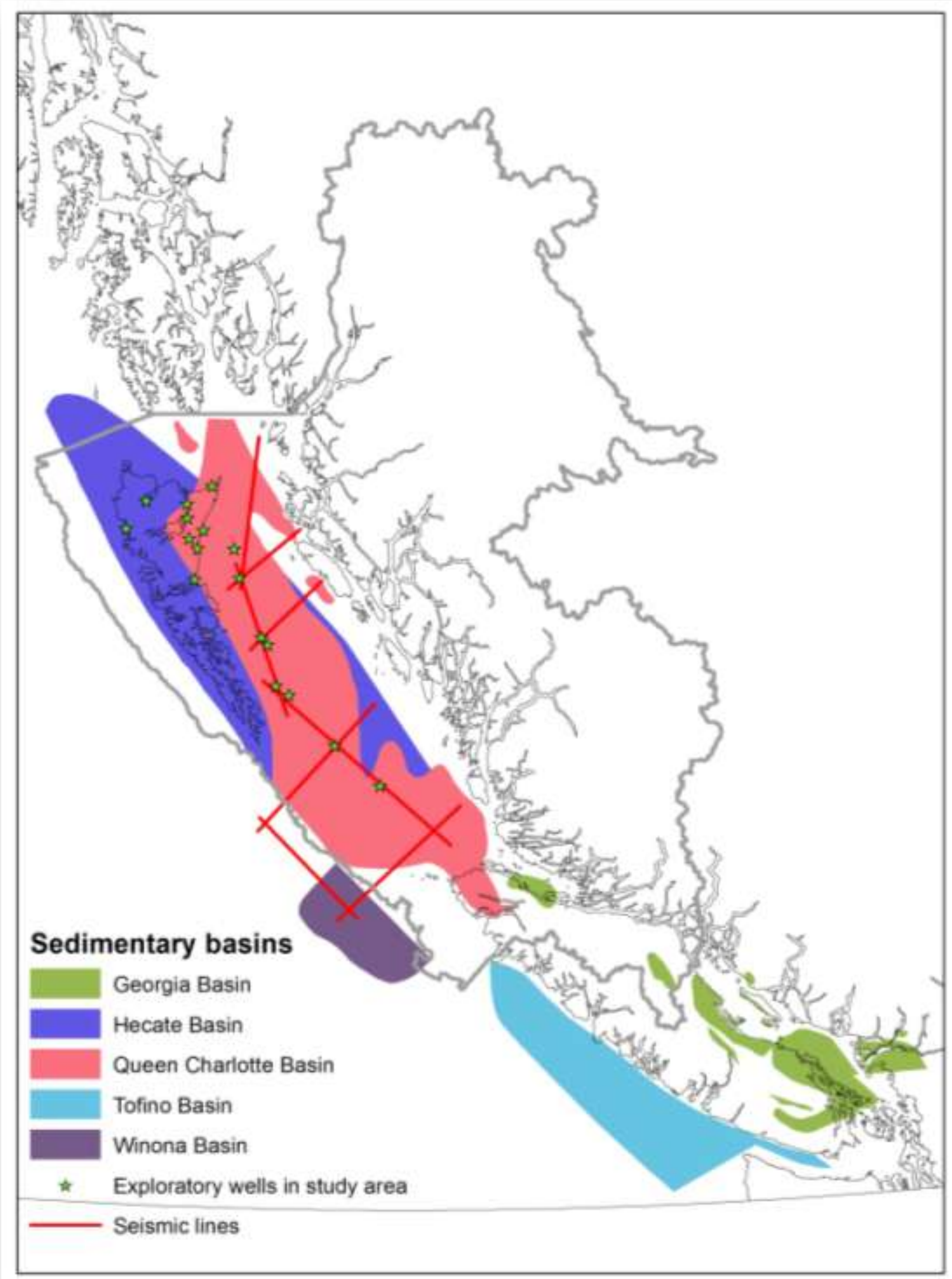

Figure 39. Sedimentary basins and oil and gas exploration activities in the PNCIMA (data: BCMEMPR 2008c, NRC 2008).

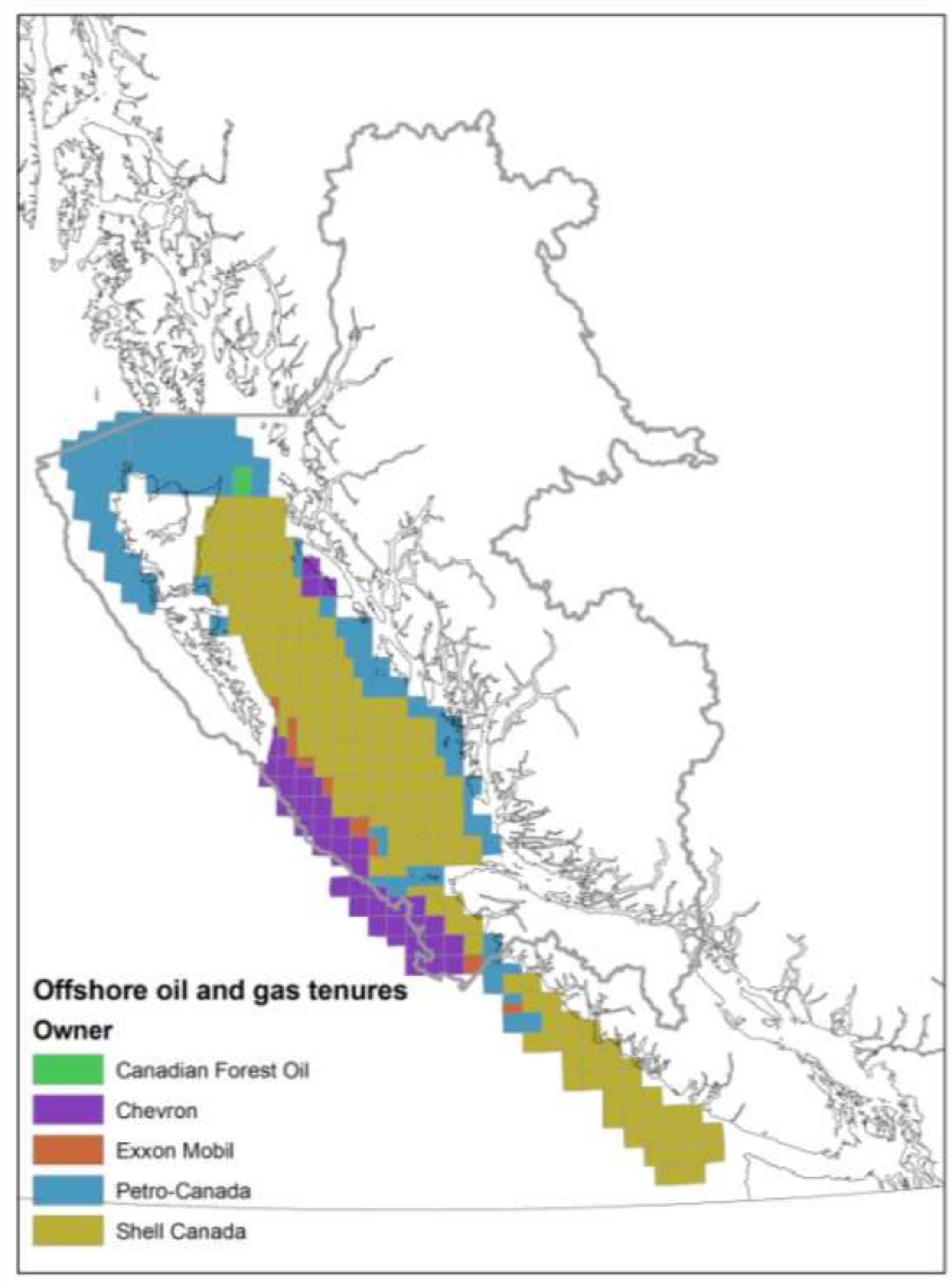

Figure 40. Federal oil and gas tenures (Canada petroleum tenures) in the PNCIMA (data: BCMEMPR 2008c).

A number of environmental impact reviews were completed in the 1980s (BCMOE 1983, Chevron Canada Resources Ltd. 1982, COGLA and BCMEMPR 1984, Petro-Canada 1983, West Coast Offshore Exploration Environmental Assessment Panel 1986). However, two subsequent coastal oil spills, the *Nestucca* (which spilled 227,000 gallons in 1988) off Gray's Harbour, Washington and the *Exxon Valdez* (which spilled 11,000,000 gallons in 1989) in Prince William Sound, Alaska, caused public concern, and no further exploration activities took place. Recently, the provincial and federal governments have begun to revisit these moratoria in light of new technologies and the rising price of oil and gas. This has prompted another series of reviews covering physical, oceanographic, geological, biological, social, and economic issues, as well as assessments of ecological and economic risk (Birtwell and McAllister 2002, Crawford et al. 2002, Cretney et al. 2002a, Cretney et al. 2002b, Cretney et al. 2002c, Jacques Whitford Environment Limited 2001, Jamieson and Davies 2003, Simon Fraser University 2000, Strong et al. 2002, The Royal Society of Canada 2004, Whiticar 2000, 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 (Strong et al. 2002, The Royal Society of Canada 2004). However, oil and gas exploration, development, and production have the potential to be significant marine pollution issues in the PNCIMA.

12.1. Pollution Sources

The main pollution concerns related to offshore oil and gas activity are (Haggarty et al. 2003, Johannessen et al. 2007a):

- oil spills (see section 11.1.7 of this report)
- increased shipping traffic (see section 11.1.1 of this report)
- potential noise pollution (e.g. from seismic activity and drilling) during the exploration and drilling phase of oil and gas development (see section 11.2.3 of this report)
- release of drilling mud during the drilling phase of oil and gas development
- release of produced water during production phase of oil and gas development

12.1.1. Drilling Mud

Drilling mud can be highly variable in nature, depending on the requirements of a particular site. The base substance of drilling mud is a liquid, such as water, diesel, or mineral oil. Bentonite is added to this base to form a stable colloidal suspension that has a slightly greater density than water. Bentonite consists of fine microparticles of the clay mineral montmorillonite, an aluminum silicate that flocculates (clumps) in water. Other components may be added to the mud produce certain properties (West Coast Offshore Exploration Environmental Assessment Panel 1986):

- Barite (barium sulfate) - for extra density
- tannins and lignosulfonates - for thinning
- caustic soda – for pH control
- biocides – for corrosion control
- carboxymethyl cellulose or starch - for gelling and filter cake properties

The primary functions of a drilling mud are as follows (West Coast Offshore Exploration Environmental Assessment Panel 1986):

- To counter-balance the pressure generated by oil trying to flow upwards to the surface, thus preventing blow-outs.
- To flush the rock cuttings out from under the bit and bring them to the surface.
- To prevent leakage (oil into the drill hole; drilling mud out of the drill hole) by sealing the permeable rock which forms the sides of the drill hole.
- To prevent cuttings from falling back down the hole and jamming the collars and bit.

Canadian regulations do not allow the discharge or oil-based or synthetic-based muds. Water-based muds can, however, be discharged (West Coast Offshore Exploration Environmental

Assessment Panel 1986). The fate of water-based muds has been modeled for the east coast, and these models may be applicable to the Queen Charlotte Basin (Crawford et al. 2002).

12.1.2. Produced Water

Produced water is the largest waste product generated by offshore oil and gas production activities. Produced water is water which is extracted from the well along with the oil and gas during the extraction process, and consists of (Haggarty et al. 2003):

- **formation water** - naturally occurring water in the geological formation. Formation water is a brine which derives its salinity from the major ions found in seawater. However, depending on the nature of the formation, it may also contain a number of organic and inorganic constituents of environmental interest, including:
    - heavy metals
    - organic chemicals including petroleum hydrocarbons
    - nutrients
    - radionuclides
- **injection water** – water which is injected into the well during the extraction process
- **condensed water** (gas production) or **seawater** (oil production) – water which is injected to maintain reservoir pressure
- **other technological waters** - treatment chemicals such as emulsion breakers, corrosion inhibitors, biocides, etc.

12.2. Environmental and Socio-Economic Impacts

12.2.1. Drilling Mud

Drilling mud is generally low in toxicity, but has a high density, which may lead to a smothering of benthic organisms. In addition, additives, such as biocides, can increase its toxicity significantly (Johannessen et al. 2007a).

Modeling the fate and effects of drilling mud discharges requires knowledge in five areas (Crawford et al. 2002):

- physical, chemical, and biological properties of the drilling mud and its components
- pathways by which drilling mud components move through the environment
- distribution (or partitioning) of the drilling mud between the different pathways
- toxicity of the drilling mud components to the organisms of interest
- physical and biological properties of the environment receiving the drilling mud discharges

Studies on biological effects have focused on the Atlantic sea scallop. It is a commercially valuable species which is susceptible to drilling mud discharges as a result of (1) its benthic lifestyle; (2) its limited juvenile mobility; and (3) its preferred habit of filter-feeding in the benthic boundary layer where drill waste concentrations are the largest. Since neither barite nor bentonite is thought to be highly toxic to scallops, these studies have looked at sub-lethal effects, such as impaired growth. Both barite and bentonite are present in the seawater as fine particles which negatively affect the scallop's ability to feed, thus reducing growth. Barite has an impact on scallop growth at much lower concentrations than bentonite for reasons that are not understood. Barite appears to affect marine organisms to a greater degree than its theoretical toxicity would suggest (Crawford et al. 2002).

At present, studies on the effects of drilling mud have assumed that most of the drilling mud fines remain in suspension in the water. The behavior and effects of drilling mud when it becomes deposited in the benthic sediments have not been studied. The impacts of the trace chemicals and metals in drilling mud have also not been investigated. It is believed that the risk of toxicity from these substances is negligible, as the released drilling mud will be sufficiently dispersed in the marine environment (Haggarty et al. 2003). However, it is possible that toxic or sublethal effects in biota could arise if a concentrating mechanism exists. Components of drilling mud could be concentrated by (Crawford et al. 2002):

- accumulation at the water-sediment interface
- accumulation at the air-water interface (e.g., in sea foam)
- accumulation in a local low energy environment (e.g., a quiet, sheltered bay)
- sequestering or binding of components to the sediments
- bioaccumulation

12.2.2. Produced Water

Modeling of the release of produced water on the east coast has generally shown that concentrations of chemicals in the water column are below lethal effects levels. However, very little work on sublethal effects, transport pathways of individual contaminants, or potential concentration mechanisms, such as particles adhering to oil droplets and rising to the surface, has been done (Crawford et al. 2002).

A recent study from Scandinavia examined sublethal effects of alkylphenols, a natural constituent of produced water, on cod. In controlled laboratory experiments, fish exposed to the levels of alkylphenols expected to be present in the vicinity of the production platforms showed evidence of reproductive impairment. In females, exposure to alkylphenols resulted in slowed egg development, leading to smaller egg size and a possible 3-week delay in spawning. Treated males had reduced testosterone levels, began to produce the egg-yolk protein vitellogenin, and produced fewer sperm than controls. A delay in spawning could also mean that the larvae would hatch after the plankton bloom had ended, thus further reducing the fitness of the larval cod by exposing them to potential starvation (Meier et al. 2001). Experiments such as these should be performed to assess the risk of produced waters on the west coast (Crawford et al. 2002).

Produced water may also contain a high level of nutrients (e.g. ammonia) and other constituents (e.g. hydrocarbons) that may increase bacterial growth, resulting in greater amounts of detritus sinking to the seafloor (Crawford et al. 2002).

12.3. Concerns in the North and Central Coast

The physical environment of the PNCIMA is very complex, with highly variable bathymetry, strong winds and currents, and high waves during storm events. The region is also one of high seismic activity, with the associated risk of slope failure and tsunami generation (Jacques Whitford Environment Limited 2001). Some of the physical challenges facing oil and gas development in the Queen Charlotte Basin are (The Royal Society of Canada 2004, University of Northern BC 2004):

- **Climate, wind, and waves**: While the overall climate is wet and mild, the Queen Charlotte Basin (QCB) experiences some of the most extreme wind and, therefore, wave conditions in Canada, especially in winter. Wind speeds average in excess of 35 km/h gusting up to 200 km/h at times. High winds can create very rough seas. Massive waves measuring up to 30 meters have occasionally been recorded in the area. The weather can be quite variable, and can change very suddenly. These sudden weather changes could have some significant effects on oil and gas operations.
- **Bathymetry and ocean currents**: Entering the QCB from the Pacific, water depths decrease from greater than 1000 meters to less than 400 meters. Water depths in the QCB average between 50 meters and 300 meters. The QCB has the highest tidal ranges in British Columbia, with up to seven meters difference between low and high tide in some areas. There are usually two high tides and two low tides per day. Tidal currents are strong. There are also non-tidal currents created by winds and river runoff.

Understanding the ocean currents is very important in trying to determine how pollutants might travel within the Basin.

- **The seabed**: The seabed in the QCB is very rugged and poses a number of hazards to oil rigs and wells, including unstable slopes (where underwater "landslides" can happen), shifting sediment, shallow gas pockets, and active faulting where subsea rocks can be broken by movements of the earth's surface. Unique sponge reefs – the only ones of their kind in the world – occur in the QCB.
- **Earthquakes and tsunamis**: Earthquakes occur frequently in and around the QCB. Most are close to the Queen Charlotte Fault, Canada's most active and powerful fault, just west of the Queen Charlotte Islands. There have also been quite a few earthquakes in the northern part of Hecate Strait along fault lines that are not well mapped. Extreme caution must be taken when drilling near active fault lines; however industry already avoids such areas and has developed safeguards specifically designed for this kind of drilling. A earthquake close to the QCB might create a tsunami (large waves caused by undersea ground movement) with little or no warning time. Fortunately, most earthquakes along the Queen Charlotte Fault do not produce large tsunamis.

The following list is some of the specific issues and concerns that have been brought forward by a number of the reviews that have been conducted on offshore oil and gas development in the Queen Charlotte Basin:

1. There is a consensus that significant scientific knowledge gaps exist regarding the impacts of offshore oil and gas development. Twenty-six areas have been identified where there knowledge gaps (Simon Fraser University 2000, The Royal Society of Canada 2004).
    - Identification of valuable species
    - Identification of unstable areas
    - Measurement of currents, winds, and waves
    - Earthquake monitoring
    - Impact assessment of acoustic propagation (sound traveling through the ocean)
    - Space-time distributions of fish
    - Identification of confined spawning areas for critical fish species
    - Space-time distribution of mammals
    - Impacts of seismic activity on diving birds
    - Baseline information on benthic fauna and habitat
    - Oil spill trajectories
    - Impact of oil spills on landfalls
    - Seasonal variation in species populations along shorelines
    - Proposed marine protected areas
    - Critical species close to shore
    - Areas of critical habitat
    - Identification of coastal zone buffers for drilling
    - Impact of water-based and alternative-based drilling muds
    - Impact of produced water
    - Behavior and toxicity of natural gas in marine environment
    - Long-term impacts of spills and recovery rates
    - Appropriate use of spill clean-up techniques
    - Cumulative environmental impacts
    - Ecological-level impacts
    - Oil spill risks
    - QCB ecosystem dynamics
2. Although improvements in technologies and management practices could continue to reduce the impacts, there is a consensus that offshore oil and gas development would have negative environmental affects. These affects would occur at all phases including exploration, development, production, and decommissioning. While some impacts are

local and short in duration, others affect larger areas and last longer (Simon Fraser University 2000).

3. The frequency and severity of oil spills is declining due to improvements in technology and management practices; however, small oil spills, defined as less than 1,000 barrels, are a common occurrence in offshore oil and gas development. A recent analysis for Cook Inlet in Alaska forecast a total of 484 small spills over the 25-year life of proposed offshore oil and gas development. The same analysis forecast that the probability of a large spill, defined as over 1,000 barrels, is 19% over the life of the project. Although probabilities vary depending on the magnitude of the project, the Cook Inlet probability forecasts are a reasonable order-of-magnitude indication of the oil spill risks for BC oil and gas development (Simon Fraser University 2000).
4. Oil spill clean-up measures are largely ineffective in mitigating the impacts of oil spills. Clean-up efforts on average recover 5-15% of the hydrocarbons and the clean-up process can itself cause additional environmental damage (Simon Fraser University 2000).
5. Recent research shows that the impact of oil spills lasts at least several decades. Recovery time from spills is therefore lengthy (Simon Fraser University 2000).
6. Offshore oil and gas development in the QCB would likely have greater negative impacts than it has in other regions because the QCB is more environmentally vulnerable. The QCB is largely an enclosed basin, so any oil spill originating within it is likely to be caught up in the internal circulation eddies, until it reaches the shore, probably within a few days. In addition, the coastal waters and shorelines are ecologically rich. Negative impacts can be expected on mammal, fish, and invertebrate populations (Simon Fraser University 2000).

12.4. Monitoring

Since many aspects of the physical, chemical, geological, and biological oceanography of the Queen Charlotte Basin are poorly understood, the following baseline monitoring has been strongly recommended (The Royal Society of Canada 2004):

- **Characterization of the spatial and temporal distribution of ecologically important, sensitive and harvested species in the QCB**: The logical place to start would be with those species already listed by COSEWIC as endangered, threatened, or of special concern (in keeping with legislation under the Species at Risk Act), as well as species that are of ecological importance, but about which little is known (e.g., sand lance), and important harvested species.
- **Swath bathymetric mapping**: Necessary to identify areas of seafloor instability associated with gas seeps, steep slopes and rapid sediment transport. Also essential in characterizing benthic environments for selection of representative monitoring sites, delineation of critical habitat, and the establishment of representative MPAs.
- **Measurement of near bottom currents**: These data are required to model environmental forces, sediment movement, and the transport of water-based drilling muds and cuttings during exploratory drilling.
- **Baseline studies of benthic fauna and habitat, including seabed sediment hydrocarbon and other chemical distributions, benthic community structure, and other appropriate indices of environmental stress**: These data allow the impacts of oil and gas activities to be assessed.
- **Drifter studies of winter surface currents, and spill trajectory modeling**: These data are essential for modeling the operation of drilling and production platforms, and for estimating oil spill trajectories.
- **Topographic modeling of winds**: These are needed so that site-specific estimates can be obtained of wind conditions at sea based on long-term observations of shore-based winds.
- **Strong motion seismograph measurements**: These data are needed to better characterize the ground motions associated with large earthquakes.

Additionally, it has been recommended that chemical and biological monitoring studies should commence as soon as possible at each of the following groups of sites (The Royal Society of Canada 2004):

- **Potential and past drill sites**: Sites representative of locations where drilling has taken place in the past or is likely to take place in the future (to allow detection of changes caused by drilling activities).
- **Control (or reference) sites**: Chosen to be representative of locations where drilling is unlikely to occur (to allow detection of trends caused by natural factors or factors unrelated to oil and gas activities).

12.5. Mitigation

Mitigation measures for offshore oil and gas development are complex and highly dependent on the location of the well site and the nature of the surrounding environment. Alaska, which has had significant experience with oil and gas development, has developed strong guidelines for the types of mitigation measures required. The list below gives some examples of the environmental and socio-economic mitigation measures that communities in the Aleutian Islands require from oil and gas leases in their region (Aleutians East Borough 2002):

- **Fisheries protection** – conflicts with prevent local commercial, subsistence, and sport harvest activities will be prevented by ensuring that:
  - adverse changes to the distribution or abundance of fish resources do not occur
  - fish or shellfish catches are not adversely impacted by oil and gas activities
  - all exploration, construction and operation activities will be coordinated with the fishing community to maximize communication, ensure public participation, and avoid conflicts
  - ballast water treatment is required to remove or eliminate non indigenous species
  - fishermen are not displaced or precluded from access to fishing areas, unless they are adequately compensated for the displacement
  - fishermen are not precluded from participating in designated fishing seasons, unless they are adequately compensated for the lost season(s)
  - fishermen will be compensated for damage to fishing equipment, vessels, gear and decreased harvest value from oil and gas operations in a timely manner
- **Transportation, utility corridors and infrastructure** – siting of transportation routes, utility corridors and infrastructure must ensure that:
  - there is free passage and movement of fish and wildlife
  - construction during critical migration periods for fish and wildlife is avoided
  - pipelines are be buried wherever possible
  - all structures except docks, roads, utility or pipeline corridors, or terminal facilities are located at least one-half mile from the coast, barrier islands, reefs and lagoons, fish bearing water bodies, and at least 1500 feet from all surface water drinking sources
- **Coastal habitat protection** - offshore operations must use the best available oil spill prevention and response technologies to prevent oil spills from adversely impacting coastal habitat
- **Local hiring and training** - a local hiring and training program is to be submitted prior to any exploration, production or permitting activity which provides plans for training, recruiting, and hiring of local residents, local contractors, and local businesses
- **Air pollution** – the best available emission control technology will be required for all industrial sources of air pollution
- **Water pollution** - a zero water pollution discharge will be required for all industrial operations
- **Marine mammals and essential habitat** - all onshore and offshore facilities and support vessel and air craft routes must be carefully sited to avoid marine mammal and essential habitat impacts

- **Social systems** - all onshore and offshore facilities must be sited, designed and operated to avoid adverse social system disruptions and impacts by ensuring that:
    - impacts on residential areas, privately-owned surface lands and native allotments are minimized
    - utilities, support services, and other community infrastructure and services are provided as needed to support local population increases resulting from oil and gas operations
    - communicate takes place with local residents, interested local community groups, and fishing organizations
- **Good neighbor policy** – oil and gas operators must:
    - provide cost effective fuel, power, transportation, medical services, emergency and other services to the local communities
    - minimize disruptions to subsistence activities and provides resources to relocate subsistence hunters and fishermen to alternate areas or provide temporary supplies if a spill affects the taking of subsistence resources
- **Cultural and historic site protection** - oil and gas operators must:
    - protect all existing cultural and historic sites
    - notify the local government as soon as possible about the discovery of prehistoric, historic and archaeological sites
- **Seismic design** - all onshore and offshore facilities must meet seismic (earthquake) design standards for the Aleutian Chain

13. Pollution Associated with Agriculture and Aquaculture

13.1. Pollution Sources

13.1.1. Agriculture

The Agricultural Land Reserve includes private and public lands that may be farmed, grazed, forested, or vacant. Some ALR blocks cover thousands of hectares, but others are small pockets of only a few hectares (BCMOE 2007c). In the PNCIMA, there is approximately 2.4×10^5 hectares of land in the Agricultural Land Reserve, or roughly 5% of the total ALR in BC. These agricultural lands are located primarily along the Skeena River valley and on Graham Island in the Queen Charlottes (Figure 41).

Agricultural land is used mainly for the production of food for human and livestock consumption. Agricultural activities also include growing plants for fiber and fuels (including wood), and for other products (e.g., pharmaceuticals, plant nursery stock) (BCMOE 2007c).

All agricultural land is not equally capable of producing agricultural products. The main limiting factors in British Columbia are climate, topography, and soils. Climate determines the heat energy and moisture available for agricultural production. Topography restricts the ability to use cultivation equipment (BCMOE 2007c).

Agricultural operations, if not properly managed, can discharge a wide range of contaminants, including (BCMOE 2007e):

- **Contaminants from manure and fertilizers**. Manure is a significant source of nitrogen, phosphorus, biochemical oxygen demand, and waterborne diseases. When too much manure or chemical fertilizers are spread onto fields for crop enhancement, excess nitrogen leaches into ground water or enters adjacent streams. Timing of manure spreading and other management practices can affect the severity of the impact. If spread in the late fall and early winter, when the plants' nutritional needs are the lowest, winter precipitation can carry ammonia, pathogens, and oxygen-demanding materials into nearby water bodies.
- **Pesticides.** Pesticides can contaminate water bodies by several routes, including spillage, improper storage, application into or near ditches and streams, leaching from soils, or washing away in runoff. Agricultural runoff can be a significant sources of pesticides in many areas, such as the Strait of Georgia and Puget Sound (Grant and Ross 2002).
- **Eroded soil particles.**

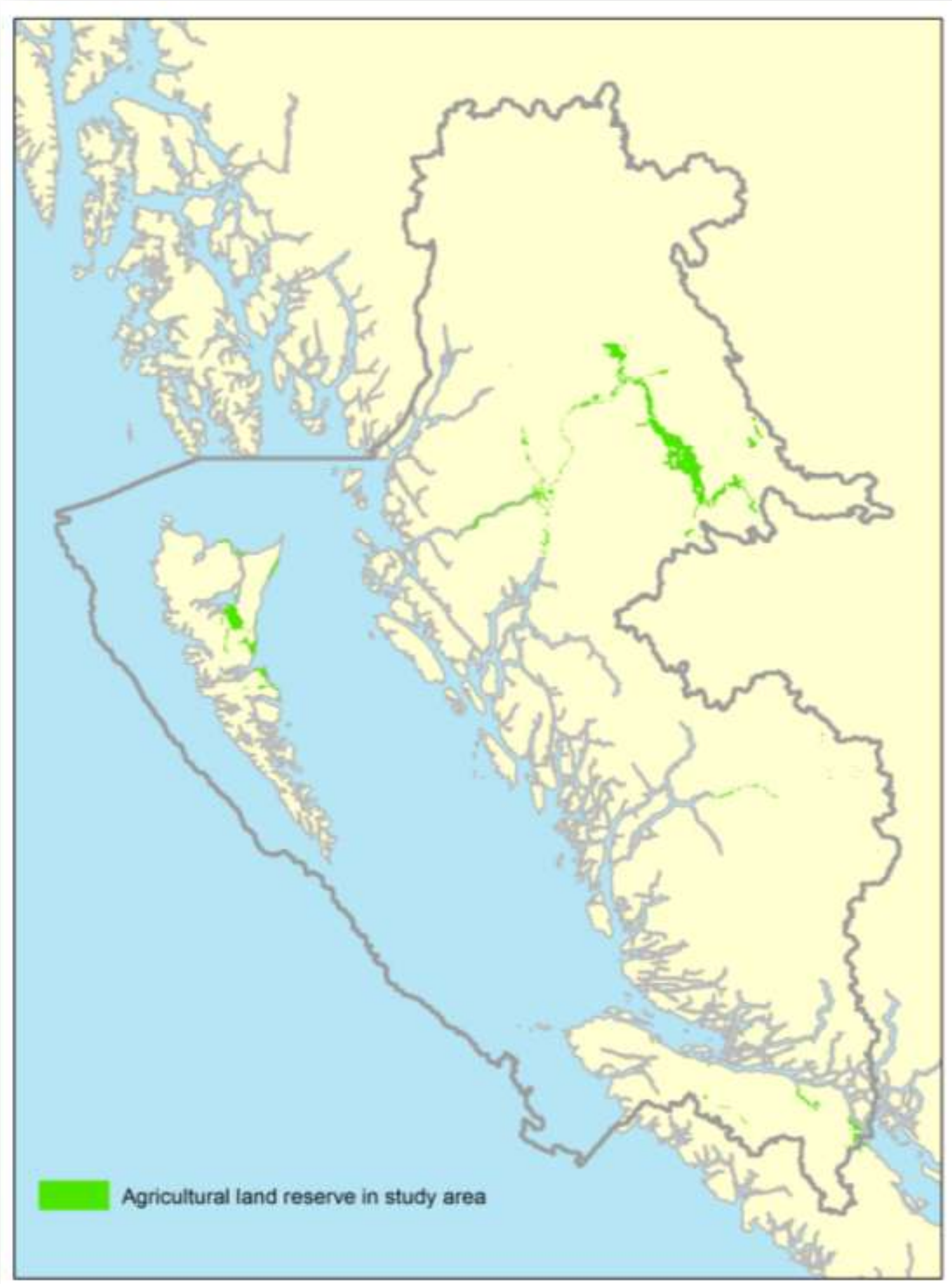

Figure 41. Agricultural land reserves in the PNCIMA (data: BCILMB 2008)

13.1.2. Intertidal Tenures

In BC, the intertidal area is owned primarily by the Crown. Activities permitted on Crown land are formalized by allocating tenures (leases, licences, and reserves) for a defined parcel of land for a specific period of time. Tenures in the intertidal and nearshore seabed include docks, intertidal shellfish aquaculture, nearshore finfish aquaculture, and floating fishing lodges. Conservation tenures are held by conservation and government agencies to protect areas with important ecological values (BCMOE 2007c). The activities which occur on economic tenures may be sources of marine pollution.

13.1.3. Finfish Aquaculture

Salmon aquaculture (fish farming) is a relatively small industry in coastal British Columbia. In 2005, the aquaculture industry generated $274 million of the province’s gross domestic product (GDP), or approximately 0.2% of the total. However, the industry has grown by nearly a factor of 100 since 1984, when its GDP was just $3 million. Most of the growth originated in the salmon farming industry, which dominates the aquaculture sector. Since 1984, the number of people working in the province’s aquaculture sector increased by nearly a third, rising to an estimated 2,100, or 0.1% of the total people employed in BC (BCMOE 2007a).

Most salmon aquaculture in BC consists of rearing Atlantic salmon in floating net pens or cages in the water. Salmon aquaculture produces both organic and chemical wastes. Other pollution issues include the transfer of disease and parasites from farmed to wild fish, the potential introduction of non-native species through the escape of Atlantic salmon (Gardner and Peterson 2003), the pollution of the wild salmon gene pool by the escape of farmed salmon, and noise pollution associated from anti-predatory devices (Hargrave 2003, Morton and Symonds 2002). As a result of these issues, a moratorium on the expansion of fish farming was put in place between 1995 and 2002 (Haggarty et al. 2003). While this moratorium has been lifted for most of the BC coast, a new moratorium has recently been put in place which will not allow any fish farm applications or issuance of licenses for coastal waters north of Klemtu (CBC News 2008). Improvements in environmental siting criteria, technological advances, and best management practices seem to have helped to regulate the industry and reduce or mitigate many of the impacts (Nash et al. 2000).

13.1.4. Shellfish Aquaculture

Commercial shellfish aquaculture has been occurring on the BC coast since the early 1900s (Jamieson et al. 2001). The most commonly cultured species are clams and oysters, although farming techniques for scallops, mussels, and abalone are being developed (Haggarty et al. 2003).

13.2. Environmental and Socio-Economic Impacts

13.2.1. Agriculture

The most worrisome contaminants from agricultural runoff are ammonia, nutrients, pathogens, and sediments. Land application of manure can help increase crop productivity, but when improperly applied, applied in excess of crop uptake, or improperly stored, it can be very damaging to the environment. Human health risks are a concern because of pathogens and nutrients (nitrates) which can contaminate drinking water. Water which is contaminated will also be unpalatable to livestock. Excess nutrients can also have an impact on water quality and fish habitat, causing excess algal and plant growth, and decreasing dissolved oxygen levels. Manure runoff also contains high levels of ammonia which is toxic to fish (BCMOE 2007e).

13.2.2. Intertidal Tenures

Estuaries in BC account for less than 3% of the province's coastline; however, these productive and diverse habitats are vitally important to many species (BCMOE 2007c). Estuaries are essential habitat for salmon, and it is estimated that 80% of all coastal wildlife use estuaries (Kelsey 1999).

In 2004, the Canadian Wildlife Service of Environment Canada and Ducks Unlimited Canada mapped 442 of the larger estuaries on the BC coast, and compiled the land tenure data for 440 estuaries. Of the 440 mapped estuaries, it was found that more than a third (38%) had some type of economic tenure allocated in the intertidal area (**Table 25**, **Figure 42**). Fewer estuaries (28%) had conservation tenures; however, the total conservation area was more than three times the area under economic tenure. Where conservation tenures exist, they usually occupy a large proportion of the intertidal area. More than half of the total estuary intertidal area had no tenures of either type. Many of these areas have important environmental values that should be assessed as part of estuary conservation planning (NRTEE 2008, Ryder et al. 2006).

Table 25. Status of economic interest tenures and conservation tenures for 440 estuaries in BC, by ecoregion (BCMOE 2007c).

	Number of estuaries (% of total)			**Intertidal area (ha) (% of total)**			
Ecoregion	Total	With economic tenures	With conservation tenures	Total	With economic tenures	With conservation tenures	With no tenures
Coastal Gap	140	37 (26%)	31 (22%)	15,949.6	886.8 (6%)	4,132.5 (26%)	10,930.3 (68%)
Eastern Vancouver Island	33	23 (70%)	15 (45%)	4,603.6	824.4 (18%)	954.8 (21%)	2,824.4 (61%)
Lower Mainland	9	5 (56%)	2 (22%)	653.6	26.6 (4%)	298.7 (46%)	328.3 (50%)
Northern Coastal Mountains	13	4 (31%)	2 (15%)	746.5	163.6 (22%)	131.9 (18%)	451 (60%)
Pacific Ranges	73	41 (56%)	17 (23%)	5,437.3	275.6 (5%)	1,683.9 (31%)	3,477.8 (64%)
Queen Charlotte Lowlands	15	3 (20%)	9 (60%)	2,393.0	165.7 (7%)	1290.7 (54%)	936.6 (39%)
Queen Charlotte Ranges	32	7 (22%)	4 (13%)	826.3	92.6 (11%)	37.8 (5%)	695.9 (84%)
Hecate Continental Shelf	1	0 (0%)	0 (0%)	0.1	0.0 (0%)	0.0 (0%)	0.1 (100%)
Western Vancouver Island	124	44 (35%)	43 (35%)	4,359.7	364.8 (8%)	1,542.7 (35%)	2,452.2 (57%)
Total	440	164 (38%)	123 (28%)	34,969.7	2,800.1 (8%)	1,0073 (29%)	22,096.6 (63%)
Georgia Basin	67	39 (58%)	30 (45%)	5,768.7	876.4 (15%)	1,397.8 (24%)	3,494.5 (61%)
Outside Georgia Basin	373	125 (34%)	93 (25%)	29,201	1,923.7 (7%)	8675.2 (30%)	1,8602.1 (64%)

Notes: The number of estuaries for the Lower Mainland excludes the Fraser River and the Serpentine/Nicomekl River, which were not evaluated. The Georgia Basin includes all or part of the following ecoregions (number of estuaries within Georgia Basin in parentheses): Eastern Vancouver Island (26); Lower Mainland (9); Pacific Ranges (21); Western Vancouver Island (11); total 67.

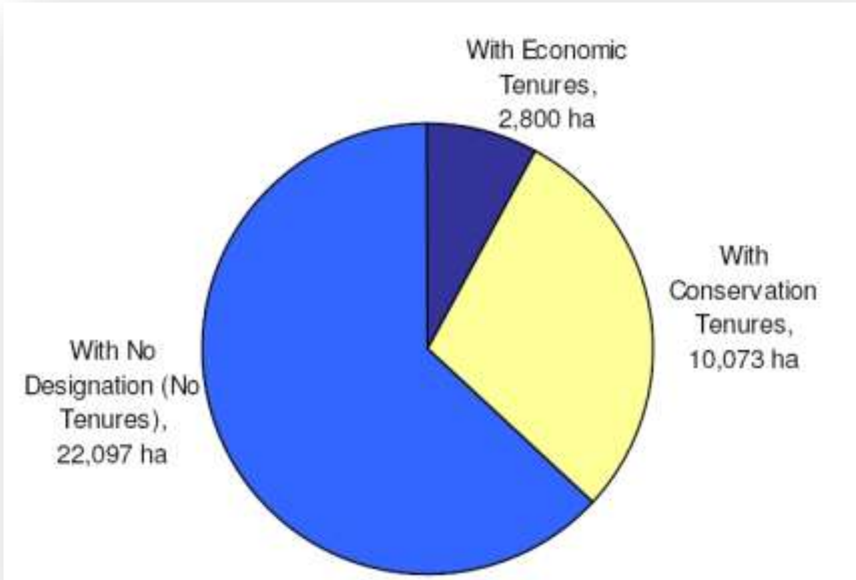

Figure 42. Area (ha) of economic and conservation tenures in 440 estuaries in BC (source: BCMOE 2007c, Ryder et al. 2006)

13.2.3. Finfish Aquaculture

Several of the major environmental concerns with fish farms are:

Organic wastes

One of the most prevalent concerns with respect to salmon aquaculture is the production of organic wastes. Sources of these wastes include excess feed, fish feces and urine, and fish carcasses (Chamberlain et al. 2005, Haggarty et al. 2003). In addition, biofouling organisms growing on the net cage structures can frequently be dislodged and released into the environment (Haggarty et al. 2003).

It has been estimated that approximately 5% (Gillibrand et al. 2002) to 20% (Gowen et al. 1989) of salmon feed goes uneaten, and that 4% is released into the water column as feces (Nash et al. 2000). Thus, there are higher concentrations of suspended particulates at aquaculture sites than in the surrounding environment (Sutherland et al. 2001). Recent advances in feed and feeding practices by the finfish aquaculture industry have decreased the nutrient load per tonne of fish produced (Hardy and Gatlin 2002). However, as a result of the expansion of the salmon aquaculture industry, the nutrient loads in 2004 appear to be 80% higher than nutrient loads in 2000 (BCMOE 2006b).

Originally, it was believed that the impacts from organic waste were generally limited to the benthic environment within several hundred meters (near-field) of net pens (Brooks and Mahnken 2003, Gowen and Ezzi 1991). However, more recently research has shown that the impacts of increased nutrient addition from re-suspended organic waste particles, coupled with dissolved organic wastes, may have wider (far-field) impacts. These effects range from eutrophication (when increased nutrients lead to excessive plant growth and depletion of oxygen in the water) to effects on the marine food web at distances farther from farm sites (Hargrave 2003, Strain 2005, Strain and Hargrave 2005).

Some researchers estimate that approximately 30 g of nitrogen and 6.7 g of phosphorus are discharged for every kilogram of Atlantic salmon produced (Nash et al. 2000). Increased nitrogen and phosphorus loads can alter the existing nutrient ratios, thus causing the species makeup of the phytoplankton community to change. 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). High nitrogen and phosphorus loads relative to silica can produce blooms of toxic dinoflagellates (Holby and Hall 1994).

While the tidal currents at many aquaculture sites on the BC coast are strong enough to dissipate and mix nutrients so that they will not reach harmful concentrations (Nash et al. 2000), some sites may be vulnerable to nutrient enrichment. Fish farms in relatively enclosed, low-flow areas have been associated with measurable increases in nutrients and associated eutrophication (Gowen and Ezzi 1992, Persson 1991). Models are being constructed to understand the effects that salmon farms have on the environment at a distance, which could then 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 particulates settle to the ocean floor, enriching the sediment with organic matter, as well as nitrates, phosphates, and ammonia. This enrichment can significantly alter the biogeochemistry of the benthic sediments (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). Since enriched sediments contain high concentrations of organic matter, they stimulate bacterial activity. In low oxygen environments, bacteria may reduce the sulfate present in the sediments. This creates toxic sulfides, which can accumulate to levels that are lethal 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). Sulfides can also interact with other elements to exacerbate hypoxia (low oxygen) and anoxia (no oxygen) conditions in the sediments, 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). The changes associated with sediment enrichment can last from several months to several years once the site ceases operation (Brooks and Mahnken 2003); in some cases, effects have been shown to last for 4 to 7 years (Brooks et al. 2004).

Chemical contaminants

Chemical use is widespread at finfish aquaculture sites in Canada, and can be divided into two categories:

Intentionally introduced chemicals

Chemicals that are used intentionally include feed additives, chemotherapeutants, disinfectants, and pesticides (Haggarty et al. 2003).

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 feed additives include zinc, color additives, and vitamins (Johannessen et al. 2007a):

- **Zinc** - zinc is used to prevent cataracts in juvenile fish (Sutherland et al. 2001). The toxic effects of zinc in the environment are not well known. However, provided that sufficient fallowing time is allowed for all the organic matter in the sediments to be degraded by bacteria, zinc does not appear to accumulate in the sediments (Brooks et al. 2003).

- **Color additives -** in the wild, the red color of salmon flesh results from the salmon consuming crustaceans such as euphausiids, from which they get red-colored carotenoids (e.g., astaxanthin). To produce this flesh color in farmed salmon, feed pellets are usually supplemented with astaxanthin, or a related carotenoid called canthaxanthin (Nash 2001). These compounds are unlikely to affect non-target organisms (Zitko 1994).
- **Vitamins** - vitamins, including biotin and vitamin B12, are added to fish feed (Haggarty et al. 2003). The use of vitamins is believed to be environmentally safe (Nash 2001).

There are several chemotherapeutants used in the finfish aquaculture industry, administered either in feed or as a bath (Burridge 2003). Traces of these drugs may be observed up to 100 m from aquaculture sites in measurable concentrations for up to 18 months. Chemotherapeutants may create drug resistance in native microbial populations. In addition, other species may be attracted to the farm for food and protection from predators, thereby risking exposure to chemotherapeutants (Hargrave 2003).

- **Chemotherapeutants used to treat diseases** – drugs 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 to treat diseases such as vibrosis, furunculosis, and bacterial kidney disease (Haggarty et al. 2003)
- **Chemotherapeutants used to treat sea lice:**
  - Emamectin benzoate (SLICE®) is used to treat sea lice infestation. SLICE® is less toxic than Ivermectin, and has been approved for use in many countries, including Canada. SLICE® is only authorised by Health Canada on a case by case basis under the Emergency Drug Release (EDR) program (CFIA 2007). SLICE® is administered to fish either as medicated food pellets or as a bath (Haggarty et al. 2003, Johannessen et al. 2007a). 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 in the tarpaulin. 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). SLICE® accumulates in sediments and has a half-life of 175 days. Studies to determine the environmental effects of SLICE® around finfish farms in Scotland found low concentrations of the compound, but no adverse effects were observed on the infaunal community or on organisms in the water column (Nash 2001, Wildish and Pohle 2005). The effects of SLICE® on Dungeness crabs and prawns from BC have been studied in the laboratory. No toxic effects were observed for either species since they both avoided feeding on the medicated pellets (van Aggelen 2002). Further research is needed to determine possible sub-lethal, synergistic (multiple compounds together causing higher toxicity), and/or cumulative effects of SLICE® on the marine ecosystem (Johannessen et al. 2007a).
  - Dichlorvos (Cyprimethrin®) is under temporary registration in Canada, and is also administered in a bath. It is adsorbed onto sediments, where it has a half-life of 35 days. It can be acutely toxic to crustaceans. The Scottish Environmental Protection Agency concluded that toxic effects to non-target species could occur within a few hundred meters of a treated farm and may last for several hours. High mortalities of shrimp and

lobster have been observed when they are exposed to a bath of dichlorvos; however, the effect has not been observed outside net pens. Dichlorvos is considered to be less toxic than azamethiphos (Nash 2001).

- o Azamethiphos, an organophosphate insecticide, is currently the only product approved for use in Canada by the Pest Management Regulatory Agency. Azamethiphos is a neurotoxin, and its effects have been studied on various invertebrates in the laboratory. Azamethiphos is toxic to crustaceans, including lobster and shrimp, but not to bivalves. Earlier larval stages of lobster are more resistant to the chemical than later stages. The sub-lethal effects of azamethiphos on lobster have also been investigated, and a significant reduction in spawning by female lobster exposed to azamethiphos has been observed. Some of the exposed lobsters died, while others reabsorbed their eggs. Those that did spawn produced normal amounts of eggs, and all clutches reached the eyed stage (Haggarty et al. 2003).
- o Ivermectin is a pesticide delivered in fish feed to treat sea lice. Unfortunately, the treated feed pellets are also consumed by the non-target Atlantic sand shrimp. Ivermectin is lethal to shrimp at concentrations below the recommended treatment dosage (Haya et al. 2001). Ivermectin has also been found to be toxic to polychaetes and nematodes (Nash 2001).
- o Teflubenzuron (Calicide®) is also registered for use to treat sea lice infestation (CFIA 2007). Calicide® is a chitinase inhibitor that is administered as a coating on food. It is not very soluble, accumulates in sediments, has a half-life of 115 days, and has been detected up to 1,000 m downstream from a farm. No adverse effects have been detected on the benthic community in a study by the Scottish Environmental Protection Agency. Since Calicide® inhibits chitinase, it is not toxic to organisms other than arthropods (Nash 2001).

Unintentionally introduced chemicals
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):

- **Antifouling chemicals** – these chemicals, which prevent the colonization of underwater structures by sedentary biota, are 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).
- **Wood preservatives** - pentachlorophenol (PCP) is a persistent chemical used as a wood preservative for structures at aquaculture sites (Levings 1994). Although this may not lead to contamination of food webs, PCP may present a threat to some species (Johannessen et al. 2007a).
- **POPs** - 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 2001). 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 have a tendency to bioaccumulate and biomagnify (Haggarty et al. 2003). As a result of predation on farmed salmon by birds and marine mammals, these contaminants could represent health risks to higher trophic levels (Nash 2001).

Sea lice

Farmed salmon are susceptible to parasitic copepods, also called sea lice (Haggarty et al. 2003). Epidemics of parasitic copepods have caused significant losses to the industry, and have been implicated in transferring sea lice to wild smolts, particularly in the Broughton Archipelago (Gardner and Peterson 2003, Haya et al. 2001). Sea lice feed on the mucus, blood, and skin of the host fish, and cause fin damage, skin erosion, hemorrhaging, lesions, and in extreme cases, death from ulceration and a failure to osmoregulate. They may also increase stress levels in the fish, and cause immune suppression, thereby increasing susceptibility to other diseases (Gardner and Peterson 2003).

Causality in the spread of sea lice from farmed fish to wild fish in British Columbia has not yet been proven to the highest standard of scientific scrutiny. However, the combination of scientific results from Europe, preliminary studies of lice on juvenile salmon in BC, and knowledge of sea lice-salmon dynamics presents a body of compelling evidence that sea lice from salmon farms do impact wild salmon. The main areas of uncertainty relate to how large or severe impacts will be, rather than to whether or not they will occur. Improvements in fish health management at the farms will reduce, but not eliminate, the potential for transfer of lice to wild salmon. Despite the natural prevalence of sea lice, wild salmon, particularly smolts, are vulnerable to them. In heavy infections, death results from erosion of the skin of the fish. Other possible consequences include premature return to spawning and reduced seawater growth (Gardner and Peterson 2003).

Bacteria.

Wild Pacific salmon are generally well adapted to the bacteria found in BC's coastal waters – they have a natural resistance to enzootic (naturally occurring) bacteria. Bacteria can, nevertheless, negatively affect their health. There is concern over the potential for transfer of furunculosis from farmed to wild salmon. The effective use of vaccines on farmed fish substantially reduces this risk (Gardner and Peterson 2003).

Viruses.

The potential of viral pathogens from farms to increase the infection of wild fish is reduced by the natural resistance of Pacific salmon to enzootic viruses. At present, there is no evidence that the viruses causing diseases at farms have had negative effects on wild salmon. However, migrating salmon could be exposed to viruses, such as infectious hematopoietic necrosis (IHN), from farms at levels higher than those to which they are accustomed. In other parts of the world, infectious salmon anaemia (ISA) has been found to transfer from farms to wild fish. Good husbandry and lower stocking densities on the farms can make farm fish less vulnerable to infection, and thus reduce the likelihood that salmon farms will act as reservoirs of viruses. Efforts to control viral outbreaks are currently limited by a lack of effective treatments (Gardner and Peterson 2003).

Escapes.

- **Genetic risks related to escapes** - genetic impacts on wild salmon (via reduction of diversity and through interbreeding) could occur as a result of farmed salmon-wild salmon interaction. In BC, the risk would be high from Pacific to Pacific interbreeding, and extremely low from Pacific to Atlantic interbreeding. Overall, risk of genetic introgression (gene flow between distinct populations) between wild Pacific salmon stocks and domesticated farm fish of the same species is the most serious escape consequence (Gardner and Peterson 2003).

- **Ecological risks related to escapes** - Atlantic and Pacific escapees are both capable of disrupting wild salmon habitat and spawning behavior, and competing with wild salmon for food and space. While establishment of feral Atlantic salmon populations in BC could occur with minimal ecological impacts on wild salmon, it remains to be determined what the actual extent of these impacts would be. Salmonids other than Pacific salmon (i.e., steelhead and trout) could be more seriously impacted.
- **Disease risks related to escapes** - the numbers of potentially diseased, escaped salmon are so low relative to the numbers of wild salmon that the potential for disease transmission is also very low. However, the issue of transfer of non-endemic (exotic) diseases could be a serious concern (Gardner and Peterson 2003).

13.2.4. Shellfish Aquaculture

The shellfish aquaculture industry does not require the use of chemicals to the same degree as seen in the finfish aquaculture industry. No pesticides are used in shellfish aquaculture (Jamieson et al. 2001). The main source of chemical contaminants appears to be occasional use of antifouling compounds, and the application of these substances must be strictly monitored in order to protect the farmed species.

One of the major concerns regarding shellfish aquaculture is the risk of infection (Bower and McGladdery 2003). Farms may form a reservoir for bacteria and viruses as a result of limited water exchange, high stocking densities, artificial feeding regimes, and accumulation of dead and/or dying larvae. Although the shellfish aquaculture industry does not use antibiotics to the same extent as in finfish aquaculture, there is concern that even limited use of antibiotics may cause the development of drug resistance in pathogenic bacteria (Boyd 1999).

Another potential issue is the possibility that through grazing, bivalves may be able to affect entire coastal ecosystems by reducing phytoplankton biomass. While this theory has been supported by laboratory and field observations, it has not been proven (Cranford et al. 2003).

Physical and biological disturbance of the subtidal area by shellfish aquaculture can also create environmental concerns. Typical activities include the use of antipredator netting over extensive areas and modification of the sediments by adding cobble material to make them more suitable for the aquaculture species. By altering the natural ecosystem to suit the needs of the aquaculture species in question, the natural diversity of the area may be restricted (Johannessen et al. 2007a).

13.3. Concerns in the North and Central Coast

13.3.1. Agriculture

Since very little agriculture takes place in the PNCIMA, agricultural runoff occurs on a relatively limited scale. However, in those areas where agriculture does take place, pollution from agricultural runoff can be locally significant.

13.3.2. Finfish Aquaculture

Figure 43 shows the distribution of finfish aquaculture sites throughout the PNCIMA. There are 84 sites located in the region, with the majority of them located in south, particularly in the Broughton Archipelago, the Queen Charlotte Straits, and the Quatsino/Holberg Inlet complex.

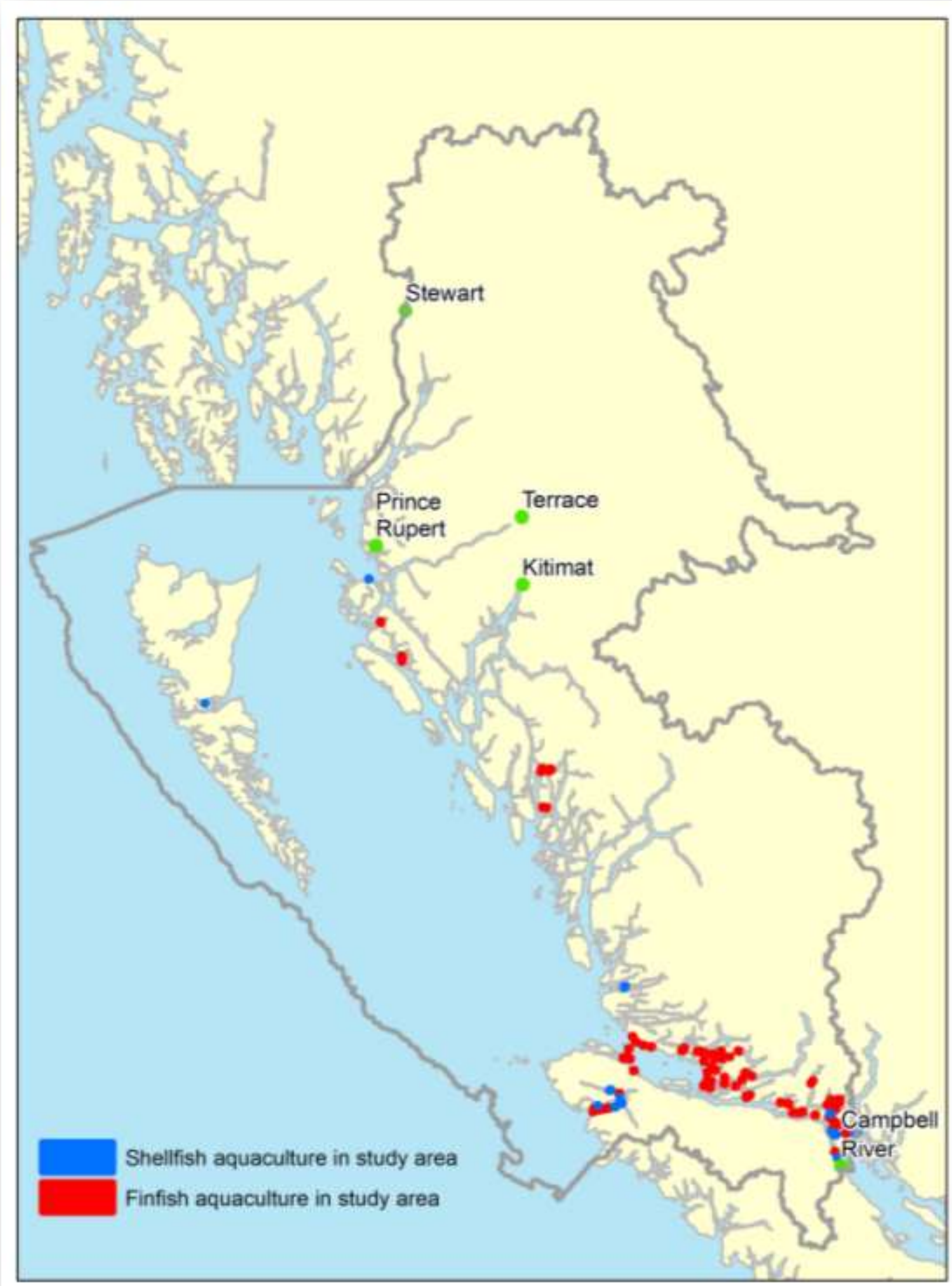

Figure 43. Location of shellfish and finfish aquaculture sites in the PNCIMA (data: BCILMB 2008).

Of the 84 sites, 75 were active as of December 2006 (the remainder were inactive or fallowed). 74 of the active sites had aquaculture licenses for Atlantic salmon. Of these 74, 33 were licensed only for Atlantic salmon. The other active sites had licenses for multiple species - 35 sites were also licensed to grow Chinook salmon and 7 sites were also licensed to grow Coho salmon (BCMAL 2006).

As a result of the recent moratorium on fish farms north of Klemtu (CBC News 2008), the farm sites located in the vicinity of Pitt Island will not be developed in the near future. However, there is still serious concern regarding the impact of Atlantic salmon farms on the survival of pink salmon in the Broughton Archipelago (Krkosek et al. 2006). Recently, the Pacific Salmon Forum, a research group funded by the provincial government, has agreed with published research suggesting that sea lice from salmon aquaculture farms in the Broughton Archipelago may cause the extinction of pink salmon in that region within 4 years (The Vancouver Sun 2008).

13.3.3. Shellfish Aquaculture

Figure 43 shows the distribution of shellfish aquaculture sites throughout the PNCIMA. There are 38 sites located in the region, mostly around Campbell River and the Quatsino Sound/Holberg Inlet complex. There is also some limited active shellfish aquaculture currently occurring on BC's North Coast. 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. As part of this initiative, shellfish pilot projects are underway at 15 sites on the north coast and Queen Charlotte Islands (BCMAL 1998).

The North Coast Water Quality and Biotoxin Program Society (Biotoxin Program) coordinates marine biotoxin and water quality monitoring and testing services on the North Coast of British Columbia. Based in Prince Rupert, the Biotoxin Program is a non-profit society that consists of representatives from local First Nations and non-First Nations communities, shellfish farmers, scientists, economic development groups, and provincial and federal governments. The program currently has 26 monitoring stations run by volunteers in the following locations (North Coast Water Quality and Biotoxin Program Society 2007):

- Humpback Bay (shellfish lease site)
- Kagan Bay (shellfish lease site)
- Metlakatla (Tsimshian)
- GitxaaLa (Tsimshian)
- Kitamaat (Haisla)
- Lax Kw'alaams (Tsimshian)
- Gitga'at (Tsimshian)
- Haida Gwaii (Recreational)
- Kitsumklaum (Tsimshian)
- Portland Inlet (Nisga'a)

Figure 44 shows the locations of these monitoring stations. These stations provide coverage for areas where potential interest in shellfish aquaculture or wild shellfish harvest may exist. The Biotoxin Program also receives food, social and ceremonial (FSC) samples from approximately eight locations and several communities (North Coast Water Quality and Biotoxin Program Society 2007).

Figure 44. Location of biotoxin monitoring stations in the Northcoast region.

At present, two commercial sites exist on the North Coast - Humpback Bay Oysters at Humpback Bay on Porcher Island and QCI Shellfish Co. at Kagen Bay in Skidegate Inlet. Growth of a shellfish industry on the North Coast has been hampered by a lack of infrastructure.

On April 27, 2001, Humpback Bay became the first area on the North Coast to be classified as open by DFO. Humpback Bay was first surveyed by Environment Canada (EC) in June 1998, and EC has been conducting regular water quality monitoring since. On September 28, 2001, Humpback Bay Oysters delivered its first commercial shipment of oysters to Prince Rupert. A local plant was certified by CFIA to process shellfish; however, it went into receivership in mid-December 2001. Humpback Bay Oysters has not been able to sell product since, due to the lack of a certified local plant (North Coast Water Quality and Biotoxin Program Society 2007).

QCI Shellfish Co. focuses on scallops as their main product. Fortunately, two plants in Masset (CB Island and Omega) were already certified for shellfish to meet the needs of the existing razor clam industry on Haida Gwaii, and were able to process the product generated by QCI Shellfish Co. (North Coast Water Quality and Biotoxin Program Society 2007).

Early in 2003, the Tsimshian Stewardship Committee, with funding from the Provincial and Federal Governments, and with the assistance of Ecotrust Canada and Kingzett Professional Services, began a pilot project in the Tsimshian communities of Lax Kw'alaams, GitxaaLa, Gitga'at, and Metlakatla to further investigate shellfish mariculture development on the North Coast. Rafts were constructed in each community in June 2003, and the growth rates of several species of shellfish and kelp were measured. Another group, Turning Point, conducted similar projects in Kitamaat, Haida Gwaii, and along the Central Coast. Since April 2003, these two groups have been working together (North Coast Water Quality and Biotoxin Program Society 2007).

13.4. Monitoring

13.4.1. Agriculture

Water quality in water bodies near agricultural sites should be sampled at the beginning of rain events when runoff starts. The first heavy rains in the fall (first flush) will usually have the highest concentration of contaminants. The following parameters should be measured (BCMAF 1994):

- dissolved oxygen (in the field)
- temperature (in the field)
- pH (in the field or lab)
- lab NH_4-N (in the lab; calculate NH_3-N from tables using pH and temperature)
- acidity (in the lab at pH 8.3 if wood waste is a concern)

If any of the above is at levels that create a concern, the following parameters should also be checked:

- iron (Fe) and resin acids (tannins and lignins) if wood waste contamination is suspected
- fecal coliforms, and NO_3-N if manure contamination is suspected
- COD (chemical oxygen demand) and/or BOD (biochemical oxygen demand) if the source of contamination is unknown

Other possible contaminants which may be monitored are phosphates, pesticides, and suspended solids.

As with other non-point source pollution, there may be a need to utilize (BCMOE 1999b):

- biological indicators of water quality (e.g., fish, invertebrate, or aquatic plant "bio-indicators"), which can integrate non-point source pollution effects over long periods
- in-stream electronic automated monitoring equipment, which can capture data during transient pollution events.

13.4.2. Finfish Aquaculture

A recent BC Ministry of Environment (MOE) pilot study investigated the possibility of using changes in benthic community structure as an indicator of impact of waste from salmon net pens. Finfish aquaculture pens in BC are located over a wide range of habitat and biotic community types, but monitoring data have been collected only for sites with soft sediment bottoms, where remote sampling of the unconsolidated sediments was possible (BCMOE 2006b).

The study examined MOE monitoring data as well as data collected by various organizations on reference conditions in coastal waters. These data were tested for correlations with benthic community structure and sediment chemistry. It was found that the proportion of non-mobile (sedentariate) marine polychaetes in samples could be used as a simple biotic indicator of gross changes in the balance of major taxonomic groups outside of reference conditions. Polychaetes are marine worms with paired, flattened, bristle-tipped organs of locomotion. They are a dominant, highly diversified group of organisms found on the sea floor, with hundreds of species present in natural marine environments. Polychaetes are used as indicator organisms in environmental monitoring, particularly in situations of organic enrichment of sediments (BCMOE 2006b).

A set of criteria was developed to categorize sediment monitoring samples according to the levels of “faunal stress.” Faunal stress was deemed to occur when the number and abundance of faunal species fell below the normal variance for benthic communities, based on the reference (control) sites. Ecosystem conditions were classified into four groups by the abundance of organisms, number of species, and type of sedentariate polychaetes present: 1. extremely stressed; 2. recovering fauna; 3. moderately stressed; 4. not impoverished (i.e., not different from reference or control conditions) (BCMOE 2006b).

The 2000–2003 monitoring data were assessed in light of these four condition categories. Samples in the extremely stressed category ranged from 0 to 38%, depending on the year. Most of the extremely stressed samples occurred at 0 to 30 m from the edges of the finfish net pens, although some were as far as 150 m from the edge (2000 data only). Some level of stress (categories 1, 2, and 3) was noted in about 12% of all samples (BCMOE 2006b).

Preliminary results showed that benthic impacts appear to be localized around the fish farm site. This is consistent with research showing that benthic impacts tend to occur within several hundred metres of net pens (Brooks and Mahnken 2003, Gowen and Ezzi 1991).

Organically enriched sediments are typically processed by bacterial and invertebrate activity fairly rapidly, as long as oxygen is available to penetrate the sediment. Once the fish net pens have been removed from the site, it appears that sediment geochemistry recovers over time, allowing benthic fauna to recolonize the area (BCMOE 2006b).

13.4.3. Shellfish Aquaculture

The following are some potential monitoring measures recommended by DFO for determining possible environmental impacts caused by shellfish aquaculture (DFO 2002):

- Measurement of suspended particulate matter (SPM), particulate organic matter (POM), or chlorophyll. These measurements can be used to characterize the food supply and calculate the potential carrying capacity of the site. They can also be used to determine if particle removal by filter feeding cultured species is potentially reducing food availability for wild species.
- Measurement of percent organic matter in the surface sediments collected using benthic grabs and/or cores. This can be used to determine if shellfish aquaculture is causing organic enrichment of the sediments.

- Depending upon the depth and currents at the site which may create the potential for organic enrichment, or depending upon the distance to sensitive fish habitat, measurements of specific sediment properties (e.g., sediment redox potential, total sulphides) may also be useful in determining the impact of the site on the environment.

13.5. Mitigation

13.5.1. Agriculture

Impacts from agricultural runoff can be mitigated by (BCMOE 2007e):

- **Site planning**. Proper site planning can help prevent or reverse damage to fish and wildlife habitat and water quality. A site plan should contain information on the physical attributes of the farm (including the native vegetation, wetlands, watercourses and other natural habitats), the topography of the land, the soil types, areas where lands are marginal for farming, and the climatic conditions. This information can be used to evaluate prime production areas, identify natural areas to remain, and those requiring remediation.
- **Livestock management**. Grazing patterns, livestock numbers and distribution, and manure management all have implications for soils, water quality and fish and wildlife habitat. Off-stream livestock waterers should be used whenever possible. Where access to natural watercourses is needed, it should be restricted to locations where developed access has been established.
- **Waste management**. The proper management of waste products prevents pollution of water, soil and air. The following issues need to be addressed:
    - **Appropriate manure storage**. The manure storage facilities must be constructed to prevent escape of manure or manure leachate to surface and ground water.
    - **Manure Application**. Applications must be planned and timed so that there is no runoff or excessive leaching to any body of water.
    - **Excess Manure**. If the amount of nutrients in the manure exceeds what can be used as a fertilizer, then either (1) the feed must be balanced to reduce the nutrient levels in the manure or (2) off-farm disposal of the manure must be arranged.
    - **Other wastes**. Milking parlor wastes, woodwaste, dead animals and pesticides must also be handled in a manner that minimizes the impact on the environment.
- **Soil management and conservation**. Soils develop slowly, but can be easily harmed by human activity, causing decreased crop production, higher management costs, and impacts on the aquatic environment. Many steps taken to protect soils (e.g., crop rotation, conservation tillage, terraces, riparian zones) can also benefit water quality and fish habitat.
- **Pest management**. Integrated pest management (IPM) techniques can reduce the overall use of pesticides while maintaining farm profitability:
    - cultural (e.g., crop rotation which reduces impacts from crop-specific pests, and companion crops which can be used to out-compete weeds between crop rows)
    - physical (e.g., stick traps)
    - chemical (e.g., pheromones, biocides)
    - biological (e.g., predator insects)

13.5.2. Finfish Aquaculture

The Special Committee on Sustainable Aquaculture (BC Legislative Assembly 2007) made the following recommendations which were to assist in mitigating the impacts of finfish aquaculture:

- A rapid, phased transition to ocean-based closed containment, financed by the provincial government in partnership with the federal government and the salmon aquaculture industry, should begin immediately, and should be fully developed within three years.
- There should be no new finfish sites approved north of Cape Caution. The existing Klemtu sites would be grandfathered subject to negotiations between First Nations of the area and Marine Harvest.
- Once all of the existing sites have transitioned to ocean-based closed containment, the opportunity to expand to new sites with this technology would be considered with the following conditions:
    - Restoration of local governments and residents' right to approve the siting of new finfish sites. Affected First Nations, local residents, local governments, regional districts, rural area representatives, town/village councils etc. must be fully involved in applications of aquaculture tenure siting. This should include early notification of applications, timely discussion and public hearings.
- A "watchman" program should be established under which First Nations in whose territory fish farms are located are contracted to monitor farm sites for best practice.
- There should be increased capacity for finfish aquaculture site monitoring within the provincial and federal governments.
- Effective fallowing regimes must be developed to protect juvenile salmon populations during migration periods. Identified migratory routes should not have stocked adult fish in pens during times of migration.
- There must be no increase in production levels per site or per tenure.
- No new species of finfish should be introduced for ocean-based aquaculture in existing tenures. Production levels on active tenures with finfish species other than Atlantic and Chinook salmon (eg. sablefish) must be frozen. Inactive licenses to grow sablefish (including those within salmon tenures) must be suspended.
- No additional finfish aquaculture tenures should be approved.
- Government should ensure that the commercial farming of transgenic (genetically modified) salmon is prohibited, irrespective of containment technology.
- Protocols must be established for sea lice monitoring and control, including:
    - Separation of generations (no smolts placed beside growers)
    - Regular fallowing of farm sites
    - Early harvest of two-sea-winter fish
    - Adult fish should not be placed in the pens until smolts have traveled through the migratory areas
    - Synchronous treatment of farms in the same geographic areas
    - Consideration of tidal effects on disease transfer (e.g. the separation distance of farms and wild fish established according to tidal excursion distances, not randomly-chosen distances).
- Government should continue its stringent action level of 3 motile lice (all stages) and introduce a measurement of 0.5 egg producing female lice throughout the year as is the best practice in Norway.
- During the transition to ocean-based closed containment, the use of anti-fouling paint on nets must be prohibited to protect the marine habitat. It is recommended that industry phase out the use of anti-fouling paint within one year.
- Use of fish meal and fish oil derived from wild sources must not exceed one pound of wild fish harvested for every pound of aquatic animals grown.
- After the transition period to ocean-based closed containment, all fish meal and fish oils used in BC must be harvested from independently verified sustainable sources.

13.5.3. Shellfish Aquaculture

Table 26, taken from the "Interim Guide to Information Requirements for Environmental Assessment of Marine Shellfish Aquaculture Projects" (DFO 2002), describes a variety of possible mitigation measures which may be taken at shellfish aquaculture sites. Additionally, the Special Committee on Sustainable Aquaculture (BC Legislative Assembly 2007) made the following recommendations which were to assist in mitigating the impacts of shellfish aquaculture:

- The provincial government should designate coastline where shellfish farms can be sited that minimize competition with residential and recreational use.
- Municipalities, regional governments, and First Nations must have the authority to approve siting of tenures.
- Operations must not interfere with navigation in the waterways they occupy or make the coastline inaccessible or inhospitable to recreational boaters, swimmers, or pedestrians.
- No new species are to be approved for commercial aquaculture without a consensus of independent peer-reviewed science affirming that the potential impact on the marine environment is minimal. Recently approved geoduck clam tenures should be rescinded until these conditions are met.
- A Code of Practice must be developed and implemented that respects the interests of other coastal stakeholders, including First Nations, residential communities, small shellfish operators, tourism and other businesses, and recreational users.
- Ministry of Environment must increase enforcement to eliminate release of debris from shellfish operations, particularly plastics and Styrofoam. The government should work with growers to reduce overall use of plastics, Styrofoam, and other equipment/materials with known toxins (such as treated wood).
- Underwater nets around suspended strings which violate HADD (Harmful Alteration, Disruption or Destruction of fish habitat) under the federal Fisheries Act must not be used.
- Efforts should be made to simplify the regulatory burden for smaller growers.
- A liaison should be established within the Ministry of Agriculture and Lands to assist First Nations and potential industry partners to set up commercial joint ventures.
- Shellfish testing facilities must be financed by the Ministry of Environment on the North Coast and other suitable regions, (as was done on the South Coast) so that the shellfish aquaculture industry can better serve that area.

Table 26. Mitigation measures for potential environmental effects from marine shellfish aquaculture operations (source: DFO 2002).

A. Marine Habitat (including water quality)				
Project Activity	**Potential Environmental Effects**	**Possible Mitigation**	**Significance of Adverse Environmental Effects**	**Follow-up Monitoring**
Construction and Operation	Reduced water quality and effects to water column flora and/or fauna. Organic loading smothering or alteration of habitat. Impacts on the health of local marine organisms. Reduction of phytoplankton in the ecosystem.	Avoid of low-water exchange areas for large projects (intense culture). Minimize in-water activities to reduced release of sediments and sediment-laden water into any water body. Time in-water activities to avoid migration and spawning windows. No foreshore modifications without consulting with DFO. Location of sites where current and flow provide adequate movement of nutrients. Catch nets or double socking to catch fall-off.	Determination of significance of adverse environmental effects to be made by DFO.	Established monitoring program.
Refuse Disposal	Waste accumulation in the water column and on benthic habitat. Degradation of water quality.	Solid wastes to be removed from the site and disposed of in an approved manner (no disposal of materials to the water column). Periodic removal of all garbage (e.g., ropes, socks) from site and disposal in approved landfill. Catch nets or double socking to catch fall-off.	Determination of significance of adverse environmental effects to be made by DFO.	
Accidental events/spills (e.g., fuel, hydraulic fluid and lubricants)	Degradation of water quality. Release of hazardous materials. Effects to shellfish health and production.	Use of less toxic alternatives to hazardous products. Development of Emergency-Spill Response Plan. Designation of areas for storage and refueling with proper containment. Training of workers in the safe and effective use of fuel, lubricants.		

A. Marine Habitat (including water quality) - continued				
Project Activity	**Potential Environmental Effects**	**Possible Mitigation**	**Significance of Adverse Environmental Effects**	**Follow-up Monitoring**
Debris accumulation of the seabed	Alteration of the substrate by smothering.	Catch nets or double socking to catch fall-off. Waste projects to be removed from the site and disposal at a suitable location.		
Biofouling control measures (physical removal and treatment of equipment)	Degradation of water quality (increased particulates, toxicity to some species).	Use of appropriate defouling methods and proper disposal of waste. As appropriate, allow fouling organisms to be released back into suitable habitat, rather than allowing to "dry out". Land- or boat-based defouling.		
Placement and removal of anchoring system	Physical disturbance to benthic habitat.	Minimize extent of in-water activities. Provide minimum buffer zone around sensitive habitats like eelgrass, saltmarsh areas and kelp beds.		

B. Fisheries Resources				
Project Activity	**Potential Environmental Effects**	**Possible Mitigation**	**Significance of Adverse Environmental Effects**	**Follow-up Monitoring**
Construction and Operation	Alteration of fish migration patterns.	Location of sites away from important migration routes.	Determination of significance of adverse environmental effects to be made by DFO.	

C. Wildlife (including birds, crabs, mammals and species at risk, etc.)				
Project Activity	**Potential Environmental Effects**	**Possible Mitigation**	**Significance of Adverse Environmental Effects**	**Follow-up Monitoring**
Construction and presence of infrastructure (e.g., physical presence, noise, disturbance, attraction) and bird deterrent programs	Predator attraction to sites as food source. Alteration of staging and distribution patterns. Disturbance to shorebirds and displacement or reduced access to traditional areas of use. Entanglement/drowning of birds in predator nets.	Site selection to reduce predator interest and avoid areas of high concentration of migratory birds. Proper on-site maintenance and cleanliness. Predator management plans. Mesh sizes of predator nets should be in accordance with recommendations of Canadian Wildlife Service, Environment Canada.	Determination of significance of adverse environmental effects to be made by DFO.	
Accidental spills (e.g., fuel and lubricants)	Potential mortality from oiling. Long-term effects, such as impairment to reproduction.	Use less toxic alternatives to hazardous products. Follow manufacturer's instructions for application. Proper storage of materials. Develop emergency spill response plan. Spill kits to be maintained on-site in case of accidents. Designate areas for storage and refueling with proper containment. Train facility workers in the safe and effective use of fuel and lubricants. All machinery to be in good working conditions, free of leaks.		Monitoring further to responding to emergency spill response.

D. Traditional Use of Lands and Resources by Aboriginal Persons				
Project Activity	**Potential Environmental Effects**	**Possible Mitigation**	**Significance of Adverse Environmental Effects**	**Follow-up Monitoring**
Access to site and harvesting activities	Interference with use of infrastructure (wharf, roads, etc.).	Consult with local aboriginal groups. Avoid areas of current use of lands and resources for traditional purposes.	Determination of significance of adverse environmental effects to be made by DFO.	
Construction and Operation	Interference with traditional uses.	Consult with local aboriginal groups Avoid areas of current use of lands and resources for traditional purposes.		

E. Fisheries Activities (e.g., commercial, recreational and aboriginal)				
Project Activity	**Potential Environmental Effects**	**Possible Mitigation**	**Significance of Adverse Environmental Effects**	**Follow-up Monitoring**
Operation of cage site/vessel traffic	Interruption of access to fishing areas.	Abide by Navigable Waters Protection Act approvals and conditions, including site-marking requirements. Consult with local fishermen and other marine user groups. Avoid sites with significant fisheries. Maintain access to site by fishers, as operational and safety conditions permit.	Determination of significance of adverse environmental effects to be made by DFO.	

F. Historical, Archaeological, Paleontological and Architectural				
Project Activity	**Potential Environmental Effects**	**Possible Mitigation**	**Significance of Adverse Environmental Effects**	**Follow-up Monitoring**
Site operations and activities	Information gap identified.	Consult with interested and knowledgeable parties. Avoid areas of significant physical and cultural heritage. Background check into history of area.	Determination of significance of adverse environmental effects to be made by DFO.	

14. Pollution Associated with Forestry and Forest Products

Forestry is an important industry in the PNCIMA. There are 9 forest districts represented in the region: Campbell River Forest District, Chilcotin Forest District, Fort St. James Forest District, Kalum Forest District, Nadina Forest District, North Coast Forest District, North Island – Central Coast Forest District, Queen Charlotte Islands Forest District, and Skeena Stikine Forest District (see **Figure 45**). Total revenue from the entire Coast Forest Region was approximately 166 million dollars in 2007, representing 13.8% of total forest revenue in BC (BCMFR 2007). Many forestry companies hold tree farm licenses in the PNCIMA (see **Figure 46**), with approximately 30,630 km^2 under license.

14.1. Pollution Sources

Chemicals associated with forestry in British Columbia include byproducts of the pulp and paper industry, pesticides, fire control chemicals, wood preservatives, and toxic leachates associated with log booming and log storage. These chemicals can present a risk to aquatic ecosystems in freshwater, brackish and marine areas. Other environmental effects of forestry include damage to fish habitat and sedimentation (Haggarty et al. 2003).

14.1.1. Pulp and Paper Mills

Pulp mills have historically had major impacts on the local marine ecosystems, including releasing mercury in the early 1970s, and discharging dioxins and furans until the early 1990s (BCMOE 2006b). Pulp bleaching (which used liquid chlorine) and the condensation of polychlorinated phenoxyphenols were important sources of dioxins and furans in pulp mill effluent. In 1991, there were nine pulp and paper mills which discharged secondary-treated effluent into BC’s coastal waters. These mills were monitored annually for dioxins and furans. The elimination of furans and dioxins from defoamer products, the exclusion of chlorophenol-contaminated wood chips, and the introduction of chlorine dioxide bleaching led to a dramatic decrease in the production of dioxins and furans in mill effluent after the implementation of regulations in 1992 (Yunker et al. 2002). Since then, some mills have closed and more have switched to a bleaching technology that does not use elemental chlorine. By 2002, only six mills required annual monitoring, and by 2004 only three mills were monitored annually. Due to low levels, mill effluent monitoring for dioxin/furans is now conducted at 3-year intervals (BCMOE 2007c).

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 (Fox 2001, Hewitt and Servos 2001, Hodson et al. 1992, Kiparissis et al. 2001, Yang and Randall 1996).

Figure 45. Forest districts represented in the PNCIMA (data: GeoBC 2008a).

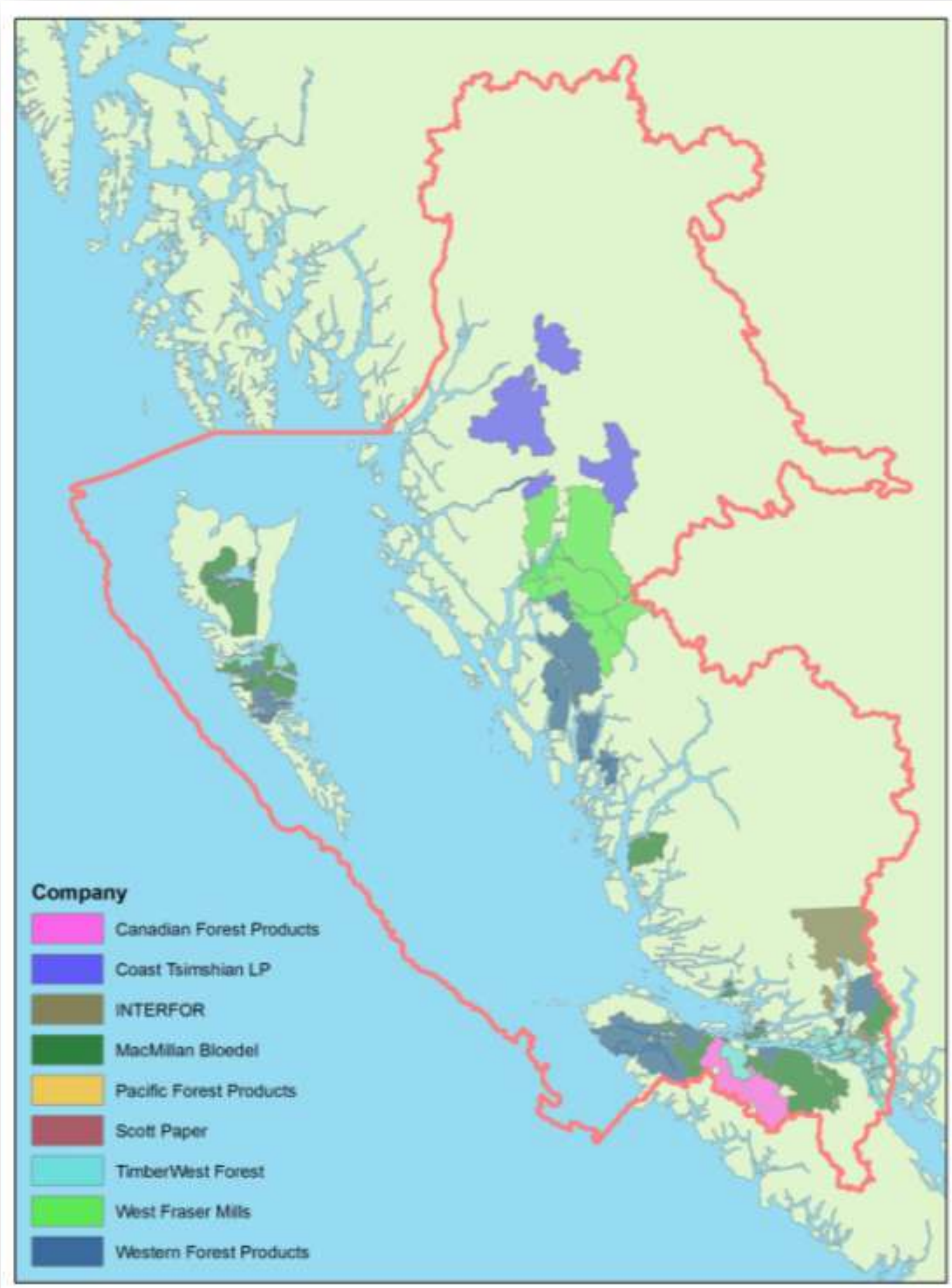

Figure 46. Tree farm licenses in the PNCIMA (data: GeoBC 2008a).

14.1.2. Pesticides

Pesticides applied in the forestry industry are either insecticides used to battle destructive pests such as bark beetles or herbicides used to inhibit the growth of undesired plants during silviculture (Johannessen et al. 2007a). In BC, the use of most pesticides has decreased over the last 15 years, with the notable exception of two herbicides: glyphosate and triclopyr (National Forestry Database 2007a). 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). Since 1997, gylophosphate use in BC has been declining. Triclopyr use increased steadily from 1991 to 1998; however its use has now declined as well. Insecticide use in BC has been very limited, with the only significant applications being MSMA (monosodium methanearsonate) from 1992 to 1998 on the mountain pine beetle. However, an alternative biological control agent, *Bacillus thuringensis*, has been fairly widely used from 1992 to 1999 on the spruce budworm, and from 2001 to 2005 on the jack pine bud worm (National Forestry Database 2007b).

Pesticides used in forestry are of concern in the marine environment if they are applied directly to, or if they are allowed to drift onto, the surface of aquatic ecosystems, particularly anadromous fish habitats (Haggarty et al. 2003). Glyphosate is applied either by ground application or aerial spraying (Haggarty et al. 2003), whereas triclopyr is only licensed for ground application, which significantly reduces the chance of stream overspray and over-application (Johannessen et al. 2007a). MSMA is either injected or applied directly to cuts in the bark at the base of selected trees in a stand, thus there is very little chance of it entering the marine environment unless it was spilled directly into or immediately adjacent to a water body (Dost 1995).

Glyphosate is a broad-spectrum, nonselective, systemic herbicide sold under the trade names of Vision®, Gallup®, Landmaster®, Pondmaster®, Ranger®, Roundup®, Rodeo®, and Touchdown®. Glyphosate may be used in formulations together with other herbicides. It is used for control of annual and perennial plants including grasses, sedges, broad-leaved weeds, and woody plants in forestry, as well as on cropland. Glyphosate is an acid that is commonly used in salt form (either isopropylamine salt or trimethylsulfonium salt). Glyphosate is generally distributed as water-soluble concentrates and powders (EXTOXNET 2003b), and is applied at a rate of application of up to 4.48 kg/ha (Norris et al. 1983).

Triclopyr, a pyridine, is a selective, systemic herbicide used for control of woody and broadleaf plants along rights-of-way, in forests, on industrial lands, and on grasslands and parklands. Triclopyr is commercially available as a triethylamine salt or butoxyethyl ester of the parent compound. Trade names for herbicides containing triclopyr include Release®, Access®, Crossbow®, ET®, Garlon®, Grazon®, PathFinder®, Redeem®, Rely®, Remedy®, and Turflon® (EXTOXNET 2003a).

MSMA is an organic arsenic compound MSMA which is applied as a frill injection to individual trees. The highest dosage of use is about 40 ml of MSMA product per tree, depending on tree size. Approximately 750 kg of MSMA product are applied in British Columbia each year on average. The area of use is widely dispersed, covering most of the interior of the province where bark beetle infestations may occur. The average annual total area of treatment is 650 hectares. In any one landscape drainage infested with bark beetles, it is unlikely that, of the many thousands of trees that may exist there, more than 50 trees would be treated with MSMA (Dost 1995). Therefore, as a result of its limited usage in areas that are distant from the coast, the likelihood of MSMA entering the marine environment is low.

14.1.3. Fire Control Chemicals

Forest fires can impact aquatic environments and fish habitat through the loss of forest cover, increased siltation, soot and ash smothering, introduction of PAHs, and the use of fire suppression or retardant chemical (Haggarty et al. 2003).

Forest fires are fought with complex chemical mixtures, including short-term fire suppressants (foams) and long-term retardants (chemical salts). Most of the long-term retardants contain mixtures of salts, such as diammonium phosphate, ammonium sulphate, ammonium phosphate, or ammonium polyphosphate, as the active fire retardant (Johannessen and Ross 2002).

14.1.4. Anti-Sapstain Compounds

Anti-sapstain compounds are used by lumber mills as short-term means to prevent fungal growth and staining on lumber (Johannessen et al. 2007b). Anti-sapstain chemicals used in BC during the 1990s include TCMTB (2-(thiocyanomethylthio)benzothiazole), DDAC (didecyl dimethyl ammonium chloride), IPBC (3-iodo-2-propynyl butyl carbamate), sodium carbonate, two forms of borate (disodium octaborate tetrahydrate and disodium tetraborate decahydrate) and Azaconazole. Increased regulations and best practices have reduced the overall amounts of anti-sapstain chemicals used, particularly TCMTB. The use of TCMTB, sodium carbonate and Azaconazole has been reduced to very low levels or discontinued. Use of DDAC and IPBC decreased during the 1990s; however, they are still the two most frequently used compounds. Borax was used relatively steadily throughout the 1990s (Johannessen and Ross 2002).

Creosote, and less frequently chromated copper arsenate (CCA), are used by industry as a more long-term method to preserve wood.

14.1.5. Log Storage, Handling, and Booming Operations

Coastal waters are often used as a low cost means of transporting and storing logs (Haggarty et al. 2003). Ease of road access and a need for protected waters frequently results in log dumps being located in sensitive estuarine habitats (Johannessen et al. 2007b).

14.1.6. Erosion

In 2006, British Columbia's forest sector accounts for 7.4% of the province's gross domestic product and 41% of all exports (COFI 2007). Much of the land is harvested by clear-cutting, a method which can cause substantial soil erosion, particularly in rainy areas, and higher accumulation of snow than if trees were left standing. When warm spring weather arrives, higher-than-normal snowmelt can cause elevated sediment levels in the water. In addition, there are over 37,000 kilometers of logging roads throughout the province, far exceeding the length of the provincial highway system. Logging road construction, use, and maintenance are the primary causes of non-point source water pollution from forestry activities, causing up to 90% of the sedimentation from forestry activities (BCMOE 1999b).

A 1988 study of soil degradation by the timber industry estimated that between 1976 and 1985, at least 400,000 hectares of forest land were degraded in some way. This represents 22% of the total area harvested in that period (BCMOE 1999b).

14.1.7. Other

The forestry sector is the largest user of PCB containing electrical equipment in BC, 50% of which is found in pulp and paper mills (Kay 1989). High PCB levels in sediments around pulp mills are likely the result of leaks from PCB-containing electrical equipment (Haggarty et al. 2003). PCBs are a persistent environment contaminant (see Section 6).

There are also potentially numerous contaminated sites associated with logging camps in the PNCIMA. Sources of contaminants in logging camps include PAHs from gasoline at fuel refilling sites, batteries, pesticides, and other chemicals (Haggarty et al. 2003).

14.2. Environmental and Socio-Economic Impacts

14.2.1. Pulp and Paper Mills

In the 1960s and 1970s, pulp mill effluent was a reported to be major source of fine particles (total suspended solids or TSS) and biochemical oxygen demand (BOD). Bacterial decomposition or chemical oxidation of the organic material in the effluent depletes the oxygen in the mill's receiving waters. Depleted oxygen levels caused mass mortalities in fish and other biota adjacent to pulp mills on a regular basis (Beak Consultants 1970, 1974, Packman 1977, Packman and Bradshaw 1977, Waldichuk 1962, 1963).

More recently, mills were also found to release chlorinated organic compounds in both atmospheric and aqueous discharge as a by-product of the bleaching process and the burning of salt laden wood. Among these compounds are the highly toxic dioxins and furans, which bioaccumulate in organisms and biomagnify through the food chain (Colodey et al. 1990, Harding and Pomeroy 1990, Servos et al. 1996, Yunker and Cretney 1995, Yunker and Cretney 2000a, b, Yunker et al. 2002).

In the 1980s and 1990s, the addition of secondary treatment for effluent, and a change from liquid chlorine to chlorine dioxide gas for pulp bleaching, reduced TSS and BOD levels to well below regulatory limits, and nearly eliminated dioxins and furans in mill effluent across Canada (McGreer and Belzer 1999). Dioxin and furan levels in the hepatopancreas of crabs in the vicinity of pulp mills have shown a steady decline since these changes were made (see **Figure 47**). Additionally, the standard test for mill effluent toxicity, 96 hour exposure of fish to effluent, changed from 50% survival prior to the changes, to 100% survival afterwards (Hagen et al. 1997, McGreer and Belzer 1999),emphasizing the positive impact of regulatory changes on aquatic animal health.

Traces of past dioxins and furans remain, however, in sediments around mill sites and are still present in smokestack emissions (CCME 2001). Contamination in sediment has dropped, but not as rapidly as in crab tissue, in part because dioxins and furans have a strong affinity for sediments and break down very slowly. The continuing low, relatively stable, levels of dioxins and furans in sediments and crab tissue are indicative of the persistence of these chemicals. They may also indicate that there is a continuing low level input of dioxins and furans from other sources (e.g., regional incinerators and other local combustion, global atmospheric transport). Unfortunately, given their persistence, low levels of dioxins and furans will remain in the environment for many years (BCMOE 2006c).

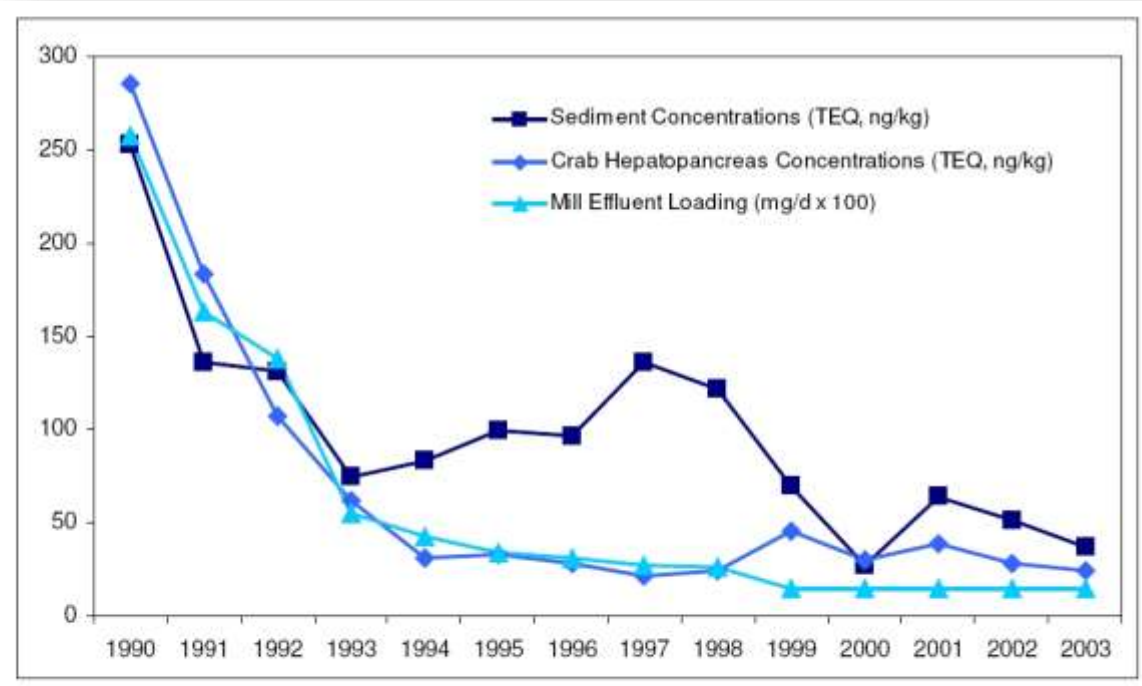

Figure 47. Total 2,3,7,8-TCDD loadings in pulp mill effluents from all mills reporting at each date, and dioxin and furan concentrations in sediments near the outfall and in crab hepatopancreas, 1990–2003. Note: Number of mills reporting: 9 mills for 1990–1997; 8 mills in 1998; 4 mills for 1999–2003 (source: BCMOE 2007c, EC 2005b).

Fisheries and Oceans Canada closed several areas around pulp mills to shellfish harvesting in 1988 when the health risk from dioxin and furan contamination became known (see **Figure 48**). As monitoring expanded to include more mills, more affected areas were found. By February 1995, nearly 1200 km^2 of BC coastal waters had been closed. The total area closed to shellfish harvesting near eight BC coastal pulp and paper mill locations peaked in 1995 (BCMOE 2006b).

The sharp decrease in effluent loadings from pulp mills in the early 1990s made it possible to lift restrictions for all shrimp, prawn, and oyster harvesting in 1995, and later reopen some areas to crab harvesting. More than 46% (550 km^2) of the maximum area closed in 1995 had been reopened by the end of 1997. No restrictions have been lifted since, in part because Health Canada is currently reassessing the safe consumption limits for dioxins and furans. The remaining shellfish closures prohibit crab harvesting only (BCMOE 2006b). The full economic impact of these closures is not known, but the Dungeness crab fishery ranks as one of the most valuable invertebrate fisheries in BC. In 2006, the wholesale value was $42.2 million (BCMOE 2007g).

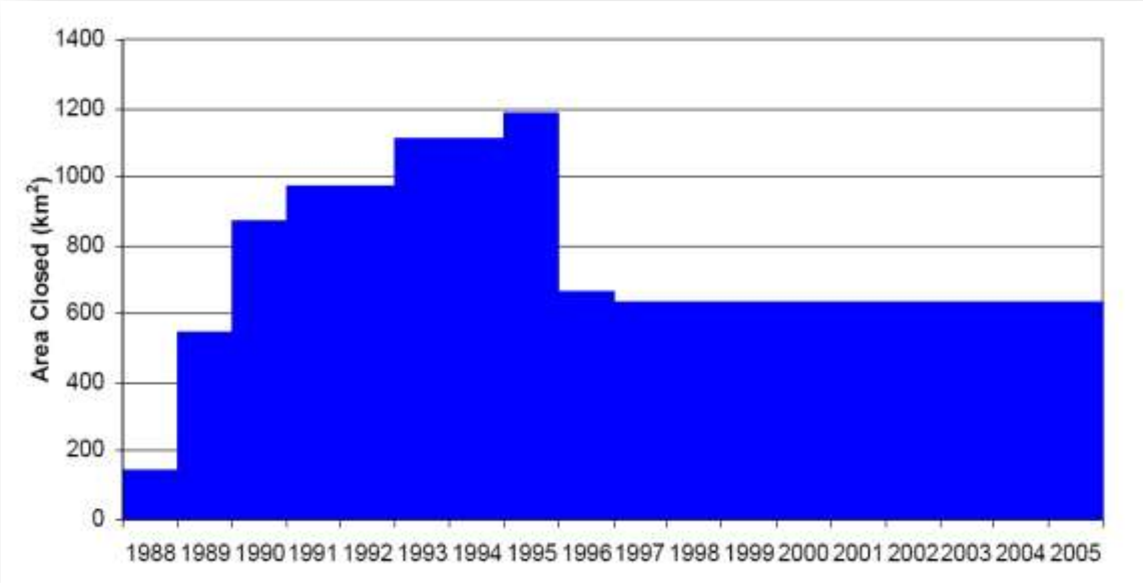

Figure 48. Areas closed to harvesting for crabs, shrimp, oysters, and prawns near eight coastal BC pulp and paper mills, 1988–2005. After 1995, all closures were for crab harvesting only (source: BCMOE 2006b).

Despite these improvements, pulp mill effluent continues to contain metal contaminants, natural plant compounds including hormones, other chlorinated compounds, and surfactants (Fox 2001, Hewitt and Servos 2001, Hodson et al. 1992, Kiparissis et al. 2001, Yang and Randall 1996). Little information exists on the environmental effects of many of these compounds. In the past, the focus has been on acute toxicity. However, there is growing evidence that exposure to diluted effluent concentrations over the long-term can cause sub-lethal effects in aquatic organisms, ultimately causing mortality or impaired reproductive ability with community and population level consequences (Johannessen et al. 2007a). Although some research has shown that secondary treatment reduces the amount of endocrine disrupting compounds in effluents (Janz et al. 2001), the full endocrine disrupting potential of effluent is poorly understood because chemical degradation byproducts were not evaluated. While secondary treatment breaks down many toxic compounds, the products of the breakdown may be just as, or even more toxic than the parent compound in terms of endocrine disruption (Johannessen and Ross 2002).

14.2.2. Pesticides

Both glyphosate and triclopyr have short half-lives (on the order of days) and relatively low toxicity to aquatic organisms, dependent on the form of the compound and its purity (Johannessen et al. 2007b).

Glyphosate is highly soluble in water , and is moderately persistent in soil, having an estimated average half-life of 47 days (Norris et al. 1983). Glyphosate strongly adsorbs to most soils, even those with low organic and clay content. Thus, even though it is highly soluble in water, field and laboratory studies show that glyphosate does not leach appreciably from soil, and has low potential for runoff (except as adsorbed to colloidal matter). One study estimated that less than 2% of the applied chemical is lost to runoff. Microbes are primarily responsible for the breakdown of the product. Glyphosate also strongly adsorbs to suspended organic and mineral matter, and has a half-life in pond water ranging from 12 days to 10 weeks (EXTOXNET 2003b).

Glyphosate acid and its salts are classified as moderately toxic compounds in the Environmental Protection Agency's (EPAs) toxicity class II; however, glyphosate acid is considered to be practically nontoxic to fish, and only slightly toxic to aquatic invertebrates (see **Table 27**). It is considered to have a very low potential to bioaccumulate in aquatic animals (EXTOXNET 2003b).

Table 27. 96-hour LC_{50} toxicity measurements of pesticides used in forestry in the central coast (EXTOXNET 2003a, b).

Test Species	Glyphosate mg/L	Triclopyr (parent compound) mg/L	Triclopyr (ester) mg/L
Bluegill sunfish	120	148	0.87
Rainbow trout	86		0.74
Atlantic oysters	>10	117	
Fiddler crab	934		
Shrimp	281		
Daphnia	780*	1170	

* 48-hour LC50

In natural soil and in aquatic environments, the ester and amine salt formulations of triclopyr rapidly convert to the acid form, which in turn is neutralized to a relatively nontoxic salt. Triclopyr is effectively degraded by soil microorganisms, and has a moderate persistence in soil environments. The half-life in soil ranges from 30 to 90 days, depending on soil type and environmental conditions, with an average of about 46 days. Unlike glyphosate, triclopyr does not strongly adsorb to soil particles, and has the potential to be transported in runoff. Triclopyr readily breaks down in water through photolysis. Reported half-lives in water are 2.8 to 14.1 hours for the acid, and 12.5 to 83.4 hours for the ester formulation (EXTOXNET 2003a).

The parent triclopyr compound is considered nontoxic to fish and to the aquatic invertebrate *Daphnia*, a waterflea (see **Table 27**). The compound has little, if any, potential to accumulate in aquatic organisms. The bioconcentration factor for triclopyr in whole bluegill sunfish is only 1.08 (EXTOXNET 2003a). However, the ester form of triclopyr, which is used in many herbicide formulations, is significantly more toxic (Wan et al. 1987).

There is no information about the behaviour of either gylphosate or triclopyr in the marine environment (Haggarty et al. 2003).

14.2.3. Fire Control Chemicals

The toxicity of fire retardant salts is considered to be very low to insignificant (100-10,000 mg/L), while the fire suppressant foams are more toxic (10-100 mg/L) due to surfactants used to make the foam (Gaikowski et al. 1996). However, toxicity is greatly increased in the long-term fire retardants by the addition of corrosion inhibitors which are used to prevent corrosion of storage containers and fire-fighting equipment. Sodium ferrocyanide is often used as a corrosion inhibitor in products like Fire-Trol® (Johannessen and Ross 2002). When sodium ferrocyanide is exposed to sunlight, it produces cyanide. Therefore, even very dilute solutions of sodium ferrocyanide are highly toxic to fish (Little and Calfee 2000, Norris et al. 1983). The addition of sodium ferrocyanide to fire retardants increases their toxicity by 100-fold in rainbow trout (Little and Calfee 2000).

There is little information about the mobility or persistence of fire-retardant chemicals, or on the behaviour of these chemicals in salt water. The BC Ministry of Forests, Protection Branch has an agreement in place to only use suppressants or retardants that have been tested and approved by the USDA Forest Service (Haggarty et al. 2003).

14.2.4. Anti-Sapstain Compounds

Anti-sapstain and wood preservatives are toxic to marine organisms. TCMTB, IPBC, and DDAC have been shown to be highly toxic to salmon (Haggarty et al. 2003). The chromium, copper, and arsenic found in CCA are all toxic substances (Johannessen and Ross 2002). Creosote is a complex chemical mixture, and when used to preserve dock pilings, its toxicity is localized to a small portion of the surrounding environment, particularly if it is allowed to "age" before use (Hutton and Samis 2000). Further information on the toxicity of anti-sapstains and wood preservatives is given in section 10.2.3.

14.2.5. Log Storage, Handling, and Booming Operations

Log storage facilities cause physical, chemical and biological disturbances (Williamson et al. 2000).

Physical disturbances include (BCMOE 2006b, Conlan and Ellis 1979, Kathman et al. 1984, Picard 2002, Waldichuk 1979, Williamson et al. 2000):

- sediment compaction which brings the anoxic zone closer to the surface
- scouring of benthic habitats (from prop wash and submerged logs)
- damage and local elimination of aquatic plant communities, including shading which can negatively impact eelgrass beds and other benthic algae
- sediment smothering by wood debris that may limit oxygen exchange and eliminate aerobic benthic infauna

Chemical disturbances include (Anderson and O'Connell 1977, Frankowski and Hall 1999, Picard 2002, Samis et al. 1999, Waldichuk 1979):

- local reductions in dissolved oxygen in sediment porewaters, surface waters near stored logs, and occasionally in the water column. On the sea floor, microbial degradation of wood debris uses up oxygen, potentially creating anoxic conditions and toxic levels of hydrogen sulfide and ammonia.
- production of toxic substances that also consume oxygen and exacerbate depressed dissolved oxygen conditions. Rain and water percolating through wood chip piles and log storage areas will leach naturally occurring chemicals from the wood. The leachate can be characterized by a high carbon content, strong color, and high concentrations of wood sugars, tannins, lignins, resin acids and phenolics. This leachate may exacerbate low dissolved oxygen conditions, since bacterial degradation of the dissolved organics will result in the consumption of oxygen. Some of the compounds in the leachate can be toxic to aquatic life in sufficient does (particularly tannins, lignan, other phenolic compounds, terpenes, tropolones and several resin acids).
- pesticides used to treat beetles and shipworms. Benzene hexachloride and sodium arsenite were applied in the past to protect logs while they were being stored at marine sites; however, this process was discontinued due to possible toxic effects.

Biological disturbances include (Kirkpatrick et al. 1998, Picard et al. 2003, Picard 2002):

- effects on intertidal estuarine habitats. Most studies have focused on the effects of woody debris accumulation on the benthic prey species of juvenile salmon, such as amphipods, copepods, and other invertebrates. Smaller prey species (e.g., copepods) seem to be resilient to sediment compaction and scouring, while wood debris loading negatively affects larger invertebrates. Vegetation changes resulting from debris accumulation may affect certain prey species; however salmon smolt abundance and growth may not be negatively affected if alternate food sources that do not rely on vegetation are available. Impact severity seems to be greater in areas with poor water circulation, while well flushed areas are more resistant to log and wood debris effects.

- effects on subtidal habitats. Infaunal diversity, abundance and biomass are depressed in areas where wood debris accumulates. Filter-feeding species (e.g., clams) are reduced in habitats containing woody debris, whereas small, opportunistic, deposit-feeding polychaetes tend to dominate. In bark-dominated habitats, low dissolved oxygen, toxic conditions, and changes to physical sediment characteristics reduce the number of species which are able to inhabit the sediments. In contrast, minor additions of wood debris may increase infaunal abundance by providing additional food resources.
- effects on epifaunal communities. There appears to be a trend towards less abundant and diverse epifaunal communities at severely impacted sites. Low dissolved oxygen, elevated toxin concentrations, reduced food availability, or a combination of all three may be responsible for the observed trend. Epifaunal communities may be a better indicator of habitat impact than porewater redox potential. Large epibenthic predators, such as Dungeness crabs and sunflower seastars, are more abundant in habitats without woody debris. However, there are some organisms which prefer habitats with wood accumulations (e.g., squat lobsters, holothurians). Sparse wood debris accumulations and sunken logs often increase epifaunal abundance by increasing habitat complexity without detrimental effects to physical or chemical sediment conditions.
- effects on salmon habitats. Marine log handling facilities are most likely to affect the following salmon habitats:
    - estuarine/intertidal nursery and feeding habitats due to smothering by sunken debris, reduced food production, dissolved oxygen depletion, possible scouring of aquatic vegetation and sediments, and shading.
    - subtidal vegetation and benthic habitats due to debris smothering, changes to sediment conditions potentially reducing food resources, in extreme cases reduced bottom water dissolved oxygen, and possibly shading reducing plant growth.

Tidal action is an important moderator of the degree of impact of woody debris on the benthos. Minor or negligible woody debris accumulations occur at sites where debris is continuously removed by tidal current flushing. In contrast, extensive and persistent (lasting several decades) accumulations have been recorded at sites where water circulation is low. Bark thickness also varies with flushing rates, but always increases with proximity to the log dump site. Wood volume processed at a given facility will also influence the amount of accumulated woody debris. Little is known about whether debris which is generated at one site and subsequently flushed away by tidal currents accumulates in other, deeper habitats. The effects of woody debris on deeper benthic communities is not well researched (Picard 2002).

14.2.6. Erosion

Clear-cutting increases storm runoff volumes and advances the timing of floods. Changes in run-off volumes and timing are most strongly seen in small to moderate early autumn storms. The creation of logging roads also increases storm runoff. Because clear-cutting and road development can increase the delivery of water to soil and streams, stream-flow is increased, slope failures are induced, debris torrents and flows are initiated, and sediment and coarse woody debris become entrained in streams (Slaymaker 2000).

In unlogged forested areas, landslides, debris slides and debris flows produce approximately 1000 $m^3\ km^{-2}\ yr^{-1}$ of sediment, surface erosion produces approximately 10 $m^3\ km^{-2}\ yr^{-1}$ of sediment, and soil creep produces approximately1 $m^3\ km^{-2}\ yr^{-1}$ of sediment. In harvested areas, debris slides and flows produce on the order of 10,000 $m^3\ km^{-2}\ yr^{-1}$ of sediment, unpaved roads, covering no more than 10% of a watershed, generate about 1000 $m^3\ km^{-2}\ yr^{-1}$ of sediment (abandoned, deactivated roads produce only 1% of that produced by unpaved roads), and bank erosion is estimated to generate 1–10 $m^3\ yr^{-1}$ of sediment per km length of channel. Thus, there is a 10-fold increase in sediment production associated with forest harvesting activity in British Columbia's mountains. Debris flows and unpaved logging roads are the chief agents of this accelerated sediment production (Slaymaker 2000). Much of this increased sedimentation will ultimately end up in the marine environment, where it will cause increased siltation and turbidity, resulting in smothering of benthic organisms and decreased photosynthesis in marine algae.

14.3. Concerns in the North and Central Coast

14.3.1. Pulp and Paper Mills

There are four active pulp mills in the PNCIMA (see **Figure 49**), with two on Vancouver Island (Neucel Specialty Cellulose in Port Alice and Catalyst Paper Corporation in Elk Falls just north of Campbell River) and two on the northern mainland coast (Skeena Cellulose in Prince Rupert and Eurocan in Kitimat). BC's pulp and paper industry has recently experienced an economic downturn, and both the Port Alice and Prince Rupert mills have undergone recent closures (Johannessen et al. 2007b). The Port Alice mill has been re-opened under new ownership, but it appears unlikely that the new owners of the Prince Rupert mill will re-open any time in the near future.

Table 28. Pulp mills in the PNCIMA (Data: Reach for Unbleached Foundation 2006). CTMP=Chemical Thermal Mechanical Pulp. TMP = Thermal Mechanical Pulp.

Mill Name	Location	Type	Discharge ($m^3 \cdot d^{-1}$)	Bleach Used
Catalyst Paper Corporation	Elk Falls	Kraft, TMP	270,000	Chlorine dioxide
Neucel Specialty Cellulose	Port Alice	Dissolving sulphite	190,000	Chlorine dioxide
Eurocan	Kitimat	Kraft, CTMP	75,000	None
New Skeena Forest	Prince Rupert	Kraft	Not active	Chlorine dioxide

Three of the four pulp mills in the PNCIMA use a chlorine dioxide bleaching process (elemental chlorine free, or ECF; see **Table 28**). The fourth, Eurocan, does not bleach its pulp. The use of chlorine dioxide rather than elemental chlorine reduces the toxicity of the effluent (Pierce et al. 1998). All four mills have secondary treatment of their effluent. A 98.6% compliance with the requirements of the Chlorinated Dioxins and Furans Regulation of the Canadian Environmental Protection Act (CEPA) has resulted in a decline of over 99% in the discharge of dioxins and furans from the currently operating pulp mills. At present, the major source of dioxins and furans from pulp and paper mills are via air emissions from burning salt laden wood and incineration or disposal of sludge, rather than effluent discharge (Haggarty et al. 2003). Dioxins and furans can reach biota through atmospheric transport and deposition into aquatic ecosystems (Grant and Ross 2002).

Following the reductions of dioxins and furans in pulp and paper effluent in the 1990s, contaminants that had been produced during operations in the past have tended to become buried under layers of sediment. However, disruption of sediments by water currents and bioturbation (mixing of the surface sediments by infauna) can return the contaminated sediments to the surface (Haggarty et al. 2003). This appears to have been the case at the Elk Falls mill, which is located near a high current environment. Strong tidal currents (up to 7.9 m/s) are found in Seymour Narrows, 10 km to the north of the mill. As a result of these high currents, contaminated sediments at this site have not been buried under cleaner sediments. Moreover, dioxins and furans associated with this mill have been found in sediments as well as Dungeness crab (the standard indicator species used to study dioxins and furans) as far as 60 km away and as late as 1995, indicating that the contaminants continued to be bioavailable (Yunker et al. 2002). It has been recommended that the monitoring of dioxins and furans in crabs and sediments in this area be continued.

Figure 49. Pulp mills in the PNCIMA (source: BCILMB 2008).

Sulphite pulp processing requires much lower bleaching levels than does the Kraft process. As a result, the dioxin and furan levels in the Port Alice mill effluent have always been well below those from mills using the Kraft process. Sediment samples from 1987/88 showed much lower concentrations of these contaminants at the Port Alice site than at mills in comparable locations. Contaminants in crab hepatopancreas from both 1987/88 and 1997 were also well below all other samples (Yunker et al. 2002).

The New Skeena Forest pulp mill, originally Skeena Cellulose Inc., has been closed since June 2001 due to poor economic conditions. The original pulp mill was built in 1951 as a sulphite mill and was converted in 1976 to a kraft mill process. Initially, effluent discharged into Wainwright Basin, but the diffuser was shifted to Porpoise Harbour in 1978. In the late 1970s, the Canadian government increased pressure to improve the quality of effluent which resulted in the installment of a final effluent clarifier. Primary and secondary treatment facilities have been in operation since 1991 to reduce effluent and atmospheric emissions (De Raedemaecker 2004). In mid-1993, a 20 m deep multi-port submarine diffuser was installed to ensure a more efficient dispersion of mill effluent (Hatfield Consultants Ltd. 1994). Unfortunately, although Skeena Cellulose is a relatively small production mill, it caused extensive habitat deterioration due to the fact that the effluent was discharged into a confined basin which was poorly flushed by tidal action. By comparison, some large production mills with high effluent loadings, like NorskeCanada Powell River Division, are located in areas with high assimilative capacity and cause much less observable environmental degradation. Thus, environmental impact is not always proportional to the volume of pulp and paper production or the waste loading (De Raedemaecker 2004). Since the mill closure in 2001, the environment around the mill site has been recovering (Bard 2004).

Since Eurocan does not bleach the pulp it produces, it generates much lower levels of dioxins and furans. However, it has had at least one reported spill event. Between December 11th and 12th , 2002, a spill that occurred at the mill. The investigation revealed that the systems designed to contain spills in emergencies were deficient. Pulp mill effluent containing weak black liquor was spilled and entered Symes Creek, which resulted in a fish kill. As a result of the investigation, charges were laid against West Fraser in December 2004. West Fraser was sentenced to a financial penalty totaling $100,000, comprising fines of $2,000 and a payment of $49,000 into the Conservation Trust Fund of British Columbia for habitat development and preservation. It also included a payment of $49,000 to the University of Northern British Columbia to support their Environmental Science program, which is directed at the conservation and protection of fish and fish habitat in northwestern British Columbia (EC 2006c).

14.3.2. Pesticides

Glyphosate was the only pesticide reported as sold in the North Coast region in 1999 (ENKON Environmental Limited 2001); however triclopyr was reported as used for the first time on the North Coast in 1999 (Verrin et al. 2004). Only two herbicides have been reported as used in forestry on the Central Coast - glyphosate (Vision®) and triclopyr (Release®). No insecticides were reported as used (Haggarty et al. 2003). 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 pollutant issue in the PNCIMA (Johannessen et al. 2007b).

14.3.3. Fire Control Chemicals

Forest fires occur in all forest types in BC; however, they do not occur with the same frequency or magnitude in all forest types. While forest fires are a major disturbance regime in many of BC's forest regions, particularly in the Boreal and Cordilleran ecoclimatic provinces (interior and northern forests), they are a relatively minor form of natural disturbance in wet, coastal forests of the central coast that are part of the Pacific Cordilleran ecoclimatic province (Kurz et al. 1996).

The forest fire statistics of 2003 provide a good example of the differences in frequencies of fires throughout the province. The 2003 British Columbia fire season was one of the worst over the past two decades (see **Table 29**). There were more total forest fires in 1994, however, total hectares destroyed and total cost of fire fighting was greater in 2003. The Kamloops region was the hardest hit during the 2003 fire season, with 731 fires and over 100 thousand hectares destroyed (see **Table 30**). The Northwest and Coastal regions the lowest areas of forest burned, together making up only 0.13% of the total burned province-wide (Makarenko 2003).

Since forest fires are relatively infrequent in BC's coastal rainforests, forest fire fighting activities are not predicted to be a significant source of pollution in the PNCIMA (Johannessen et al. 2007a).

Table 29. Comparison of total fires, total hectares burned, and total cost of fire-fighting from 1992 to 2003 based on data from the Ministry of Forests (Makarenko 2003).

Year	Total Fires	Total Hectares	Total Cost of Fighting
2003*	2468	255,466	$545 million**
2002	1781	8,581	$37.5 million
2001	1266	9,677	$53.8 million
2000	1539	17,673	$52.7 million
1999	1207	11,581	$21.1 million
1998	2665	76,574	$153.9 million
1997	1175	2,960	$19.0 million
1996	1358	20,669	$37.1 million
1995	1474	48,080	$38.5 million
1994	4088	30,310	$90.9 million
1993	1497	5,183	$25.2 million
1992	3805	30,453	$69.7 million

* Current up to September 10, 2003
** Estimate released by BC Minister of Finance (10/2003)

Table 30. Comparison of fire activity for 2003 by region based on data from the Ministry of Forests (Makarenko 2003).

Region	Total Active Fires (burning on Sep 10, 2003)	Total Fires to Date (current fiscal year)	Total Area Burned (ha.) (current fiscal year)
Coastal	68	245	250
North West	1	59	78
Prince George	44	327	23,742
Kamloops	283	731	112,176
South East	288	724	85,249
Cariboo	18	382	33,971

14.3.4. Anti-Sapstain Compounds

The majority of wood preservative facilities in BC are found south of the PNCIMA, within the Fraser and Georgia basins where wood product use is highest. Furthermore, the implementation of "best practices" methodologies at wood preservative facilities in the 1990s has resulted in an estimated 90% decrease in the discharge of contaminated effluent. Through the implementation of best practices at the 14 sawmills in the PNCIMA, the risk of anti-sapstain contamination of the marine environment is minimal. Thus, wood preservatives and anti-sapstain compounds are not likely to be a significant pollution issue in the PNCIMA (Johannessen et al. 2007b).

14.3.5. Log Storage, Handling, and Booming Operations

Marine environments throughout the PNCIMA are commonly used for log sorting and transportation, both in intertidal and deeper water (Haggarty et al. 2003, Johannessen et al. 2007b). There are over 200 log booming, log dump, or log sort sites in the PNCIMA (see **Figure 50**). Most are located in the southern portion of the region.

14.3.6. Other

Figure 51 show the locations of logging camps, both floating and terrestrial, in the PNCIMA. The majority of the logging camps are located in the southern region of the PNCIMA.

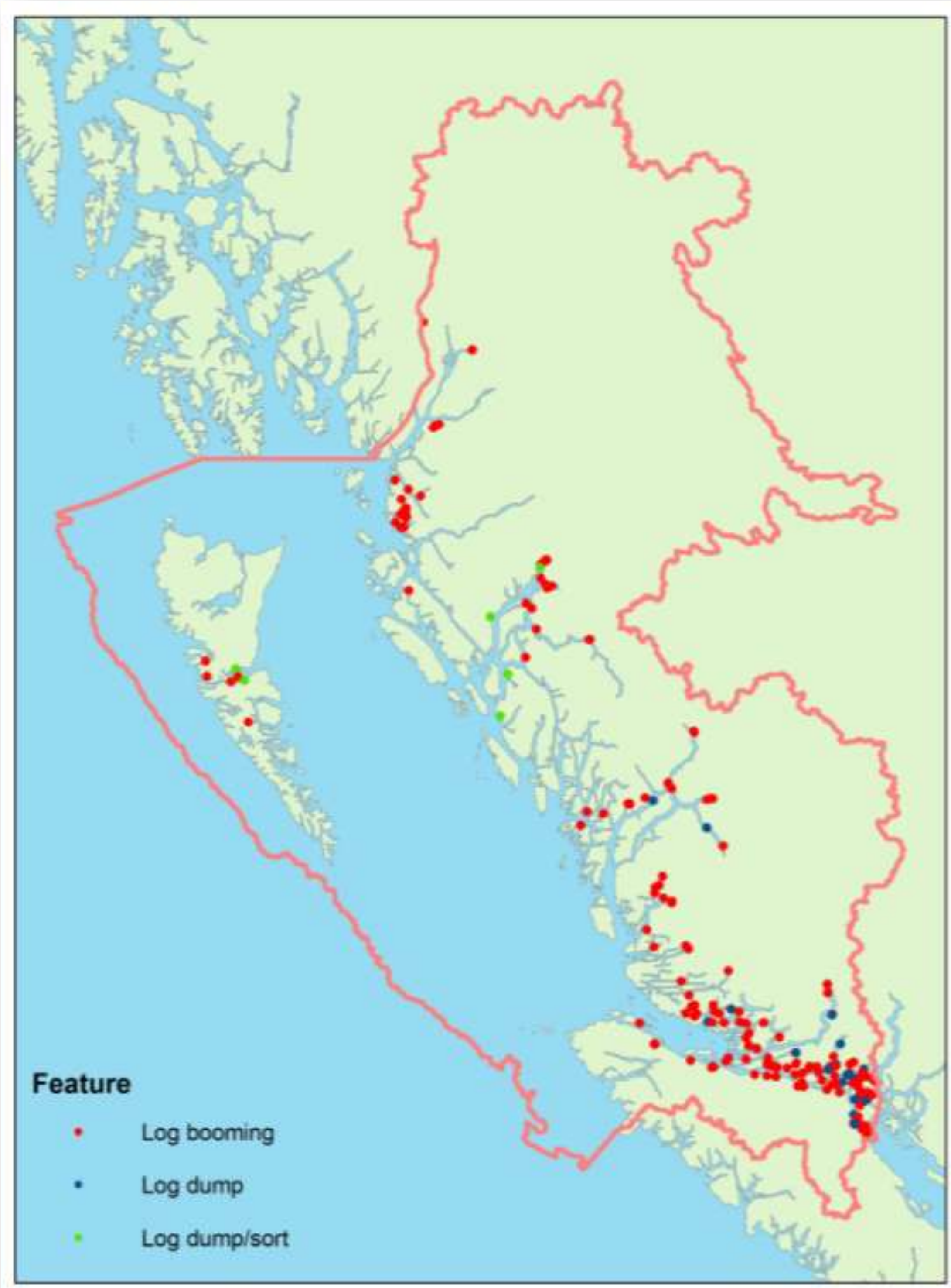

Figure 50. Log booming, log dump, and log sort sites in the PNCIMA (data: BCILMB 2008).

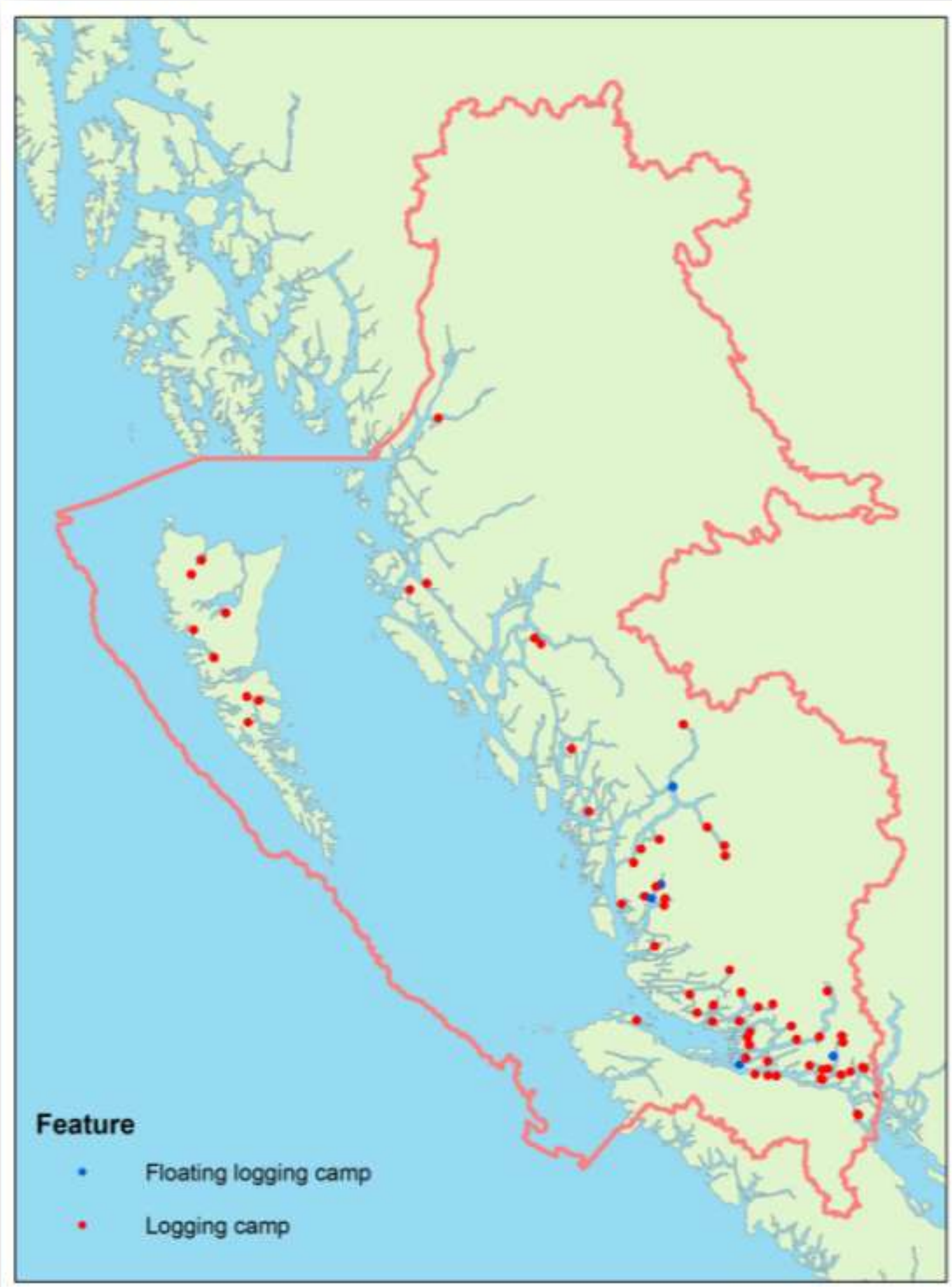

Figure 51. Logging camps in the PNCIMA (data: BCILMB 2008).

14.4. Monitoring

14.4.1. Pulp and Paper Mills

In accordance with the Environmental Management Act: Pulp Mill and Pulp and Paper Mill Effluent Control Regulation, pulp mills must sample each effluent outfall at the following minimum frequencies (Government of British Columbia 1990):

- 5 times per week for total suspended solids (TSS)
- 3 times per week for biochemical oxygen demand (BOD_5)
- for a pulp mill that bleaches pulp with chlorine or a chlorine compound, once a week for adsorbable organically bound halogens (AOX; provides a measure of dioxin and furan release)
- once per month for toxicity (using rainbow trout during a 96 hour exposure)
- continuous or daily grab for temperature
- daily for flow

Additionally, the current federal regulations require extensive environmental effects monitoring and reporting for all pulp mills (Colodey et al. 1999). The Pulp and Paper Effluent Regulations (PPER) require Canada's pulp and paper mills to conduct Environmental Effects Monitoring (EEM) Program studies on their receiving environments in order to assess and monitor the potential effects of their effluents on fish, fish habitat, and the use of fisheries resources. The EEM studies focus mainly on benthic invertebrate community and fish population surveys. Where required supporting information pertaining to the sublethal toxicity of effluents, water, sediment and fish tissue quality, and tainting of fish is also collected (EC 2003a).

Table 31 provides a summary of the most recent cycle of environmental effects monitoring (1997-2000) (Hatfield Consultants Ltd. 2000). Based on this information, Skeena and Elk Falls show no observable effects on biota, Port Alice has some present-day inhibition of biota (possibly due to historical deposits), and Eurocan shows some signs of fish tainting.

Table 31. Summary of cycle two results on biota in the receiving environment, British Columbia pulp and paper mills[1] (source: Hatfield Consultants Ltd. 2000).

Category	Freshwater	Marine	Total
No observed or observable effect on biota by present-day pulpmill effluent in the receiving environment: Northwood, PG/IC, Cariboo, QRP, Celgar, Weyerhaeuser, FCC Mackenzie, Crown, Elk Falls, Crofton, Skeena	8	3	**11**
Some enhancement of biota by present-day pulpmill effluent in the receiving environment: Crestbrook, Fibreco, HSPP, Squamish	2	2	**4**
Some present-day inhibition of biota (may be due to historical deposits) in the receiving environment - continuing improvement: Donohue, Powell River, Alberni, Harmac, Port Alice	1	4	**5**
Fish tainted, however, no observed effect on fish survey measurements or benthic invertebrate communities: Eurocan	1	0	**1**
TOTALS	**12**	**9**	**21**

[1]Scott not included, given no studies were conducted in the receiving environment. Note: Dioxin/furan contamination is considered an historical effect and not part of present-day (Cycle Two) effects.

14.4.2. Pesticides

Monitoring of pesticide applications involves collecting water samples during specified time periods before and after the pesticide has been applied to determine if any of the pesticide has leached into the drainage system. A typical monitoring program would involve the collection of seven water samples from a stream or river downstream of the treatment area (Dent and Robben 2000):

- sample 1-2 hours before the operation (control)
- sample 15 minutes after the operation
- sample 2 hours after the operation
- sample 4 hours after the operation
- sample 8 hours after the operation
- sample 24 hours after the operation.
- runoff sample if a runoff event occurs within 72 hours of the pesticide application

These samples would then be sent to a laboratory for analyses to determine if any of the pesticide was present.

14.4.3. Log Storage, Handling, and Booming Operations

The Habitat and Enhancement Branch (HEB) and Canadian Coast Guard (CCG) of DFO, under the Fisheries Act, require the preparation of a site-specific Debris Management Plan for each log storage, handling, or booming site. These plans describe the environmental management objectives, operation- specific best management practices (BMPs) to be followed, and methods to be used in monitoring BMPs. After approval by DFO, the plan is posted at the site, and staff is advised of the procedures (G3 Consulting Ltd 2003).

As part of the Debris Management Plan, monitoring of intertidal and subtidal areas for accumulated bark and other wood waste may be required. Monitoring requirements will vary, depending on the operation and its location. Monitoring should be conducted prior to the operating season and at defined intervals during the operating season. Monitoring should assess the effectiveness of debris control measures. At intermittently used facilities, monitoring should occur during the operational period. At long-term facilities, underwater surveys of subtidal areas may be required annually or every few years (G3 Consulting Ltd 2003).

Monitoring may involve walks of the intertidal area, or a more comprehensive underwater survey (dive, towed video camera, or remotely operated vehicle) of intertidal and subtidal areas, including permanent transects and measurements of thickness and percent coverage of bark debris, may be required (G3 Consulting Ltd 2003).

Monitoring reports submitted to DFO (CCG and HEB) as part of the Debris Management Plan are intended to inform CCG of the occurrence of large woody debris (e.g., logs, deadheads) that can pose navigational hazards and HEB of occurrence of woody debris accumulation that can negatively impact habitat (G3 Consulting Ltd 2003).

14.5. Mitigation

14.5.1. Pulp and Paper Mills

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_2 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) noted a decrease of 97% between 1989 and 1994.

Further reductions in pollutants contained in the effluents generated by pulp and paper mills could be achieved by following the recommendations put forward by the World Bank (World Bank Group 1998):

- Use energy-efficient pulping processes wherever feasible. Acceptability of less bright products should be promoted. For less bright products such as newsprint, thermomechanical processes and recycled fiber may be considered.
- Minimize the generation of effluents through process modifications and recycling of wastewaters, with an aim towards total recycling.
- Reduce effluent volume and treatment requirements by using dry instead of wet debarking; recovering pulping chemicals by concentrating black liquor and burning the concentrate in a recovery furnace; recovering cooking chemicals by recausticizing the smelt from the recovery furnace; and using high-efficiency washing and bleaching equipment.
- Minimize unplanned or nonroutine discharges of wastewater and black liquor, caused by equipment failures, human error, and faulty maintenance procedures, by training operators, establishing good operating practices, and providing sumps and other facilities to recover liquor losses from the process.
- Reduce bleaching requirements by process design and operation. Use the following measures to reduce releases of chlorinated compounds to the environment:
    - before bleaching, reduce the lignin content in the pulp for hardwood by extended cooking and by oxygen delignification under elevated pressure
    - optimize pulp washing prior to bleaching
    - use TCF (totally chlorine free) or at a minimum, ECF (elemental chlorine free) bleaching systems
    - use oxygen, ozone, peroxides (hydrogen peroxide), peracetic acid, or enzymes (cellulose-free xylanase) as substitutes for chlorine-based bleaching chemicals
    - recover and incinerate material removed from bleached pulp
    - where chlorine bleaching is used, reduce the amount chlorine required by better control of pH and chlorine additions.

14.5.2. Pesticides

The use of herbicides in forestry in BC is regulated by both federal and provincial governments. Regulations require there to be a pesticide free zone around streams and water bodies, as well as a buffer zones around the pesticide free zone. The width of these zones depends on whether the streams are fish-bearing, and on the application method. No buffer zone is required for application of herbicides to individual plants (Samis et al. 1992). These regulations are considered sufficient for preventing glyphosate and triclopyr from entering water bodies if the pesticides are applied according to regulations and label instructions (Wilington 1987). Accidental spraying over small streams or spills could, however, introduce these compounds into aquatic environments (Haggarty et al. 2003).

14.5.3. Log Storage, Handling, and Booming Operations

Best management practices now guide log handling facilities to deeper water with rocky substrates and to areas without concentrations of sensitive plants such as eelgrass and kelp beds (BCMOE 2006b). A list of some of the best management practices for log storage, handling, and booming operations in marine waters is given below (G3 Consulting Ltd 2003):

- No facilities should be developed on or adjacent to extensive tidal flats, salt marshes, kelp or eelgrass beds, seaweed-harvest areas or shellfish beds.

- Log dumps, helicopter log dumps and booming areas generally should be situated at least 100 m from the mouth of an anadromous fish-bearing stream.
- Facilities should not be developed in areas known to be important spawning or rearing habitat for commercially or recreationally important finfish (e.g., salmonids, herring or eulachon) or shellfish.
- Construction or operational activities should not occur closer than 100 m to significant wildlife trees (e.g., active raptor nests) and 300 m from heronries.
- Facilities should not be sited where there is a risk that construction or operation will have an impact on protected water resources and special habitats (e.g., marine protected areas, national or provincial parks), critical or sensitive ecosystems, seabird congregating areas, marine mammal haulouts or wildlife migration paths.
- Logs should not be dumped or stored in areas where they will ground at low tide. The minimum depth currently required by DFO is 12 m (Chart Datum) for most log storage sites and 20 m for helicopter log drops and associated temporary storage facilities.
- Currents, tides and wind exposure should be assessed at the site to ensure worker safety for water-based activities.
- Coastal facilities generally should be situated adjacent to straits, channels or deep bays with sufficient current to disperse sunken or floating wood debris. Areas to be avoided include locations adjacent to rapidly flowing waters or other turbulent water, where measures to control bark and debris cannot be effective.
- Although facilities are typically sited in waters with suitable anchorage and protected from weather, blind channels, sloughs and embayments with sills should be avoided, as they lack sufficient flow to ensure adequate, regular flushing for debris dispersal.
- Booming and storage facilities should be safely accessible to tugboats with log rafts at most tides and on most winter days and should be oriented to provide maximum tidal flushing and exchange by prevailing currents.
- Appropriate measures must be taken to control and remove wood debris generated, including daily removal (to the maximum achievable) of debris that accumulates at the site and on adjacent tidelands.
- Solid waste (wood, cables, metal bands, used equipment, machinery, vehicle or boat parts, metal drums, appliances, etc.) should be removed routinely and disposed of in an approved manner, not in or adjacent to any waters, wetlands or tidal areas.
- Treated wood cuttings and absorbents must not be incinerated.
- Logs should be bundled or sorted on land wherever possible; in-water sorting should be done within the log pocket.
- Log bundles should be placed in receiving waters at a single specified point.
- Log bundles should be broken on land or at a mill, not in the water, where possible.
- Easy let-down devices (e.g., A-frames, stiff-legged derricks) should be used to place logs in water, wherever feasible, to reduce generation of wood debris.
- Free-fall, violent dumping of logs into water is prohibited, as this is the major cause and point source of loose bark and other wood debris.
- Steel skids should be used at long-term skidways to minimize bark deposition; containment of wood waste using debris nets made of flexible steel mesh is recommended to reduce entry of wood waste to the water. Nets should be installed between the steel skids and draped over the high foreshore.
- Bark and wood debris that accumulates in upland traffic areas should be removed and disposed of regularly to prevent debris and leachate from entering the water.
- Foreshore and intertidal zones must be kept clear of debris (including deadheads).
- Logs to be boomed should be limbed and cleaned of all debris on land; debris and chunks should not be mixed with logs.
- Bundle wires must be secured tightly around logs to prevent escape, breakage or excessive shifting during handling.
- A low- or no-wake zone for booming boats should be established near shore and in shallow waters where wave action would cause erosion, suspend sediment or damage nests, resting grounds or feeding grounds.

- Logs and log bundles that have been transferred to water should remain floating at all times and not be allowed to rest on or touch the bottom.
- Logs should be rafted and stored in waters at least 12 m deep (Chart Datum), in an area with currents strong enough to disperse wood debris.
- Logs or log bundles should be moved out of assembly and storage areas at the earliest possible time to minimize retention of logs in the water.
- The number of logs stored in the water should be minimized; onshore log storage is preferable, where feasible.

14.5.4. Erosion

Some strategies mitigating the potential effects of forest harvesting on soil erosion include (Campbell et al. 2007):

- Conducting detailed studies (e.g., terrain stability) to examine how susceptible watersheds are to the effects of harvesting, and developing harvesting plans and forest management plans accordingly.
- Ensuring that the forest regenerates, either naturally or by planting. As forests regenerate, hydrologic functions recover, and the potential for soil erosion is reduced.
- Limiting the size of cut-blocks.
- Using alternative methods of harvesting, such as partial cutting or selective logging, rather than clear-cutting.
- Reducing the amount of sediment entering streams to protect water quality (e.g., by ensuring that riparian buffer zones and stream crossings are functioning correctly).
- Constructing road-drainage features to reduce the ability for runoff to concentrate.
- Deactivating forest roads.

15. Pollution Associated with Mining and Smelting

15.1. Mining

British Columbia has hundreds of both active and out-of-production (historical) mineral and metal mines (BCMOE 2006b). Some terminology associated with mining in BC is given below (BCMEMPR 2007a):

- **Underground mining** - a mining operation which extracts rocks and minerals from below the surface of the ground. Generally access to the underground mine workings is through an adit (entrance in the side of a hill), down a mine shaft or through some other tunnel configuration.
- **Open pit mining -** a mining operation which extracts minerals that lie near the surface. Overlaying rock, or overburden, is removed to expose the ore body, which is then drilled, blasted, and loaded into trucks for haulage from the pit.
- **Ore** – a natural rock mineral which contains valuable metals (e.g., copper, lead, molybdenum, zinc, gold).
- **Construction aggregates** - includes all construction materials such as sand, gravel, crushed rock, clay and other naturally occurring and generally low-value fine grained materials.
- **Concentrate -** enriched ore after the removal of waste rock. Typically, ore from the mine is crushed, ground, and run through a froth-flotation tank to remove waste rock.
- **Refinery** - a plant in which metal is extracted from an ore or concentrate.
- **Smelter** – a facility in which ore is melted in order to separate impurities from pure metal.

15.1.1. Pollution Sources

Open-pit mining involves the excavation of large quantities of waste rock (material not containing the target mineral) in order to extract the desired mineral ore. The ore is then crushed into finely ground tailings and processed with various chemicals to extract the final product. In Canada the average grades of mined copper are under 1%, meaning that for every tonne of copper extracted 99 tonnes of waste material (made up of soil, waste rock and the finely ground “tailings”) must also be removed. The amount of gold extracted per tonne of material disturbed is even less. Almost three tonnes of ore is needed to produce enough gold for one typical wedding band. The Canadian mineral industry generates one million tonnes of waste rock and 950,000 tonnes of tailings per day, totalling 650 million tonnes of waste per year (MiningWatch Canada 2000).

After being removed, waste rock, which often contains acid-generating sulphides, heavy metals, and other contaminants, is usually stored above ground in large free-draining piles. This waste rock, and the exposed bedrock walls from which it is excavated, are the source of most of the metals pollution caused by mining in British Columbia. In other regions of North America tailings may also represent a major source of heavy metals contamination of waterways (MiningWatch Canada 2000).

There are four main types of mining impacts on water quality (MiningWatch Canada 2000):

Acid Mine Drainage. Acid rock drainage (ARD) is a natural process whereby sulphuric acid is produced when sulphides in rocks are exposed to air and water. Acid mine drainage (AMD) is essentially the same process, greatly magnified. When large quantities of rock containing sulphide minerals are excavated and exposed to the atmosphere, they react with water and oxygen to create sulphuric acid. After the water reaches a certain level of acidity, a naturally occurring bacterium called *Thiobacillus ferroxidans* will start to grow, accelerating the oxidation and acidification processes, and resulting in even more leaching of trace metals from the wastes. Sulfuric acid will leach from the rock as long as it is exposed to air and water, and there are still sulphides present – a process that can last hundreds, even thousands of years. Acid is carried off the mine site by rainwater or surface drainage, and enters nearby streams, rivers, lakes and groundwater.

- **Heavy Metal Contamination and Leaching**. Heavy metal pollution is caused when metals such as arsenic, cobalt, copper, cadmium, lead, silver, and zinc contained in rock which has been excavated or exposed in an underground mine come in contact with water. Metals are leached out and carried downstream as water washes over the rock surface. Although metals can become mobile in neutral pH conditions, leaching is accelerated in the low pH conditions created by AMD.
- **Pollution from Processing Chemicals**. This kind of pollution occurs when chemical agents (such as cyanide or sulphuric acid used by mining companies to separate the target mineral from the ore) spill, leak, or leach from the mine site into nearby water bodies.
- **Erosion and Sedimentation**. Mining activities disturb soil and rock in the course of construction and maintenance of roads, open pits, and waste impoundments. In the absence of adequate prevention and control strategies, erosion of the exposed earth may carry substantial amounts of sediment into streams, rivers and lakes.

15.1.2. Environmental and Socio-Economic Impacts

Table 32 briefly describes the activities that take place at each stage during the development, operation, and decommissioning of a mine, and the potential environmental and socio-economic impacts which may occur. With respect to the marine environment, mines can have the following serious impacts on water quality (MiningWatch Canada 2000):

- The low pH levels caused by the ARD severely degrades water quality, and can kill aquatic life.
- Heavy metals contained in the ARD, such as copper, zinc, and cadmium, can be toxic to fish and animals, and can adversely affect environmental health (see section 7).
- Processing chemicals can be highly toxic to humans and wildlife.
- Excessive sediment can smother vegetation, wildlife habitat, and aquatic organisms.

Once ARD conditions have been established, they are difficult and expensive to mitigate and can last for centuries. As such, metal and coal mines are required to develop mitigation plans prior to mine closure. Historic mines (e.g., Britannia and Mt. Washington) that were closed before the ARD regulations came into effect, have caused significant environmental impacts (BCMEMPR 1998).

Table 32. Potential environmental impacts from each phase of mining (source: EC 1996, MiningWatch Canada 1998).

Development Phase	Potential Activities	Potential Environmental and Socio-economic Impacts
Exploration	• airborne and ground-based geochemical and geophysical surveys • prospecting and claim staking • line cutting, stripping, drilling and trenching • road/trail building and/or helicopter transport • bulk sampling	• generally low or no impact, involving issues such as: o land removal from protected status o access to harvesting and fishing areas o camp garbage o noise pollution • when exploration reaches a stage which requires trenching, drilling, or road access, habitat disturbance increases, involving issues such as: o trail/road and trenching erosion o acid mine drainage o habitat disruption
Mining and milling	• environmental impact assessment • mine design and construction • stripping/storing of "overburden" of soil and vegetation • ore extraction • crushing/ grinding of ore • flotation or chemical concentration of ore • mine and surface water treatment • storage of waste rock and tailings	• wildlife and fisheries habitat loss as a result of waste rock piles and tailings disposal areas • changes in local water balance • increased erosion, sedimentation, and silting of lakes and streams • containment of toxins in tailings ponds • tailings ponds stability failure • potential acid generation from waste rock and pit walls • discharge of acid mine drainage that contains contaminants that are released to surface water and groundwater; particular concerns are related to: o heavy metals originating from the ore and tailings o organic compounds originating from the chemical reagents used in the milling process o cyanide, particularly from gold milling processes o ammonia • wind borne dust • noise
Smelting and refining	• processing of mineral concentrate by heat or electro-chemical processes	• discharge of contaminants to air, including heavy metals, organics, and sulphur dioxide (which contributes to acid rain) • toxic chemical (e.g., ammonia, sulphuric acid) use for processing • loss of habitat due to slag heaps • indirect impacts as a result of energy production (smelting and refining have high energy requirements)
Mine closure	• recontouring of pit walls and waste dumps • covering of reactive tailings dumps • decommissioning of roads • dismantling of buildings • re-seeding/planting of disturbed areas • ongoing monitoring and possible water quality treatment	• continued discharge of acid mine drainage into ground and surface water • revegetation failure • wind borne dust • wildlife and fisheries habitat loss may occur as a result of slope and tailings impoundment failures

15.1.3. Concerns in the North and Central Coast

Mining is one of the few major active industries in the PNCIMA (Johannessen et al. 2007a). Much of the PNCIMA has been prospected for mineral claims, and has a long history of mining activity. The first coal mine in the area was located near Fort Rupert, and opened in 1849 to supply the Royal Navy and Hudson's Bay Company steamships with fuel. Iron ore mining followed, with significant production from the Benson Lake mine until 1967. The Yreka Copper Mine, located west of Neroutsos Inlet, was the first copper mine. It operated periodically between 1902 and 1967, and disposed of mine tailings into Neroutsos inlet, immediately south of Rupert Inlet (Haggarty et al. 2003).

A large number of decommissioned and active mines exist in the watersheds of the PNCIMA. 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 (Johannessen et al. 2007a). Acid rock drainage (ARD) is the single largest environmental problem facing the mining industry (O'Kane et al. 1997). Acidic compounds are produced when sulphide minerals in rocks are exposed to water and air. Many metals become soluble under acidic conditions and leach into the surrounding environment. Most metal mines and some coal mines are susceptible to ARD, depending on the amount and type of rock surface area exposed to weathering by blasting and crushing. Increased acidity and concentrations of dissolved metals such as copper, zinc, and cadmium can be toxic to biota (BCMEMPR 1998). Twelve sites in the PNCIMA have been identified as at risk to produce acid rock drainage and heavy metal leachate (see **Figure 52**), but monitoring has been sufficient at only six of them to evaluate environmental impact (BCMWLAP 2002). 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).

From a socio-economic perspective, high mineral prices are fuelling a "gold rush" in Northwest British Columbia. At least five new mines are proposed for the Stikine region alone. New mines create new jobs and provide other economic benefits; however, sudden drops in mineral prices can lead to unexpected mine closures and unemployment. As jobs and workers come and go, mine-dependent communities find themselves riding a population rollercoaster. Local infrastructure may be strained during booms, while people will often move away during busts. Changing levels of wealth, population, and employment can also fuel social problems, including drug and alcohol abuse, and loss of culture. When mines close for good, the social problems they created often remain (The Pembina Institute 2000).

Figure 52. Mines at high risk for acid rock drainage in the PNCIMA (data: BCMEMPR 2008b, BCMWLAP 2002).

15.1.3.1. Prospects

Prospects are documented mineral deposits which warrant further exploration. These are sites where which may be developed into mines in the future. **Figure 53** shows the locations of prospects in the PNCIMA.

15.1.3.2. Developed Prospects

A developed prospect is a mineral deposit on which exploration and development have progressed to a stage that allows a reasonable estimate of the amount(s) of one or more of the potentially mineable commodities. These are sites that could potentially be mined if the commodity prices are sufficiently high enough to warrant the cost of extraction. **Figure 54** shows the locations of developed prospects in the PNCIMA. Depending on the amount of soil and rock disturbed during the exploration process, developed prospects may also experience some ARD problems.

15.1.3.3. Active Mines

A producer is a currently producing, or active, mine. It consists of a mineral deposit from which ore containing one or more commodities is being mined for commercial gain or benefit. There are 6 active mines in the PNCIMA (see **Figure 55**). Five of them, Apple Bay (silica), Benson Lake (limestone), Tsitika Grey (granite building stone), Quisam (coal), and Myra Falls (copper), are located on Northern Vancouver Island. The sixth, Anyox Slag Heap (silica), is located in Alice Arm (BCMEMPR 2008a). Studies have been carried out at several of these mines which have ARD problems:

- **Quinsam**. Quinsam Coal Mine started as an open pit mine in 1987, went underground in 1990, and has been fully underground since 1994. The mine produces approximately 520,000 tonnes of coal per year, and employs 91 people. A coal preparation plant is associated with the mine. Coal is loaded onto barges at the Middlepoint Storage and Barge Loading Facility in Campbell River, and delivered directly to Vancouver or Seattle, or it is barged to a ship loading facility on Texada Island for international shipments (Hillsborough Resources Limited 2005).

  The Quinsam Coal Mine is located on the Quinsam River, which drains 280 km^2 of land on the east coast of Vancouver Island. The Quinsam River drains into the Campbell River 3 km upstream of the Strait of Georgia. Regular, biweekly water quality monitoring has taken place since 1986. Major ions such as sulphate, cadmium, magnesium, sodium, and strontium, as well as the related indicators of hardness and conductivity, have shown increasing trends at the mouth of the Quinsam River since the early 1990s. These changes have been attributed to the mine. Despite these increases, water quality indicators are well below safe levels for water uses. The sulfate levels upstream near the coal mine are higher, and may pose a threat to aquatic life, though no effects have been observed. There is no evidence of acidification of the waters near the mine (BCMELP and EC 2000). There is no information on any possible downstream effects. There is a possibility of ARD from this mine (Office of the Auditor General of British Columbia 2003).

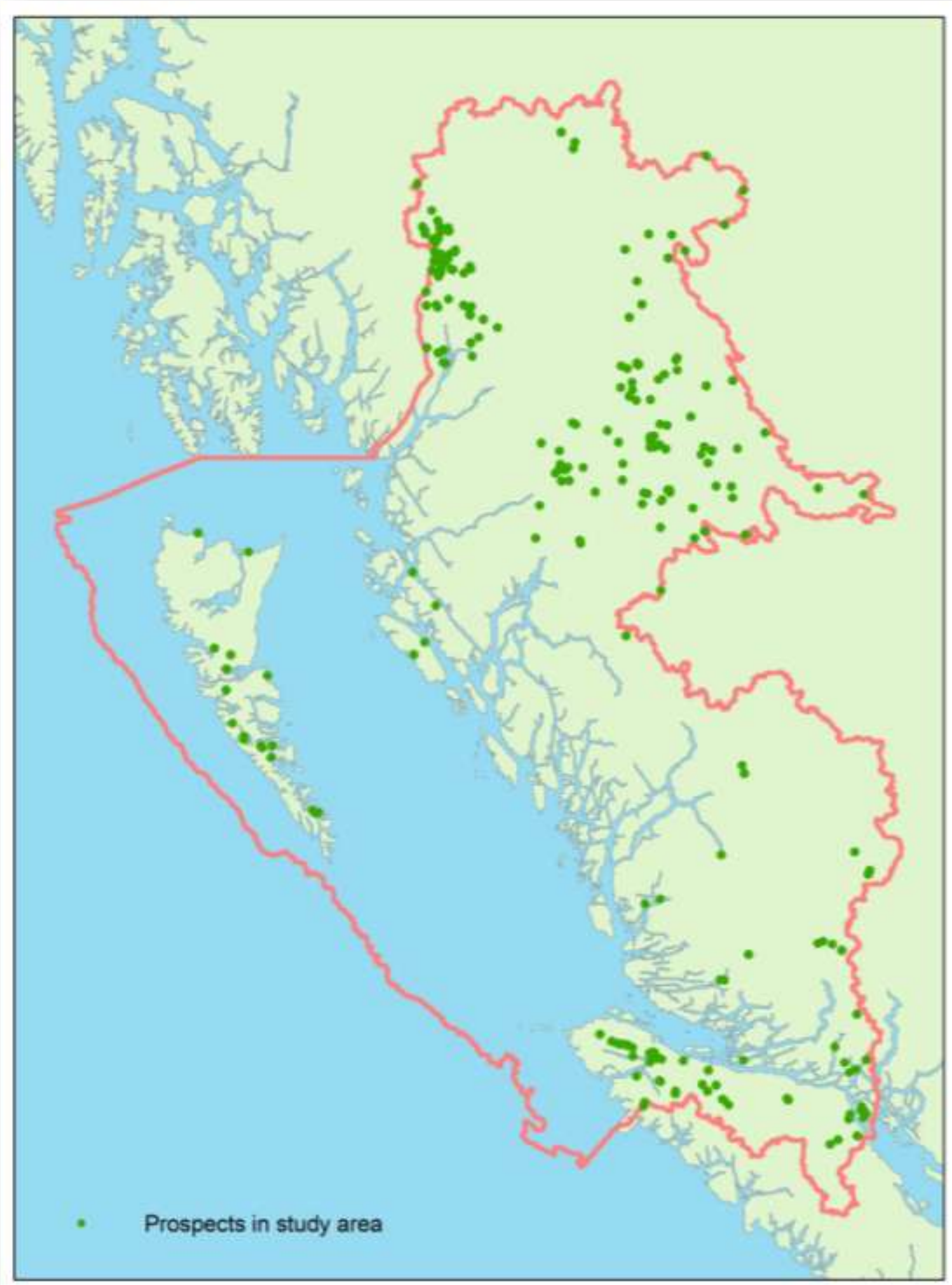

Figure 53. Prospects in the PNCIMA (data: BCMEMPR 2008a).

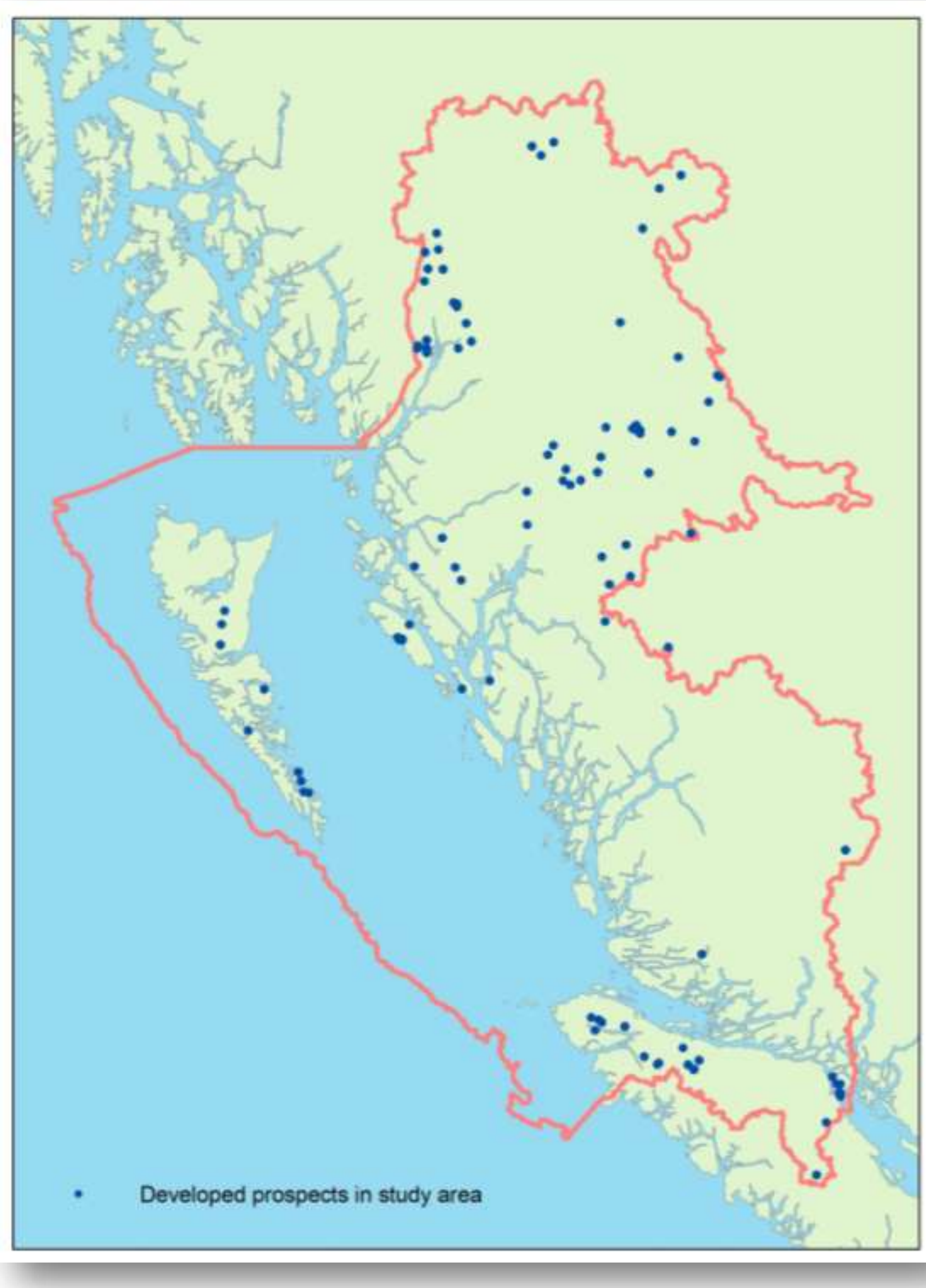

Figure 54. Developed prospects in the PNCIMA (data: BCMEMPR 2008a).

Figure 55. Active mines in the PNCIMA (data: BCMEMPR 2008a).

- **Myra Falls**. The Myra Falls Metal Mines are located in Strathcona Park Provincial Park on Vancouver Island. The mines, operated by Boliden-Westmin (Canada) Ltd., are situated approximately 90 km southwest of Campbell River, and employ approximately 440 people. Myra Falls was first opened as an open pit mine in 1966, which was expanded in 1985; however, underground bulk-mining methods are now primarily used to extract zinc, copper, lead, gold and silver. As of the end of 2005, proven reserves were 6 metric tonnes, grading 6.4% zinc, 1.1% copper, 1.3 g/t gold and 46 g/t silver. In 2000, Boliden recommenced open pit mining. After having unsuccessfully sought to sell the mine, it was closed from December 2001 until March 2002 to develop an action plan for solving persistent problems relating to ARD. After re-opening in 2002, the 20% cost reduction achieved made the operation profitable. In mid-2004, 'New' Boliden sold the operation to the Canadian company, Breakwater Resources, for $12.5m in shares and options, plus the assumption of environmental liabilities (Mining Technology 2005).

  Studies have been undertaken to develop a mitigation plan for the ARD produced by the Myra Falls Mines (Desbarats 2002, O'Kane et al. 1997, O'Kane et al. 2001). While water discharged from the mine has a near neutral pH for most of the year, it drops sharply to 2.2 with the first autumn rains. The mine discharge is directed to treatment and settling ponds. Treated mine water that meets regulatory standards is discharged to Myra Creek and flows into Buttle Lake. Buttle Lake eventually drains via Campbell River to Discovery Passage (Haggarty et al. 2003). Mitigation methods have involved the use a soil cover system over the mine tailings and waste rock that functions as a barrier to oxygen and water, and as a medium for establishing vegetative cover (O'Kane et al. 1997, O'Kane et al. 2001). By preventing oxygen and water from reaching the tailings and waste rock, ARD is reduced or even stopped.

- **Anyox Slag Heap.** Copper deposits in the area of Granby Bay 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 1982a, 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. Tailings from the copper mining were discharged into small tailings ponds behind the smelter and adjacent to Hidden Creek. It is suspected that seepage 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 (Goyette and Christie 1982a).

  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. Sediment cores obtained near Anyox in 1978 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 (Goyette and Christie 1982a).

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

Currently, the slag heap is being mined by Tru-Grit Abrasives for silica which is used in sandblasting abrasives and asphalt shingles. The Anyox area has not been as well studied as the adjacent Alice Arm, 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. 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 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 is not unavailable.

15.1.3.4. Historical Mines

A past producer is a historical, or past producing, mine. It consists of a mineral deposit that is not currently being mined, but which has had recorded production in the past. Over 200 historical mines are located in the PNCIMA (see **Figure 56**). Approximately 160 of these sites have been ranked with respect to their potential ecological (see **Figure 57**) and human health impacts (see **Figure 58**), and their potential capacity to generate ARD (see **Figure 59**). Based on these rankings, there are four main areas (listed in order from greatest to least impacts) in the PNCIMA where historic mines have the potential to cause significant ecological or human impacts:

1. Northern Vancouver Island
2. Hazelton – Smithers area
3. Stewart – Alice Arm area
4. Northern Moresby Island – southern Graham Island in the Queen Charlotte Islands

Three historic mines, Kitsault, Tasu, and Island Copper, have disposed of their tailings in deep, low-oxygen water in an attempt to avoid ARD (Johannessen et al. 2007b). A number of studies have been carried out on these mines:

- **Amax/Kitsault mine**. The Kitsault mine was operated by BC 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 discharged range from 9.3 million tons (AMAX of Canada 1991, Burd et al. 2000) to 12 million tons (Goyette and Christie 1982a). The property was subsequently acquired by Amax of Canada Ltd. and production continued from April 1981 to October 1982 (Burd et al. 2000, Goyette and Christie 1982a, Littlepage 1978). During this operational period, approximately 4.1 million tons of tailings were discharged directly into Alice Arm through a submarine disposal pipe at 50m depth (AMAX of Canada 1991, Burd et al. 2000).

  In addition to the Kitsault mine, a second mining operation, the Dolly Varden silver mine, also discharged tailings into Alice Arm. The Dolly Varden mine was located roughly 32 km up the Kitsault River from Alice Arm, and 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, suggesting that these metals are attributable to buried tailings from the Dolly Varden operation (Odhiambo et al. 1996).

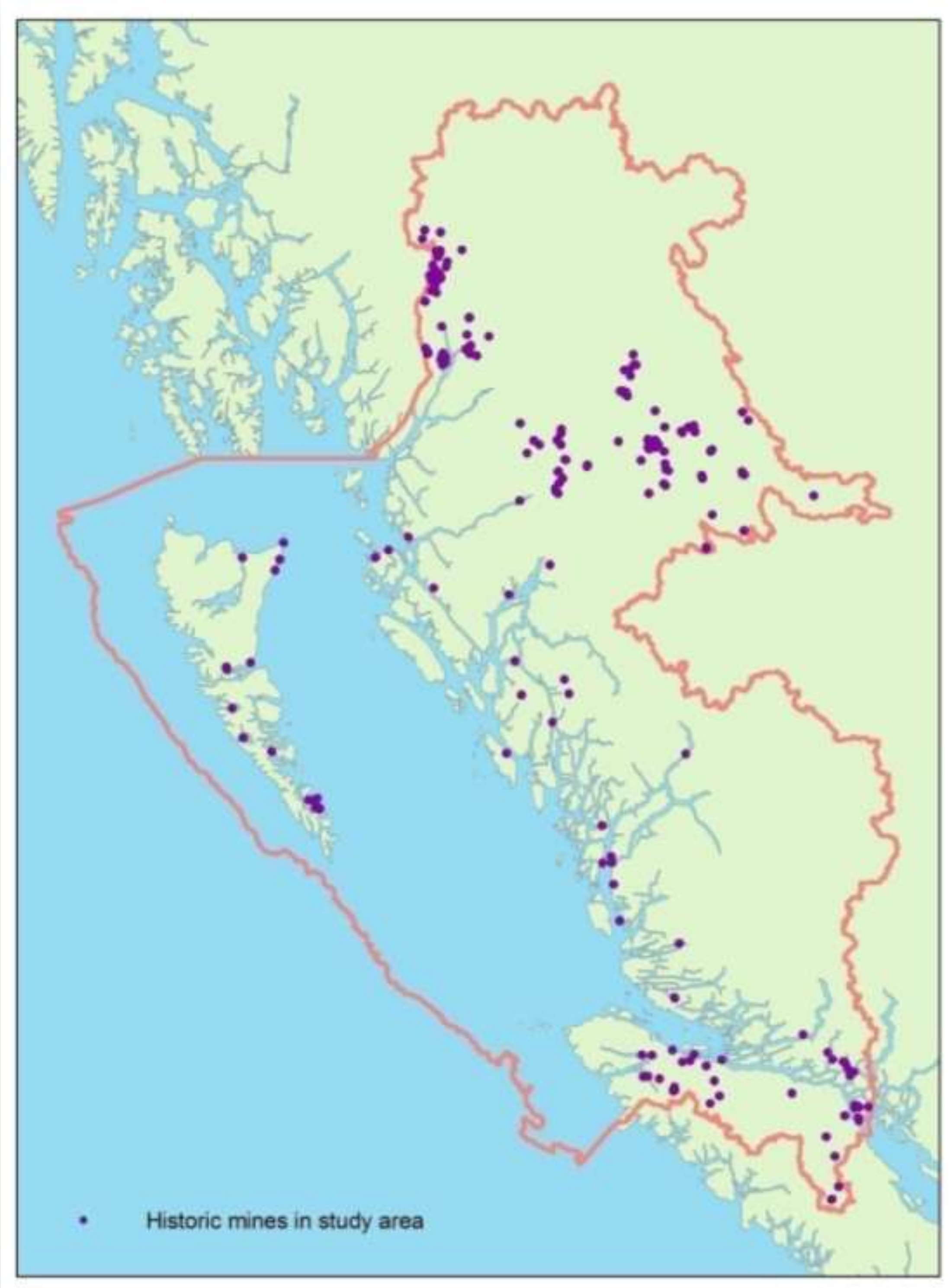

Figure 56. Historical mines in the PNCIMA (data: BCMEMPR 2008b).

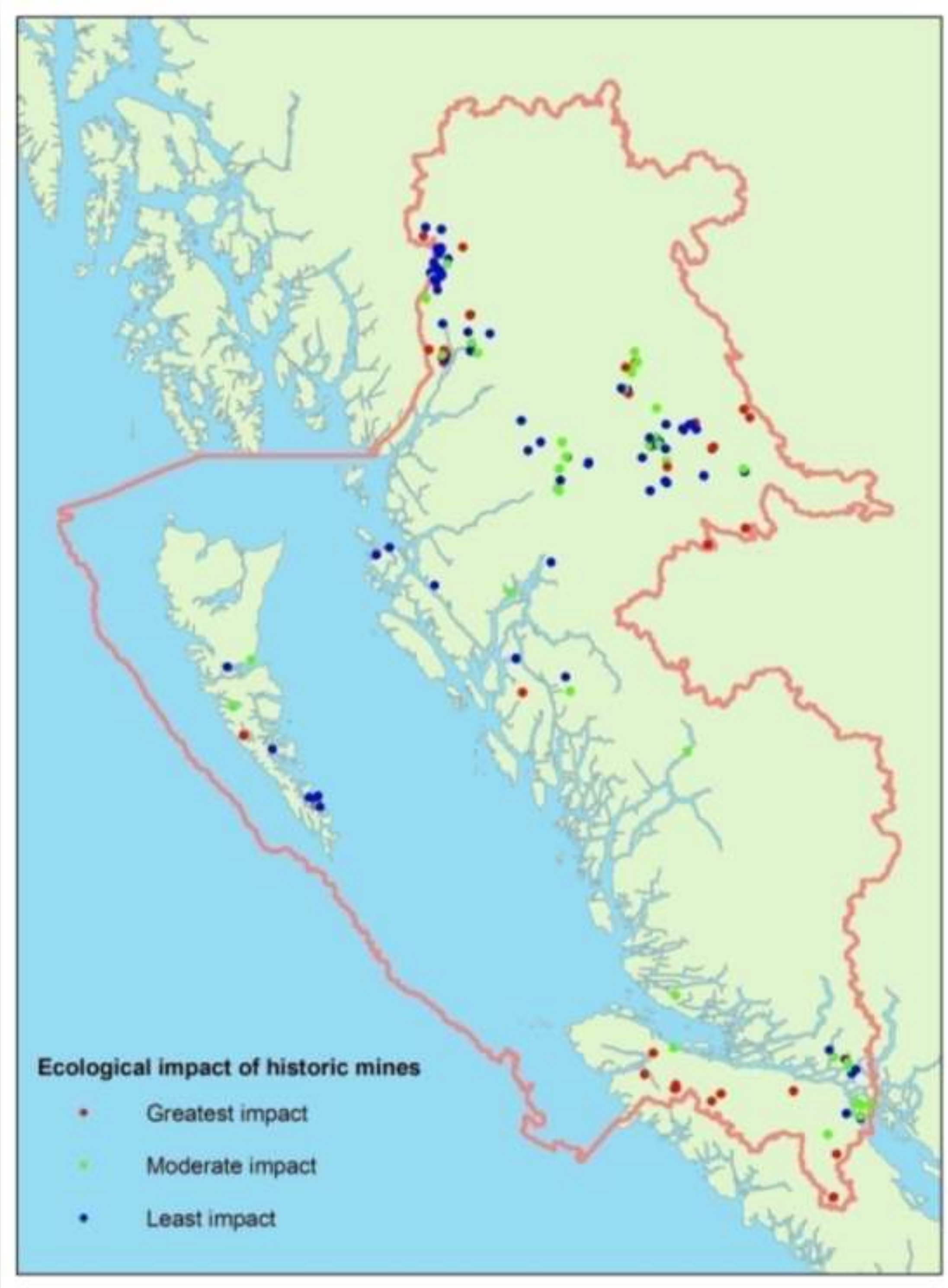

Figure 57. Ecological impact of historic mines in the PNCIMA (data: BCMEMPR 2008b).

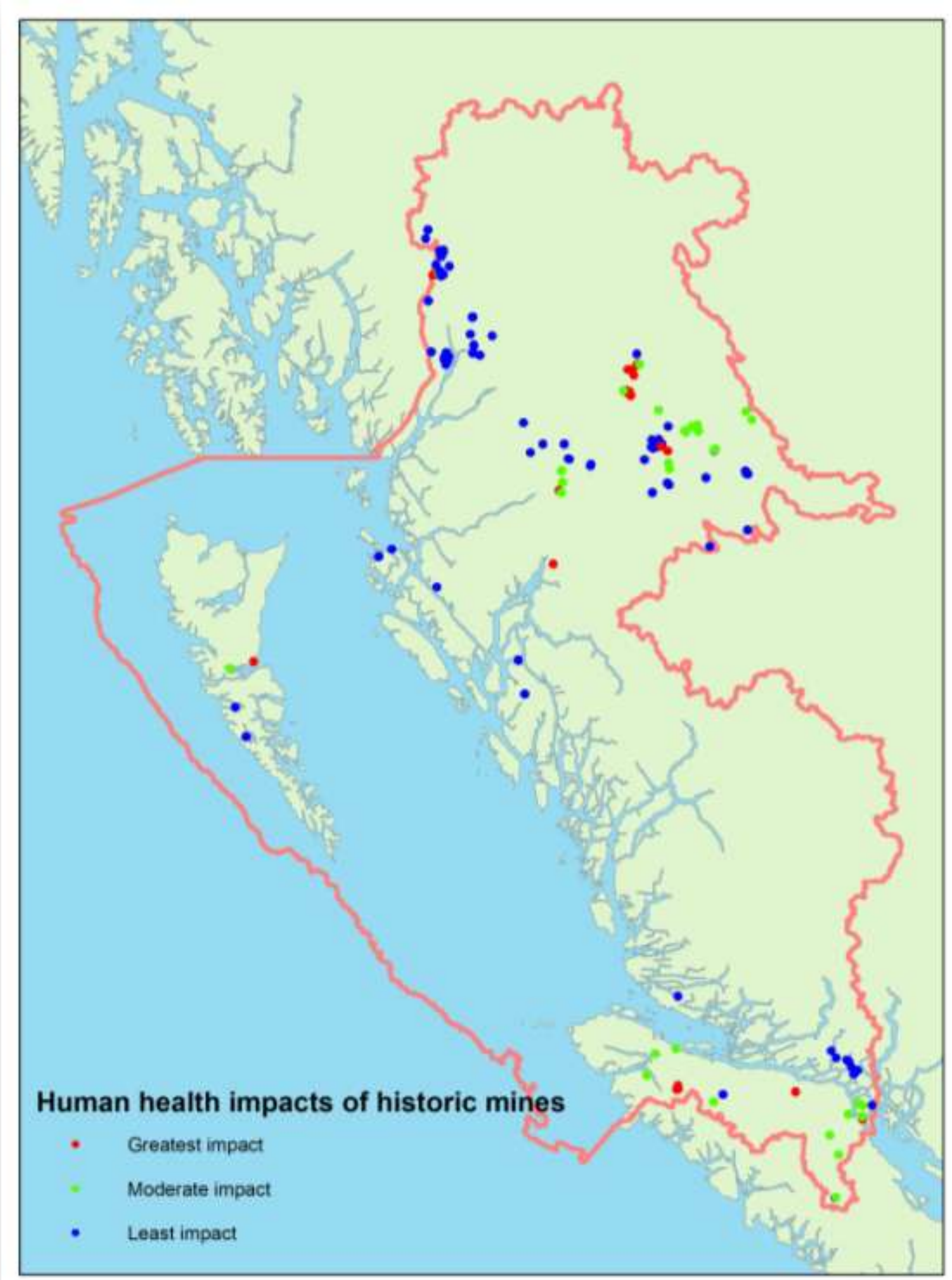

Figure 58. Human health impacts of historic mines in the PNCIMA (data: BCMEMPR 2008b).

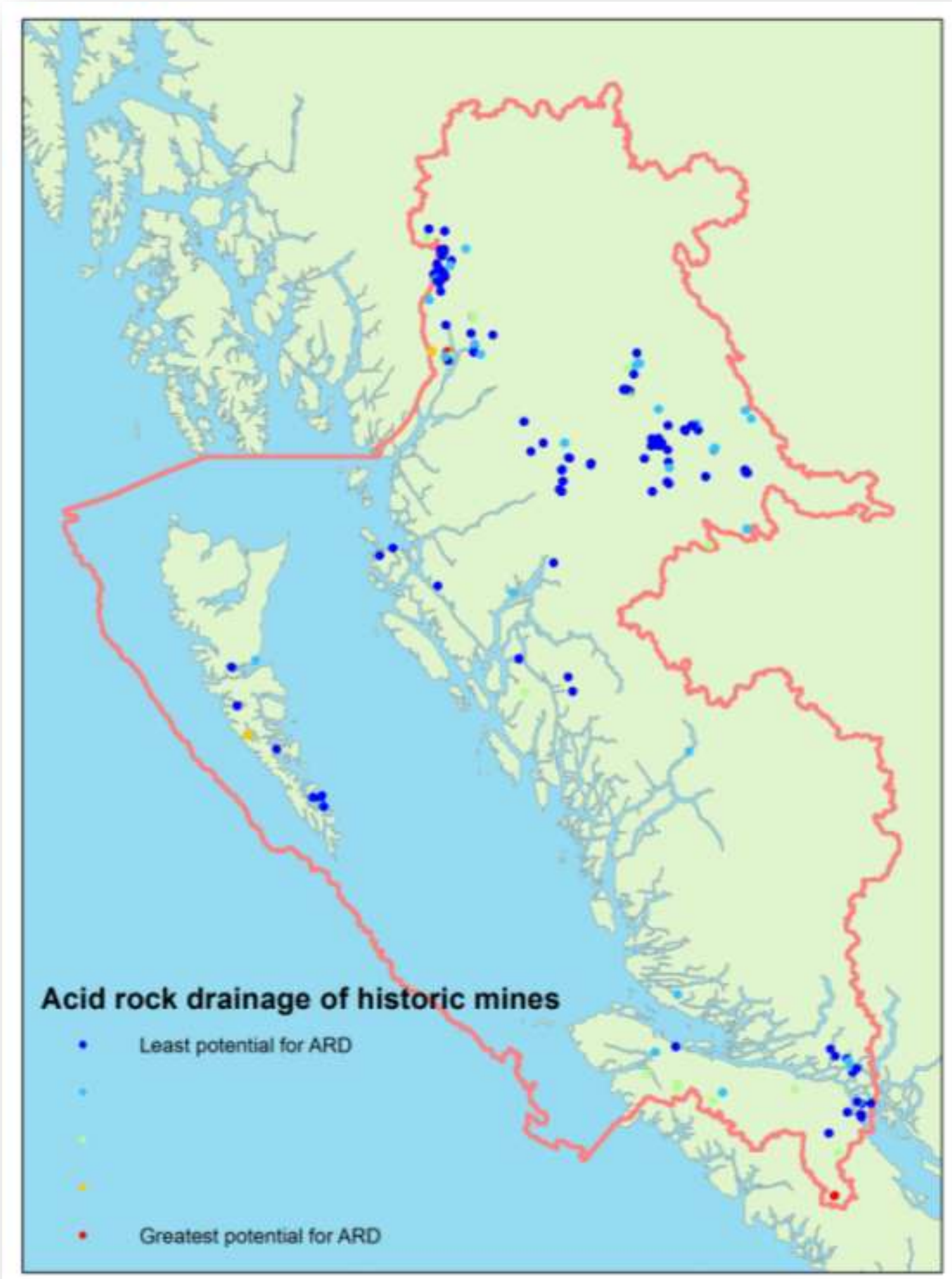

Figure 59. Acid rock drainage potential of historic mines in the PNCIMA (data: BCMEMPR 2008b).

A significant research program at the Amax site was commissioned by Climax Molybdenum Corporation of British Columbia Limited (Amax). It ran from1974 to 1977, and the results of the program were published in 35 technical reports covering physical, chemical, and biological oceanography, as well as biological and hydrological studies. A number of the studies looked at heavy metal content in sediments, water, and biological tissues (Dempsey and Ernst 1975, 1976, Goddard 1974a, b, Lea 1976). The program continued to analyze metal contamination of marine and suspended sediments and biological tissues into the 1980s (Erasmus and Yunker 1983, Smyth 1982, Yunker et al. 1981, 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 (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, 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, b, c, O'Brien and MacDonald 1995), benthic infaunal survey data (Brinkhurst et al. 1987, Burd and Brinkhurst 1990, Kathman et al. 1983, Kathman et al. 1984), data on heavy metal concentrations in various biological tissues (Brand et al. 1984, Byers et al. 1984, Farrell and Nassichuk 1984, Futer and Nassichuk 1983, Thompson et al. 1986), and studies on the effect of the tailings on zooplankton (Anderson 1986, Mackas and Anderson 1983). The data from these studies supported a number of journal articles on topics such as sediment and benthos (Burd et al. 2000, MacDonald and O'Brien 1996, Odhiambo et al. 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 produced a number of reports on submarine tailings disposal in Alice Arm which focused on sediment and tissue metal contamination and water turbidity and chemistry. These reports include studies carried out prior to the 1981 resumption of disposal (Goyette and Christie 1982a, Sullivan and Brothers 1979), studies conducted during mine operation (Goyette and Christie 1982b, Goyette et al. 1985, Hinder and Goyette 1982), 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 sediments have largely been buried, and their impacts on the environment have been reduced. Tailings discharged by the more recent operation of the Kitsault mine are believed to have remained within Alice Arm. Both metal concentration analysis (Odhiambo et al. 1996) and sediment trap data (MacDonald and O'Brien 1996) 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.

Approximately 96% of the tailings (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. Roughly 4% of the tailings formed a mid-water depth plume with an upper edge at 65-125 m 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). 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). Based on these results, it appears that metals in the Alice Arm tailings are not making their way into the foodweb in significant amounts. One exception to this observation is the elevated metal concentrations detected in deposit feeding clams (*Yolida* spp.). Concentrations in these clams closely match those found in the tailings themselves, and it has been suggested that the clams may be contaminated by undigested tailings particles (AMAX of Canada 1991); however, this hypothesis is not universally accepted (Burd et al. 2000).

The only clear impact of submarine tailings disposal in Alice Arm is the physical smothering of benthic infauna. This was predicted, and organisms were expected to recolonize the affected area after mine closure as the tailings became buried by natural sedimentation. Considerable recovery was noted three years after mine closure, although only by some species. Larger organisms showed much slower recovery (Burd et al. 2000). Unexpected slumps and tailings re-suspension occurred after the mine closed, causing new benthos smothering events and re-exposing tailings at the sediment surface (Burd et al. 2000).

- **Tasu Sound Mine, 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 when ore reserves were exhausted.

  Environment Canada completed an environmental assessment on the effects of the discharge in 1977. The assessment determined that the mine tailings 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 the sampling grid was too small. 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. Increased water column turbidity, reduced 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; however no further research has been found to confirm this.

- **Island Copper Mine (Rupert Inlet)**. Exploration of Northern Vancouver Island had found more than 254 million tonnes of ore containing an average of 0.52% copper plus 0.017% molybdenum metals. As a result, the Utah Construction and Mining Company established the Island Copper Mine on the north shore of Rupert Inlet in 1971. The Island Copper Mine, an open pit mine, provided 30,000 tonnes of low-grade ore each day to a processing plant. Ore was crushed to a fine sediment, and processed to physically separate solid particles into copper (as chalcopyrite), molybdenum (as molybdenite), and tailings. The mine produced an estimated 630 tonnes of copper concentrate, 4.93 tonnes of molybdenite and 29,000 tonnes of tailings per day. Once the ore body was exhausted, the mine was closed at the end of 1995 (Haggarty et al. 2003). It produced some 358 million tonnes of tailings which were discharged into Rupert Inlet through an underwater tailings placement system (Poling et al. 2002).

  Although submarine tailings disposal avoids acid mine drainage that is common with land disposal (Burd et al. 2000), deposition of tailings smothers benthic organisms. Due to the anticipated impacts (see **Table 33**), extensive monitoring of Rupert Inlet was required. A long-term data set for the mine was collected over the period from 1970 to 1999 (Poling et al. 2002).

Table 33. Potential environmental impacts of marine disposal of mine tailings (source: Kay 1989).

Category	Environmental Impacts
Physical	▪ Loss of habitat, especially for bottom-dwelling organisms ▪ Increased turbidity around the point of discharge ▪ Spread of tailings and other associated contaminants
Chemical	▪ Increased concentration of trace elements in water column, particularly metals and certain organic compounds ▪ Changes in the redox potential and pH of seawater ▪ Increase in chemical O_2 demand and possibly biochemical O_2 demand ▪ Creation of a reservoir of contaminants in the sediments and/or tailings which may be remobilized through time into water column
Biological	▪ Lethal and sublethal toxic effects on plants and animals ▪ Loss of diversity and possible disappearance of life in severely affected areas ▪ Bioaccumulation and bioconcentration of certain trace elements in biota ▪ Change in benthic community ▪ Decreased photosynthesis due to high turbidity levels

The extensive monitoring program allowed scientist to evaluate the environmental impacts of the Island Copper Mine. These effects are summarized here (Poling et al. 2002):

- Only minor redistributions of the sediment have occurred as a result of the placement of mine tailings.
- No measurable changes to the water temperature and/or salinity, or phytoplankton or zooplankton assemblages were attributable to mine operations.
- Mild eutrophication in the inlet may have occurred, but this may be partly due to other uses.
- Levels of dissolved copper and arsenic did not change, while dissolved manganese increased slightly and dissolved zinc decreased. Following closure of the mine, these two metals reversed their behavior, with manganese decreasing and zinc increasing.
- Water turbidity increased over one station due to upwelling of tailings; however this had no measurable effect on euphotic depth, primary productivity or biodiversity of algal forests.
- Deposition of tailing sediments caused immediate loss of species due to smothering and burial; however, opportunistic and highly mobile species usually persisted (around 10 species). Following closure, there was a rapid recolonization of the sediments, and communities at all stations are thought to have recovered. The rapid recovery of the sediments in Rupert Inlet is encouraging, given that ecological communities from tailings at another mining site in Howe Sound still showed visible signs of impact 12 years after mine closure (Ellis and Hoover 1990).
- Commercial stocks of Dungeness crabs and salmon from Quatsino Sound and Rupert Inlet were not affected by the mine; however, a salmon hatchery developed by the mine may have affected salmon populations (positively or negatively). Concern for commercial species, in part, led to this extensive monitoring project.

Throughout the operations of the mine, effluent was regularly tested for toxicity by measuring the 96-hr LC_{50} of juvenile rainbow trout or coho salmon. The survival rate was almost always 100%.

In the early 1970s, there was concern that the tailings might release biologically active toxic trace metals. Throughout the operation of the mine, many organisms were tested for bioaccumulation of trace metals, such as copper, cadmium, zinc, and arsenic. As a result, a 20-year data set on trace metal bioaccumulation is available for the following species: rockweed, eelgrass, blue mussels, butter clams, littleneck clams, and Dungeness crabs. Throughout the testing period, there were relatively few instances where trace metals exceeded reference levels. The following observations on trace metal bioaccumulation have been made:

- Mussels sampled near the Island Copper Mine loading dock showed the greatest accumulations of cadmium, copper, and zinc. Given the location of the affected mussels, this was thought to reflect the influence of surface-settled dust from concentrate loading rather than metals in mine tailings (Poling et al. 2002).
- Increases in copper and zinc in rockweed and eelgrass tissues were also observed during the mine's operation. Following the mine closure, these levels declined. The slightly elevated metal levels in algae and eelgrass may have reflected the presence of attached particles rather than absorbed and assimilated metals (Poling et al. 2002).
- Dungeness crabs did not have elevated metal concentrations, despite possible sources of trace metals in their food. Metal concentrations in Dungeness crabs at both test and reference areas fluctuated synchronously (Harding and Goyette 1989).
- A study of background levels of metals in shrimp, prawn and fish tissue from various locations in BC (Barkley Sound, Quatsino Sound, Laredo Sound, Surf Inlet and Hecate Strait) found that metal levels for shrimp and prawns from Quatsino sound did not differ from any of the other locations. Fish samples did not allow for statistical comparison among areas (Harding and Goyette 1989).
- The lack of accumulation of copper in biota is not surprising. It has now been shown that the source of copper from this mine, chalcopyrite, is virtually insoluble, and therefore not bioavailable (Poling et al. 2002).

After the Island Copper Mine was closed, the open pit was flooded with seawater and capped with freshwater, thus creating a meromictic lake and forming a passive treatment system for ARD. ARD problems, as have been found in the Britannia Beach Mine site in Howe Sound, are not expected, although the possibility remains a concern, particularly in the exposed waste rock at the site (Office of the Auditor General of British Columbia 2003). The remainder of the mine site surrounding the pit has been reclaimed. The mine site has received many reclamation awards (Poling et al. 2002).

There are indications that metal concentrations in the sediments and organism tissues, particularly copper, had returned to background values by 1997 (Poling et al. 2002).

15.1.4. Monitoring

Long-term environmental monitoring should take place during the operation of the mine and for many years following the mine closure to ensure that measures taken to prevent pollution from the mine are effective. The type of monitoring required will depend on the type of mine operation, the mineral composition of the ore, the climate, the proximity of the mine to sensitive habitats, the potential of the mine to impact human health, and a number of other factors. Typical monitoring activities include measurement of:

- dissolved metals in the marine environment (both in seawater and sediment)
- metals in the tissues of a variety of marine organisms
- water turbidity
- sediment transport, slumps, and resuspension

- bioconcentration of metals in local food chains
- changes in ecosystem diversity and species composition

15.1.5. Mitigation

Before the BC Ministry of Energy and Mines will issue a mining permit, metal and coal mines must now predict the potential for metal leaching and acid rock drainage and have mitigation plans in place for potential ARD if necessary (BCMOE 2006b). Some possible mitigation strategies are listed below (BCMEMPR 1998):

- **Avoidance** - From the perspective of environmental protection and minimizing liability and risk, the most effective mitigation strategy, and the first that should be considered, is avoidance through prediction and mine planning. Total or partial reduction in excavation or exposure of problematic materials can limit or prevent sulphide oxidation and metal release. Unfortunately, physical avoidance and ore extraction are often mutually exclusive.
- **Underwater Storage** - If problematic rock types are to be excavated or exposed, underwater storage is generally the most effective means of preventing ARD and reducing metal leaching. Since flooding may increase the rate at which weathered minerals dissolve, flooding must be done prior to significant acid weathering. After flooding, the storage location must remain permanently flooded and geotechnically stable.
- **Chemical Treatment** - Where contaminated drainage can be collected, chemical treatment (e.g., adding lime) can neutralize the ARD, reduce downstream metal concentrations, and prevent off-site impacts. Chemical treatment does not reduce sulphide oxidation in or leaching of weathering minerals from the tailings; contaminated drainage will continue to exist upstream of the collection location.
- **Blending and Covers** - While blending (e.g., mixing the tailings with other materials that can neutralize the ARD) and surface covers (e.g., placing an engineered cover over the tailings to reduce exposure to oxygen and infiltration by water) may be used to reduce metal leaching, concerns regarding reliability and effectiveness presently restrict their use.
- **Waste Segregation** – Mine wastes are segregated, based on their reactivity and potential to create ARD, in order to reduce oxygen exposure and drainage, and to increase neutralization. Segregation may be used together with blending as a means of mitigation (e.g., potentially ARD generating materials [PAG] are separated from not-potentially ARD generating materials [NPAG]; if the NPAG has excess neutralization potential, it can be blended with the PAG to reduce its potential acidity).

15.2. Coalbed Methane

Coalbed methane production involves the extraction of methane (natural gas) from coal seams. Coalbed methane exists wherever coal deposits are found. The main areas in BC where coalbed methane is found are in the Peace country in the northeast and in the Elk Valley in the southeast. Other areas with coalbed methane potential include Vancouver Island, the south-central Interior (Hat Creek, Merritt, Princeton), northwest BC (Telkwa, Iskut), and the Queen Charlotte Islands (Campbell and Rutherford 2006).

As of December 2007, a total of 87 wells and test holes have been drilled in BC. These have been primarily in the northeast, and also in Princeton, the Elk Valley, on Vancouver Island and near Iskut. BC has an estimated resource potential of 84 Tcf (trillion cubic feet) of coalbed gas from coalfields around the province. Commercial production is not yet underway (BCMEMPR 2007b).

15.2.1. Pollution Sources

Pollution associated with coalbed methane is a result of the extraction of the methane gas from the coal field. Coalbed methane development is distinguishable from conventional gas extraction in three primary ways (Campbell and Rutherford 2006):

1. In order to access the methane gas, coal seams need to be dewatered. The amount of produced water will vary from basin to basin; however, in some cases large quantities of brackish water, possibly containing heavy metals, may be produced. The disposal of this water may be an issue.
2. Coalbed methane wells generally require much denser spacing than conventional gas wells. In addition to the wells and well pads, other necessary infrastructure includes roads, compressor stations, gas flares, and pipeline rights of way, all of which have the potential to dramatically alter the land.
3. Coalbed methane wells have a longer lifespan than conventional oil and gas wells, and can be in operation for up to 40 years, whereas conventional wells tend to be exhausted after 25 years.

From a marine perspective, the greatest pollution source from coalbed methane is the produced water, which may enter streams, lakes, and groundwater, ultimately reaching the ocean.

15.2.2. Environmental and Socio-Economic Impacts

Coalbed methane has the following potential environmental and socio-economic impacts (Campbell and Rutherford 2006):

- **Concentrated Nature of Development**. Coalbed methane projects can involve hundreds of wells, with each well requiring individual road access. Wells are spaced closer together than in a typical natural gas project, where spacing is generally set at one well to approximately every 259 hectares. Existing BC guidelines allow coalbed methane wells to be spaced “to any density” provided a “scheme approval” is in place. In the US, spacing has been as close as one well approximately every 16 hectares. Concentrated development can have a significant impact on the land.

- **Coalbed Methane Produced Water**. The methane gas is often held in the coalbed by water pressure, and a company must first decrease this pressure by “de-watering” or pumping out the groundwater. The amount of water generated in the production process will differ from basin to basin, ranging from relatively insignificant amounts to volumes so large that aquifers have been depleted, forcing local residents to drill deeper for water. “Produced” water can vary in nature from being relatively fresh to quite saline, and may contain heavy metals that can have long-term effects on aquatic ecosystems. Surface disposal of produced” water can have serious impacts on soil (creating saline, nonproductive soils) and water quality.

  In February 2007, the Provincial Government released the BC Energy Plan which indicated that companies will not be permitted to surface discharge any produced water. Produced water must be re-injected back into the ground well below any domestic water aquifer (a process referred to as deep well reinjection). Companies must isolate the subsurface disposal areas from potential groundwater zones, and line all disposal wells steel casing that to prevent cross-contamination with drinking water (BCMEMPR 2007b).

- **Use of Toxics to Fracture Coal Seams.** To allow water or coalbed methane to flow more easily, companies often inject a high-pressure mixture of sand and chemicals into the well to fracture or ‘frac’ the coal seam. Fraccing compounds may contain diesel fuel and other hydrocarbons. These fluids can travel along the cracks created by the fraccing process and contaminate groundwater. Remediation of groundwater can be very difficult, if not impossible to undertake, and is extremely expensive. As a result, the use of water-based fracturing fluids is preferred to oil based or toxic fracturing fluids.

- **Air Quality Issues**. Methane gas that comes up to the surface during de-watering is usually ignited or "flared." Flaring may also be necessary during work to maintain or improve production levels. The flaring of fossil fuels releases large numbers of chemicals into the air, many of which are carcinogenic, and have been known to impact human health. While coalbed methane has fewer impurities than gas produced in conventional oil and gas wells, flaring of coalbed methane will add to BC's greenhouse gas emissions and contribute to climate change.

- **Noise and Nuisance**. Traffic, drilling, noise, and dust are can be ongoing issues in communities affected by coalbed methane development. Each new well brings drilling rigs, generators, earthmoving machines, and trucks. The noise from gas compressors and pumping stations can exceed 50 decibels at a distance of 90 m. This noise can continue 24 hours a day.

- **Loss of Farmland**. Direct loss of agricultural land and livestock may result from coalbed methane wells and related infrastructure. The use of farmland for coalbed methane development requires approval by the Agricultural Land Commission.

- **Potential Harm to Wildlife**. Wildlife may be affected in a number of ways:
    - new roads and pipelines will fragment wilderness and reduce large contiguous tracts of wilderness needed by some large species
    - predator-prey relationships can be altered as a result of fragmentation (wolves, for example, are able to move faster along roads than in the forest, increasing predation pressures on caribou);
    - higher reproductive failure rates have been identified in bird habitats near linear disturbances
    - poaching and hunting often increase when roads open up previously inaccessible areas.

- **Risk of Methane Migration into Water Supplies and Soils**. The US Geological Survey reports that in some areas, methane migration may have contaminated groundwater sources. It has also been known to travel into ponds, cattle troughs, and people's basements.

15.2.3. Concerns in the North and Central Coast

There are four coal fields in the PNCIMA – Groundhog-Klappen, Telkwa, Suquash, and Comox (see **Figure 60**). The Groundhog-Klappen field is by far the largest, with an estimated potential methane reserve of 8.1 Tcf. This coal field is located in a region referred to as the "Sacred Headwaters" by the Iskut and Tahltan First Nations who live in the region. The Sacred Headwaters is so named because it is the area from which the Nass, Skeena, and Stikine Rivers all originate. The watersheds of these three rivers collectively cover over 126,000 square kilometers. They are central to the cultures and health of the Tahltan, Tlingit, Gitxsan, Nisga'a, Tsimshian, Wet'suwet'en and other interior and coastal First Nations. The Sacred Headwaters area is also a highly productive boreal ecosystem, supporting large populations of migratory birds, ungulates, and many other species of wildlife (Wilderness Committee & Rivers Without Borders 2007a, b).

Figure 60. Coal fields and potential coalbed methane reserves (in trillion cubic feet) in the PNCIMA (data: BCMEMPR 2008a).

Shell Canada's Klappan Coalbed Methane project could see the development of new roads, open and a plethora of well sites to extract coalbed methane in the Sacred Headwaters area. Coalbed methane extraction fragments the land, pollutes the air and water, and is a major contributor to climate change. Although the Iskut and Tahltan First Nations are not opposed to all development, they are demanding an appropriate pace and scale of development for their traditional territory and that sensitive cultures are protected (Wilderness Committee & Rivers Without Borders 2007a, b).

Environmental impacts in the upper reaches of the Stikine, Nass, and Skeena Rivers could have far-ranging effects on water quality, species abundances (particularly migratory species, such as salmon), and local economies that may extend as far as the North Coast region.

15.2.4. Monitoring

The Environmental Resource Information Project (ERIP) conducts baseline studies in the Hat Creek, Similkameen, Crowsnest, Vancouver Island, Peace River and Telkwa Coalfields. In these coalfields, streams that drain the coalfield are sampled and analyzed by a laboratory for total dissolved solids, conductivity, turbidity, total suspended solids, major cations and anions, nutrients, and 23 trace elements (BCMEMPR 2007b).

Additionally, the Oil and Gas Commission requires the following (BCMEMPR 2007b):

- that companies carry out monitoring throughout the process of deep well reinjection
- that companies carry out water well testing within a one kilometer radius of a coalbed methane gas well. Samples are required to be taken before and after drilling to ensure that drilling does not affect groundwater wells.

15.2.5. Mitigation

The following is a list of some potential ways of mitigating the impacts of coalbed methane gas production (Campbell and Rutherford 2006):

- Minimize surface disturbance and visual impacts:
    - Taking into account well siting requirements imposed by the province, and other guidelines, locate structures in a manner that minimizes surface disturbances through techniques such as directional drilling, drilling multiple wells from the same pad, and use of existing well pads.
    - Use existing disturbance corridors for roads, pipelines and power lines.
    - Avoid locating wells and other structures on highly visible ridgelines.
    - Use vegetative screens to screen operations from residences, roads and highways.
    - Use natural colored finishes for buildings and structures.
- Minimize noise disturbances
    - Taking into account well siting requirements imposed by the province, and other guidelines, locate compression equipment and well sites as far as possible from residences, churches, schools, wildlife areas, and other noise sensitive locations.
    - Require industrial users to use noise mitigation techniques including engineered noise barriers, enclosures and noise abatement equipment that in combination with siting requirements can reasonably ensure that noise will not exceed a threshold level (e.g., 40 decibels) at a property line or established noise sensitive receptor.
- Avoid contamination of water wells from methane seepage, fraccing fluids, and groundwater contamination:
    - Require coalbed methane developers to include reports by hydrological professionals regarding local hydrology.
    - Disallow use of diesel fraccing fluids in formations that contain sources of drinking water.
    - Ensure appropriate distances between coalbed methane wells and water wells to avoid contamination of water wells.

  - o Protect groundwater or surface water from contamination by requiring lining of channels and pits used for produced water.
- Protect biological and hydrological features of riparian areas, wetlands, and floodplains:
  - o Prohibit location of well pads, compressors, drilling mud pits and other facilities in wetlands or in specified buffer zones (boundaries of buffer zone may be set based on information provided by developer).
  - o To the extent possible using technologies such as diagonal drilling and to the extent compatible with other objectives, locate well pads , compressors and other facilities at the maximum distance away from riparian/wetland areas.
  - o Require specified setbacks.
  - o Construct crossings perpendicular to wetlands.
  - o Implement mitigation measures recommended by a registered professional biologist for any development within specified distance of wetland.
  - o For any construction within specified distances of wetlands, schedule construction during times which avoid impacts on fish (requiring appropriate information from registered biologists).
- Avoid habitat fragmentation in areas with high levels of biodiversity:
  - o Use two-track roads into well locations to the extent feasible.
  - o Locate wells in proximity to existing roads.
  - o Use existing disturbance corridors.
- Maintain biodiversity and habitat in sensitive areas:
  - o Reclaim disturbed sensitive areas to proper functioning condition.
  - o Use of native species in reclamation.
  - o Interim reclamation of drill sites after drilling and pipelines after construction, to the minimum area required for operation. Reclamation to include recontouring, replacement of topsoil, planting of native species.
  - o Reclaim all disturbed areas as close as possible to a natural state.
- Protect wildlife:
  - o Require fencing and netting around produced water pits.
  - o Impose conditions respecting sequence and timing of construction so that construction avoids wildlife breeding seasons.

15.3. Smelting

15.3.1. Pollution Sources

A aluminum smelting operation produces aluminum metal from bauxite. Bauxite is composed mainly of aluminum hydroxides ($Al_2 \cdot H_2O$) and iron oxides, the latter giving it its characteristic reddish tint. Alumina (Al_2O_3) is obtained by dissolving bauxite in a concentrated, hot (250°C) basic solution (NaOH) under high pressure. The residue, called red mud, is a fairly inert solid waste that is not considered hazardous. However, dust may escape from storage sites and be deposited on neighboring communities. The red mud is usually thickened and piled, with a covering layer of gypsum, in various storage areas (Government of Canada 1999).

The alumina is transformed into aluminum using an electrolytic process, which occurs in the smelter's potroom. This process requires a large amount of electricity. In the potroom, the alumina is placed in steel cells, or pots, along with various additives like cryolite (Na_2AlF_3) and aluminum fluoride (AlF_3) which reduce the melting point of alumina to 950°C (instead of 2400°C). The electrical current passes from a carbon anode, a rod located in the centre of the cell, to the cathode, the carbon lining of the cell. At regular intervals, the melted aluminum produced is siphoned off and transferred to casting facilities (Government of Canada 1999).

The process of creating aluminum metal from bauxite generates a number of potential pollutants (Government of Canada 1999):

- **Atmospheric pollutants**. The transformation of alumina to aluminum is the most polluting stage of this process. It gives off numerous gases (called pot gases) and produces hazardous waste. If no additives were used, and the reaction went to completion, only CO_2, a greenhouse gas, would be produced. I n practice, however, carbon monoxide and polycyclic aromatic hydrocarbons (PAHs) are generated, the latter coming mainly from the spent carbon anodes and pot linings. Old smelters using obsolete electrolytic processes (for example, the horizontal stud Soderberg process) produce significant quantities of PAHs, including carcinogens. The electrolytic process also produces dust, suspended particulates and sulfur dioxide (SO_2), which is present in the coke used to prepare the anodes. SO_2 is a major atmospheric pollutant contributing to the formation of acid rain and acid smog.

- **Hazardous wastes**. The internal lining of the pots is made of brick, composed mainly of anthracite and other refractory materials, and forms the cathode. This lining ages over time and must be removed. Although the lining consists mainly of carbon, it is impregnated with cryolite and aluminum fluoride, as well as cyanide, which is a byproduct of electrolysis. The old pot linings are considered hazardous waste, not only because they contain toxic substances but also because, on contact with water, acids, alkalis, or at high temperatures, they may produce toxic or even explosive gases, such as hydrogen fluoride or hydrogen cyanide. Old pot linings are usually stored in a secure place until a way to reuse or decontaminate them can be found.

- **Water pollution**. Many of the pollutants which are released into the atmosphere are also present in water, particularly fluorides and PAHs. Smelter effluent can also contain total suspended solids and oils and greases from machinery. This is more common in old smelters. Changes in production processes and the presence of treatment systems have resulted in effluents that are reduced in volume and relatively nonpolluting. A few smelters even have zero effluent discharges, except for sanitary wastewater. Some smelters have a carbon plant where the anodes for the electrolytic cells are produced. This production usually generates pollutants such as PAHs, which result from the heating of carbon compounds.

15.3.2. Environmental and Socio-Economic Impacts

Table 34 and **Table 35** list some of the potential impacts associated with an aluminum smelting operation. The most significant pollutants are the release of fluoride to the atmosphere and the release of aluminum and PAH to local water sources.

Table 34. Environmental impacts resulting from aluminum smelting operations (source: Government of Canada 1999).

Pollutant		Environmental Impacts	Zone of influence
Atmospheric contaminants	Fluorides	Dieback in plants and decalcification in mammals	Site, surroundings, neighborhood
	SO_2	Acute chronic lesions in plants	Regional (up to 100 km)
	CO_2	Greenhouse effect	Global
	PAH (anodes)	None	Site and neighborhood
Liquid contaminants	Aluminum	Toxic for fish and aquatic insects	Regional water bodies
	Fluorides	Bioaccumulation in aquatic organisms	
	Suspended and dissolved solids	Unhealthiness, reduced visibility	
	Oils and greases	Unhealthiness	
	PAH (from atmosphere)	Neoplastic and genotoxic effects	
Solid contaminants	Used pot linings	Very toxic	Site
	Dross, grit	Unhealthiness	Site
	Domestic waste	Unhealthiness	Site

Table 35. Socio-economic impacts resulting from aluminum smelting operations (source: Government of Canada 1999).

Pollutant		Socio-economic Impacts	Population at risk
Atmospheric contaminants	Fluorides	Eye, skin irritations, dental fluorosis, osteoarthritis	Workers
	SO_2	Irritations of mucous membranes in respiratory tract	None at concentrations emitted
	CO_2	Climate change	Global
	PAH (anodes)	Cancer (mainly lung, bladder)	Workers and neighbors
Liquid contaminants	Aluminum	Neurological problems	Those consuming water from local water bodies
	Fluorides	Probably none at concentrations found	N.A.
	Suspended and dissolved solids	Unhealthiness	None
	Oils and greases	Unhealthiness	None
	PAH (from atmosphere)	Cancer	Those consuming water or aquatic organisms
Solid contaminants	Used pot linings	Extreme toxicity,	Workers
	Dross, grit	Irritation of skin and respiratory tract	Workers
	Domestic waste	Unhealthiness	
Noise		Sleep disturbances stress	Neighborhood

15.3.3. Concerns in the North and Central Coast

Western Canada's only aluminum smelter, owned and operated by Alcan, is located in Kitimat (Johannessen et al. 2007a). Alcan opened its aluminum smelter operation (Kitimat Works) in 1954. With a rated production capacity of 275,000 tonnes per year, Kitimat Works has been one of British Columbia's largest industrial complexes for half a century (CBSR 2006).

In the early stage of its operation, the primary environmental concern was the release of large amounts of fluoride (Bell and Kallman 1976, Brewer et al. 1979, Hocking et al. 1980). Emission controls and changes in the smelting process have significantly reduced the release of fluoride (Johannessen et al. 2007b). However, in 2005, Kitimat Works was still ranked the number one polluter in BC (Pollution Watch 2005a), and hydrogen fluoride was the major pollutant (Pollution Watch 2005b)

Of more recent and ongoing concern is the release of polycyclic aromatic hydrocarbons (PAHs) in air emissions and water effluent via two main routes: (1) contamination by the pyrolysis and volatilization of the pitch/tar anode binder from the Söderberg electrode, and (2) by the offloading and handling of pitch and coke on-site (Simpson et al. 1998). PAHs include a wide range of compounds and can have both lethal and sublethal effects (see section 6.2). 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 (Eickhoff et al. 2003a, Eickhoff et al. 2003b, Erickson et al. 1979, Paine et al. 1996, Simpson et al. 1996, Simpson et al. 1998). Even though PAHs are present in the environment, no studies have shown a clear link between PAH contamination and health effects in biota (Erickson et al. 1979). This may indicate that the PAH bioavailability is low (Paine et al. 1996)

15.3.4. Monitoring

Table 36 provides a list of some of the monitoring requirements for an aluminum smelting operation.

Table 36. Pollution monitoring for aluminum smelting operations (source: Government of Canada 1999).

Pollutant		Monitoring
Atmospheric contaminants	Fluorides	Fluorides in ambient air
	SO_2	SO_2 in ambient air
	CO_2	Concentration of atmospheric CO_2
	PAH (anodes)	Concentration of PAHs in ambient air
Liquid contaminants	Aluminum	Concentration of Al in water
	Fluorides	Concentration of fluorides in water
	Suspended and dissolved solids	Visual or quantities of SS in water
	Oils and greases	Quantities of oils/greases in water
	PAH (from atmosphere)	Concentration of PAHs in water and fauna
Solid contaminants	Used pot linings	Accident reports from incidents
	Dross, grit	
	Domestic waste	
Nuisance		Complaints/ perceptions

15.3.5. Mitigation

Table 37 provides a list of some possible mitigation measures for an aluminum smelting operation.

Table 37. Pollution mitigation measures for aluminum smelting operations (source: Government of Canada 1999).

Pollutant		Mitigation measures
Atmospheric contaminants	Fluorides	Scrubbers, new technologies, buffer zones
	SO_2	Scrubbers, non-sulfur fuel
	CO_2	Reduce fossil fuel use
	PAH (anodes)	Capture
Liquid contaminants	Aluminum	Abstraction and treatment
	Fluorides	
	Suspended and dissolved solids	
	Oils and greases	
	PAH (from atmosphere)	
Solid contaminants	Used pot linings	Safe confinement
	Dross, grit	Recovery, recycling
	Domestic waste	Disposal, recycling
Nuisance		Noise abatement bank -buffer zone

16. Pollution from Landfills and Ocean Dumping

16.1. Pollution Sources

16.1.1. Landfills

The materials entering landfills consist of both organic and inorganic substances, and may contain toxic compounds. The waste sent to landfill is a potential source of contamination for groundwater, soil, and air. Contaminants which enter the groundwater may eventually find their way into the coastal marine environment. Landfills also use large tracts of land, which are becoming more difficult to acquire in densely populated areas (BCMOE 2007c).

Disposal of solid waste in landfills represents wasted resources and wasted energy. For example, over-packaging results in energy and resources being spent on materials that are only used briefly before becoming waste. Even with recycling, many plastic goods are still considered a waste of energy and resources because recycling them really means “down-cycling” which just prolongs the life of the plastic through one more product cycle before it is too degraded to re-use (McDonough and Braungart 2002).

In 2004, it was estimated that residential waste accounted for 35% of the municipal waste stream in BC, with the rest coming from industrial, commercial, and institutional sources (SC 2004).

16.1.2. Ocean Dumping

The following materials may be permitted for ocean dumping (EC 2003b):

- 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.

The forest products industry frequently uses ocean dump sites to dispose of wood wastes and material generated as a result of dredging of channels, harbours, marinas, bridges, wharves, ferry terminals, and berthing areas (Sullivan 1987). Dredging is also frequently required at log storage and sorting areas in order to maintain depth (Ward and Sullivan 1980). As the dredgeate from log storage and sorting areas consists largely of wood waste, it is high in organic content, and may contain 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 the possibility of toxic leachates. As a result, ocean dumping is often the only feasible alternative (Hoos 1977).

16.2. Environmental and Socio-Economic Impacts

16.2.1. Ocean Dumping

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 thus have a significant impact on the benthic environment. They also increase the dissolved organics in the water column by leaching carbohydrates, resins, tannins, and lignins. The degradation of the wood particles and dissolved organics may create a high biochemical oxygen demand, and result in the formation of toxic levels of hydrogen sulphide (Anderson and O'Connell 1977). Deposited wood debris discourages 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). Crabs avoid bark deposits when given a choice (O'Clair and Freese 1985), but when forced to inhabit them, they are less fecund and have lower feeding rates and decreased survivorship (Williamson et al. 2000). Dungeness crab populations living at a log dump in Alaska had less than half the number of ovigerous females as a control population, and the ovigerous females that were present were less than half as fecund (O'Clair and Freese 1988). Community structure is altered as wood waste increases. In an area with approximately 15 cm of waste, the fauna was limited to wood-inhabiting organisms such as shipworms and small polychaetes (Anderson and O'Connell 1977).

Ocean dumpsites can have elevated levels of mercury, cadmium, lead, zinc and copper (Haggarty et al. 2003). Fish and invertebrate were sampled for heavy metals at the Point Grey dumpsite in Vancouver. Cadmium was generally below detection levels for fish, but was slightly elevated in shrimp. Mercury levels were highest in fish and crab tissues, but were still below the 0.5 mg/kg human health guidelines for food (Kay 1989).

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).

16.3. Concerns in the North and Central Coast

16.3.1. Landfills

In the coastal regions of the PNCIMA, there are 2 municipal landfills and 14 industrial landfills (see **Figure 61**). The main industrial wastes that are being disposed of in landfills are wood wastes and asphalt.

Table 38 shows the amount of waste generated per capita for the Regional Districts located in the PNCIMA. For most districts, there has been a decrease in waste going to landfills and incinerators from 1990 to 2005. Mount Waddington and Skeena-Queen Charlotte Regional Districts produce the most waste per capita.

Waste entering landfills may create leachates which can then enter the ground water and local streams. Ultimately, these leachates may result in marine pollution.

Table 38. Regional district disposal rates per capita (tonnes of waste going to incinerators and landfills) for 1990 and 2005 in the PNCIMA (source: BC Stats 2006b, BCMOE 2007b, RCBC 2004, 2007).

Regional District	1990	2005
Mount Waddington	0.87	0.53
Central Coast	0.38	0.26
Bulkley-Nechako	0.66	0.47
Comox-Strathcona	0.65	0.47
Kitimat-Stikine	0.65	0.48
Cariboo	0.37	0.41
Skeena-Queen Charlotte	0.74	no data

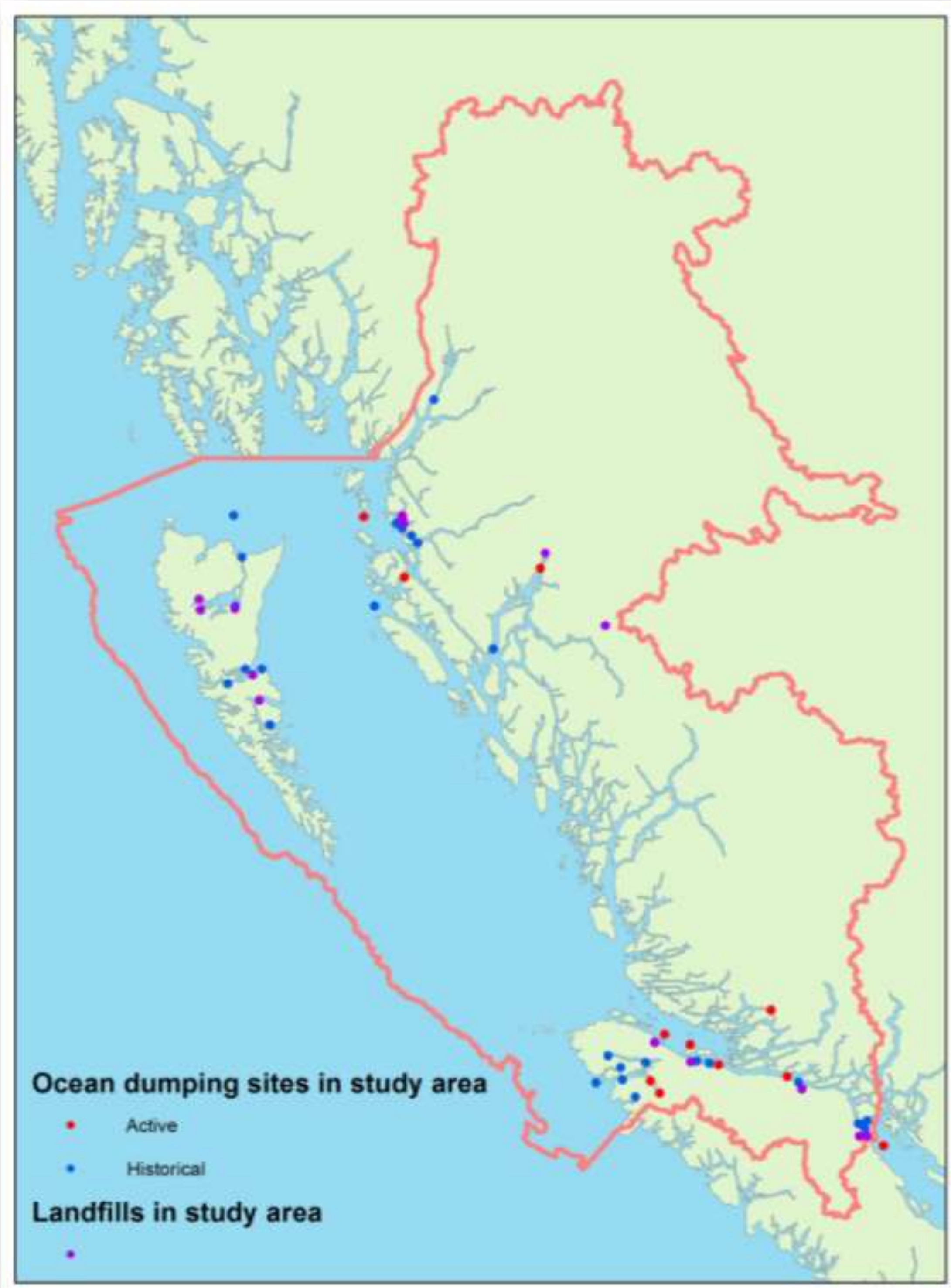

Figure 61. Ocean dumping and landfill sites in the PNCIMA (data: BCILMB 2008, Johannessen et al. 2007a).

16.3.2. Ocean Dumping

There are 11 active and 27 historic ocean dump sites in the PNCIMA (see **Figure 61**) (Johannessen et al. 2007b). Materials which are currently, or have been, disposed of in these sites include (Johannessen et al. 2007a):

- ammunition
- scrap metal
- fish offal
- dredgeate
- sewage sludge
- fertilizer
- wood wastes
- sulfite liquor
- marine vessels

By far, the most frequently disposed substances in ocean dumping sites in the PNCIMA are wood wastes and dredgeates.

Due to the permitting and monitoring of this activity, ocean dumping is not considered to be a major source of contaminants in the PNCIMA (Johannessen et al. 2007b).

16.4. Monitoring

Permitting for dumping materials at sea is governed by The Ocean Dumping Control Act (Johannessen et al. 2007b). Permits must be obtained from Environment Canada, and the waste material must undergo chemical testing prior to dumping. Disposal of hazardous material in the oceans is prohibited. The Canadian Environmental Protection Act does allow dumping of some materials containing acceptable levels of metals. For instance, mercury in waste material to be dumped cannot exceed 0.75 mg/kg dry weight in the solid phase and 1.5 mg/kg in the liquid phase. For cadmium, levels are 0.6 and 3.0 mg/kg for solid and liquid phases, respectively (Haggarty et al. 2003).

The Environment Canada Disposal at Sea program monitors disposal sites to ensure that the conditions of the permit are met and that the marine environment has not been significantly affected (BCMOE 2006c).

16.5. Mitigation

Programs to reduce the amount of disposed waste and increase recycled waste have been in place in the province for more than 15 years, longer in some areas. In 1989, the government of British Columbia adopted a goal established by the Canadian Council for Ministers of the Environment to cut municipal waste by 50% per capita by the year 2000 (compared to 1990 levels). At the same time the province introduced the requirement for regional districts to develop and submit Solid Waste Management Plans for approval (BCMOE 2007b).

17. Global Warming and Climate Change

17.1. Pollution Sources

The United Nations Intergovernmental Panel on Climate Change (IPCC) and the national science academies of eleven nations, including Canada and United States, have recognized that the Earth's atmosphere is warming, and human activities that release greenhouse gases are an important cause. Greenhouse gases in the atmosphere act like the transparent roof of a greenhouse, allowing sunlight to enter, but preventing infrared (heat) energy from leaving. The result is warming of the atmosphere and the surface of the Earth, which is critical in maintaining the temperature of the Earth within a range suitable for life. However, anthropogenic production of greenhouse gases can lead to increased trapping of heat, resulting in excessive global warming and climate change. Greenhouse gases include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and other trace compounds. These gases are released into the atmosphere by many naturally occurring processes, as well as by human activity such as fossil fuel combustion, deforestation, agriculture, and industrial activity. Human-created greenhouse gases also include perfluorocarbons (PFCs), which are a byproduct of aluminum production, sulfurhexafluoride (SF_6), which is used in electrical switches, and hydrofluorocarbons (HFCs), which now replace the ozone-depleting chlorinated fluorocarbons (CFCs) in many applications (BCMOE 2006b).

17.2. Environmental and Socio-Economic Impacts

17.2.1. Natural Sources of Climate Variation

British Columbia is affected by two major sources of natural short-term variation in the regional climate (BCMOE 2006b):

- The **Pacific Decadal Oscillation** (PDO) is a natural cycling of warm and cool phases in the sea surface temperatures of the Pacific Ocean. The PDO appears to affect the BC climate over a 50- to 60-year cycle (Moore et al. 2002a), spending roughly 20 to 30 years in each phase. In British Columbia, the warm phase of the PDO is generally associated with above-average air and ocean surface temperatures and below-average springtime snow pack.
- The **El Niño Southern Oscillation** (ENSO) phenomenon is related to shifts in tropical air pressure that change temperature and precipitation patterns along the West Coast every few years. For British Columbia, an El Niño event generally means a warmer winter with below-average precipitation, while a La Niña event means a cooler winter with above-average precipitation.

The ENSO, PDO, and global warming can reinforce or weaken each other's effects, making it difficult to discern short-term trends in the climate and to predict future impacts. The ENSO appears to be sensitive to the changes in the climate, but at this time it is not possible to predict how it will respond to global warming (Tudhope and Collins 2003).

17.2.2. Physical Impacts of Climate Change

Projected - and in some cases already observed - changes to global physical processes as a result of atmospheric warming include (BCMOE 2006b):

- increasing frequency and severity of extreme weather, such as heat waves, drought, and high-intensity rainfall (Stott et al. 2004);
- changes in the timing of river flow and water volume (Whitfield et al. 2002);
- shrinking and loss of mountain glaciers and snow packs, which is of particular concern for communities, farmers, and hydroelectricity generators that depend on snow melt for their water supply;

- rising sea level, which has increased about 15–20 cm world-wide during the 20th century;
- alteration of ocean temperature, salinity, and density, which may in turn affect ocean circulation and productivity.

17.2.3. Biological Impacts of Climate Change

Climate is the major factor controlling the global pattern of ecosystems and distribution of plants and animals. Therefore, climate change is expected to produce significant changes in ecosystems and biodiversity. The most sensitive ecosystems, such as high-altitude and high-latitude ecosystems, already show signs of being affected (Gitay et al. 2001).

Impacts on ecosystems may include changes to (BCMOE 2006b):

- ecosystem structure, such as the predominant vegetation, species composition, and distribution of age classes;
- ecosystem function, including productivity, nutrient cycling, and water flows;
- distribution of ecosystems within and across the landscape;
- patterns of disturbance, such as fires, insect and disease infestations, and invasion by alien species.

Impacts on species include changes in (BCMOE 2006b):

- phenology, which is the timing of flowering, emergence, and migration;
- growth rate, development, and reproduction;
- interactions between species, such as predation, and competition.

Some specific impacts which may affect, or are currently affecting, the BC coast are (BCMOE 2006b, 2007c):

- **Energy transfer between trophic levels**. Spring diatom blooms in the ocean signal the start of the seasonal cycle of production on the BC coast. The timing of the blooms is roughly the same each year, since the diatoms respond to increasing day length and light intensity. In contrast, the physiology of organisms such as the copepods that feed on diatoms and the salmon that feed on copepods responds to temperature. If spring warming comes earlier, these organisms may shift their seasonal cycle of development and reproduction to earlier in the year. They are then out of synchrony with the peak production of the diatoms they depend on for food. Such inefficiency in energy transfer between trophic levels may already have altered some marine ecosystems enough to contribute to the decline of fish stocks (Edwards and Richardson 2004).
- **Salmon fisheries**. Warmer river temperatures have serious implications for salmon, whose life cycle is adapted to cool and intermediate temperatures. Sockeye salmon migrate more slowly at temperatures above 18ºC, and show increasing stress with higher temperatures. Chronic exposure to 21ºC causes severe stress and early mortality. Such temperatures are now being experienced - the temperature in the Fraser River at Hope was above 21ºC for several days in a row in 2004 (DFO 2007c).
- **Ocean productivity**. Every day, oceanic phytoplankton fix more than 100,000 tonnes of carbon in the form of CO_2, which is roughly half of the Earth's net primary production. Most of this carbon cycles within the ocean's food web, sinking downward as particles and returning upward in the form of dissolved nutrients. With global surface waters of the ocean now warming faster than the deep ocean, there is less vertical mixing and therefore a smaller supply of nutrients to the surface. Research shows that warming since 1998 has reduced the amount of carbon fixed in the ocean by a very small amount, probably because the nutrient supply has diminished (Behrenfeld et al. 2006).
- **Ocean acidity**. Over the 21st century, the acidity of ocean water is expected to more than double. As atmospheric CO_2 concentrations increase, more CO_2 will become dissolved in the ocean, thus causing it to become more acidic (increasing CO_2 leads to an increase in carbonic acid). Increased acidity erodes the calcium carbonate skeleton

that protects many marine organisms, especially plankton (Riebesell et al. 2000). The increasing acidity also represents a threat to BC's coral reefs.

- **Dissolved oxygen in the ocean**. Studies show that dissolved oxygen is declining in deeper layers of water in the ocean. The summertime oxygen content in the layer 100 to 200 meters below the surface has declined slowly for at least the last 50 years. This is the result of decreased circulation of oxygen-rich waters from the surface, as the surface ocean waters become fresher and warmer faster than the deep ocean. Although not yet observed off the BC coast, low-oxygen water upwelling onto the continental shelf south of BC has sometimes caused massive marine mortality (DFO 2007b).

17.2.4. Socio-economic Impacts of Climate Change

An immediate economic effect of climate change is the cost of dealing with extreme weather events. Such events also have a social cost to people who are displaced or suffer physical injury and property loss. On the coast, the impact of rising sea level, coupled with more extreme weather, could increase the risk and costs associated with (BCMOE 2006b):

- floods in low-lying coastal areas;
- storm damage to waterfront homes, roads, and port facilities, and erosion of the shoreline;
- saltwater intrusion into groundwater aquifers and saline contamination of low-lying agricultural lands.

Communities and industries that depend on fresh water sources affected by climate change (such as snow pack) will need to invest in conservation measures, development of alternative water supplies, and building of new infrastructure. Any economic activities that depend on land-based natural resources, such as agriculture, forestry, salmon fisheries, and tourism, will feel the effects of changing climate. Long-term changes in ocean conditions will affect the human communities and resource industries that depend on the sea. Climate change may also affect human health and safety by increasing the range of certain diseases (such as malaria) and the risk of heat-related illnesses, such as heat stroke (BCMOE 2006b).

17.2.5. Coastal Ocean Temperature

The temperature of the ocean affects coastal weather and climate. Ocean temperature and salinity affect the survival, growth, and reproductive success of marine life, and the productivity and composition of marine ecosystems (BCMOE 2006b).

Over the last 50 years, the ocean has become warmer all along the BC coast, as indicated by trends in the annual mean sea surface temperatures (see **Figure 62**). The largest and most significant increase was a warming of 0.9°C in 50 years for Langara Island, at the northwest tip of the Queen Charlotte Islands. The second largest change, 0.8°C in 50 years, was for Entrance Island, in the central Strait of Georgia (BCMOE 2006b).

17.2.6. Deep-Water Warming

A warming trend in the ocean along the southern BC coast is also apparent in the deeper waters of five inlets on the mainland coast and two on Vancouver Island (see **Figure 63**). All seven inlets showed a warming of 0.5 to 1.0°C over the last 50 years, which is consistent with the sea-surface temperature trends (BCMOE 2006b).

17.2.7. Sea Level on the British Columbia Coast

One widely publicized consequence of global warming is a projected rise in sea level. Rising sea levels are due partly to an increase in the volume of water as it warms and expands and partly to the increased flow of freshwater from land as melting ice adds to the total volume of water in the oceans (Miller and Douglas 2004). Combined with extreme weather, a rise in sea level may result in more frequent flooding and salt contamination of low lying areas, as well as storm damage to areas and structures previously above high water (BCMOE 2006b).

Examination of the sea level records for Prince Rupert, Tofino, Vancouver, and Victoria shows that relative sea levels have been rising at Prince Rupert, Vancouver, and Victoria, but falling at Tofino (see **Figure 64**). Differences between stations are explained on the basis of geological processes, which cause vertical movements of the shoreline that partly or completely cancel the effects of an expanding ocean. The landmass of British Columbia is rebounding vertically after the massive ice sheet melted approximately 10,000 years ago - a process called isostatic rebound. The rate of rebound along the coast is estimated to be 0 to 4 mm per year. As well, the western edge of the North American continent is sliding over adjacent oceanic plates, resulting in crustal uplift estimated to be as high as 4 mm per year along the southwest coast of Vancouver Island near Tofino (Peltier 1996). The effect is that the measured water level drops as the coast (and the zero datum point) rises. Thus, at all stations except Tofino, continuing the long-term trend in sea level will result in mean and extreme relative sea levels higher than have yet been observed. At Tofino, it is expected that relative sea level will continue to fall, exposing more of the shoreline until the next major subduction zone earthquake causes coastal land to drop (BCMOE 2006b).

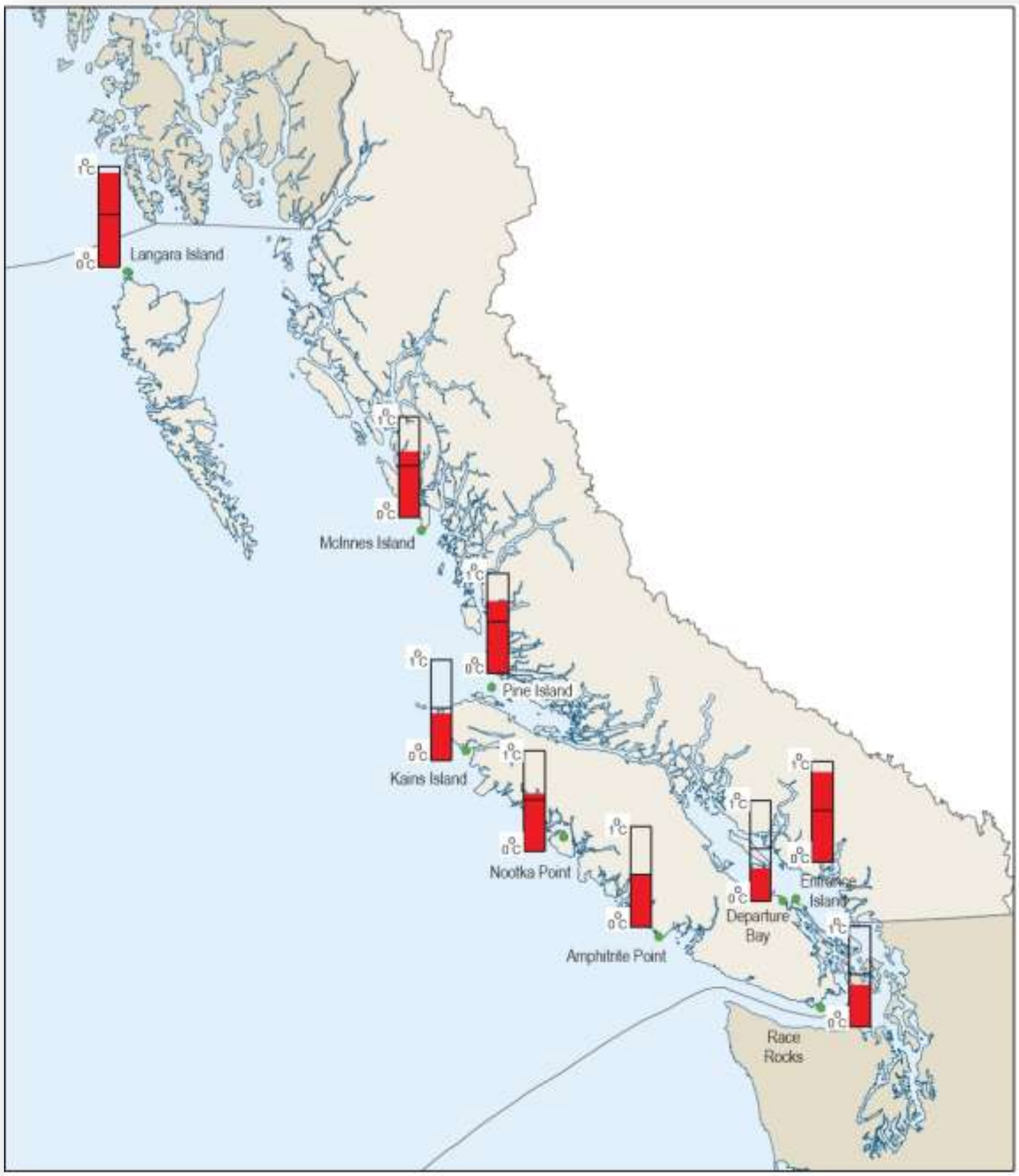

Figure 62. Rates of changes in sea-surface temperature (ºC/50 years) at nine lighthouse stations on the BC coast (source: BCMOE 2006b, DFO 2008a).

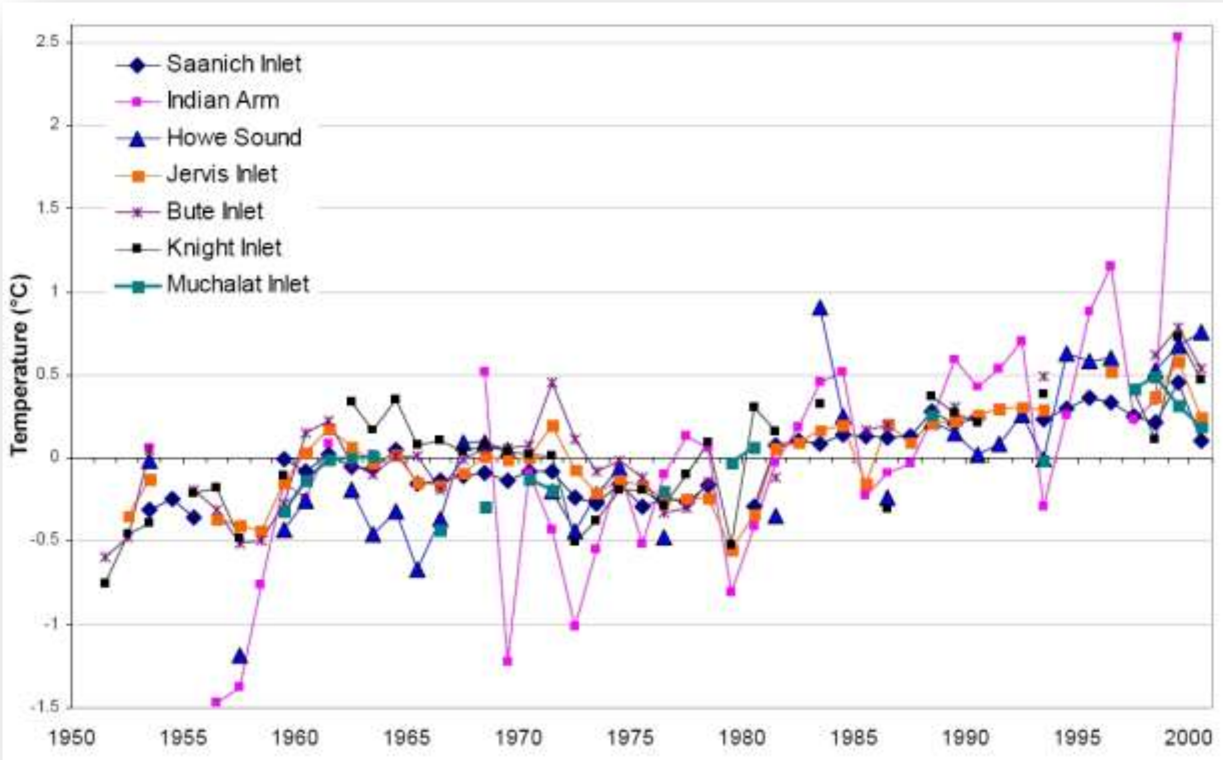

Figure 63. Deep-water temperature anomalies for inlets in southern British Columbia. Observations were collected from at least 200 m below the surface, and are not subject to daily and tidal temperature variations. Note that the graph displays temperature anomalies that depart from the average (set as 0°C) over the period for each time series. Bottom water temperatures in the inlets generally range from 6.5 to 8.5°C (source: BCMOE 2006b, DFO 2008b).

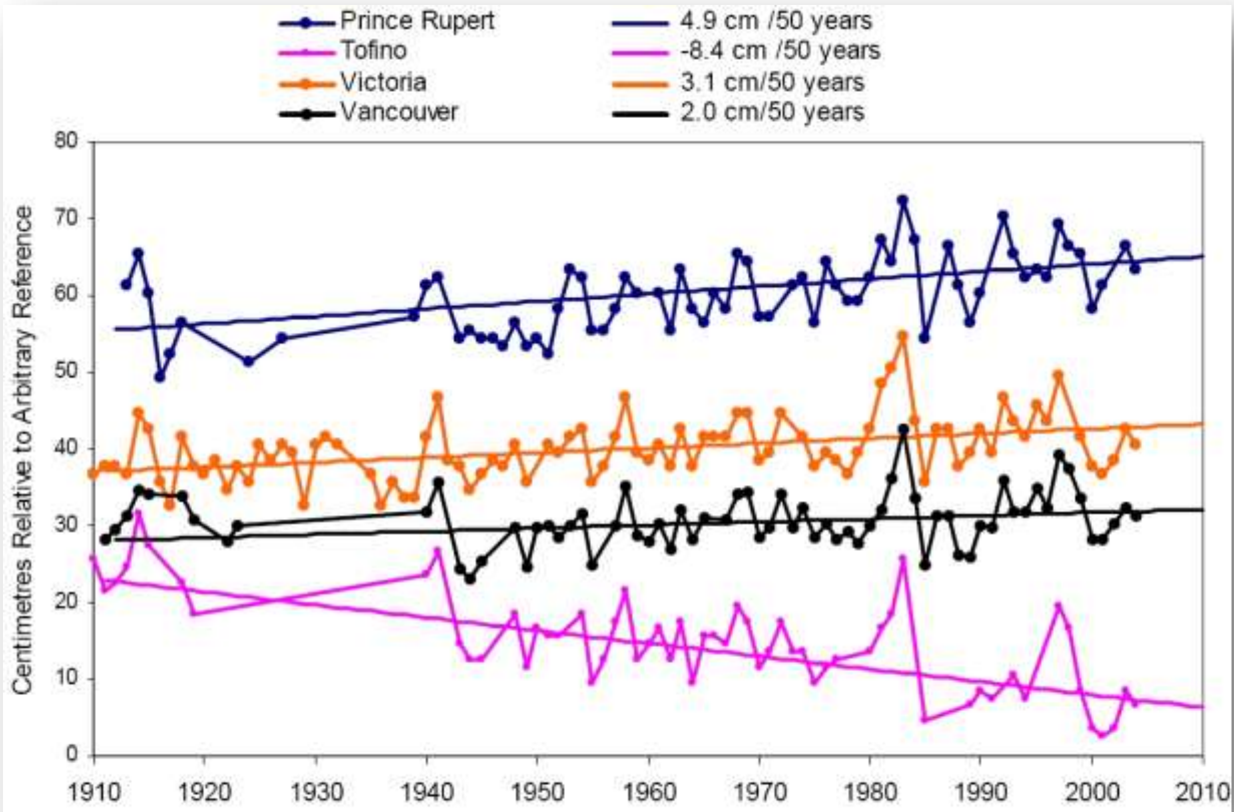

Figure 64. Changes in annual mean sea level at four locations on the BC coast (source: BCMOE 2006b).

17.2.8. Sensitivity of the BC Coast to Sea Level Rise

Rising sea level is a practical concern on the BC coast. Parts of the Lower Mainland coast are particularly vulnerable to erosion and flooding under extreme weather conditions (see **Figure 65**), whereas areas with rocky, relatively steep-sided fjords are not considered sensitive to rising sea levels, flooding, or erosion from extreme wave action. Sections of British Columbia's coast that would be the most sensitive to rising sea levels include the Fraser Delta and the Naikoon area of the Queen Charlotte Islands, which is presently eroding. These areas are vulnerable to flooding and erosion from waves, which could reach into areas not normally washed by the sea (BCMOE 2006b).

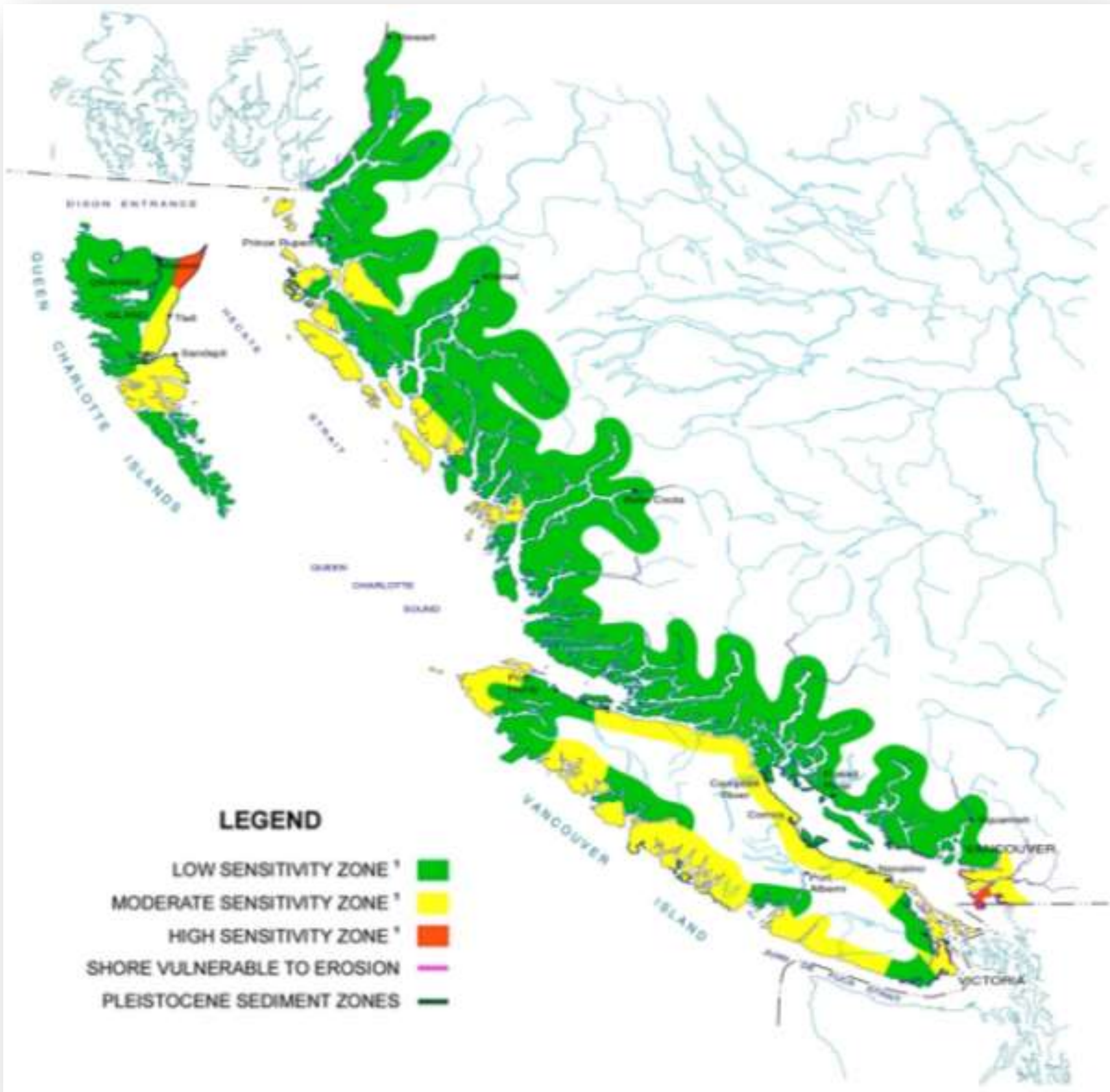

Figure 65. Sensitivity of the BC coastline to sea level rise and erosion (source: Hay & Co. Consultants 2004)

17.3. Mitigation

Reducing greenhouse gas emissions on a global scale is expected to slow the rate - and possibly the magnitude - of climate change. However, IPCC scientists estimate that greenhouse gas emissions must be reduced by 50–60% just to stabilize global atmospheric concentrations of carbon dioxide at 500 ± 50 ppm (nearly double the pre-industrial concentration) by the middle of the next century (Pacala and Sokolow 2004).

The 1992 United Nations Framework Convention on Climate Change - supported by most nations including Canada and the United States - stated that global atmospheric concentrations of these gases must be stabilized at a level that would prevent dangerous interference with the climate system. The largest international agreement on climate change is the Kyoto Protocol, which came into force internationally in February 2005, after being ratified by 140 nations. It calls on the 35 most industrialized nations to reduce fossil fuel emissions of carbon dioxide and other greenhouse gases to an average 5.2% below 1990 levels. Canada ratified the Kyoto Protocol in 2002, committing to reduce total greenhouse gas emissions across the country to a level 6% below that of 1990. It commits Canada to reaching this target by 2012 (BCMOE 2006b).

Improvements in energy efficiency in Canada reduced the growth in energy consumption by 13% from 1990 to 2002 (Behidj et al. 2004). Despite increased efficiencies, however, energy use continues to grow as the Canadian population and economy expand. For example, greenhouse gas emissions from the residential sector in Canada were 8% higher in 2002 than in 1990 (Behidj et al. 2004). Global emissions of most greenhouse gases have increased since 1992 (Houghton et al. 2001).

Even if countries succeed in reducing future greenhouse gas emissions, the excess greenhouse gases already in the atmosphere are expected to continue to drive climate change and its impacts for centuries. An effective response to climate change therefore also includes long-term planning to adapt to the impacts (BCMOE 2006b).

In Canada, both federal and provincial governments are making some movement towards addressing climate change. In 2005, the federal government released the report “Moving Forward on Climate Change: A Plan for Honouring our Kyoto Commitment”. However, with the change in government, this plan is currently under review. In December 2004, the province released “Weather, Climate and the Future: BC’s Plan.” The plan outlines how the province will work with the federal government, industry, local government, and individuals to address climate change. It lists 40 actions aimed at reducing greenhouse gas emissions and adapting to climate change (BCMOE 2006b).

Each of us contributes to global warming. By taking responsible action, we can all help reduce greenhouse gas emissions (BCMOE 2006b):

- Consider fuel economy when purchasing a vehicle. Road transportation is responsible for almost a quarter of all greenhouse gas emissions in British Columbia.
- Reduce greenhouse gas emissions produced by your household by
  - obtaining an energy audit for your home and following the recommendations to reduce consumption;
  - using automatic setback thermostats for night-time and periods of absence;
  - selecting lighting fixtures and bulbs that use less energy(e.g., compact fluorescent bulbs);
  - turning off lights and computer equipment at night;
  - selecting appliances with an Energy Star rating when purchasing new ones.

18. Other Potential Pollution Issues

There are a number of other potential sources of pollution in the PNCIMA for which there is limited or no data available. These potential pollution issues are areas where further study may be required.

18.1. Coast Guard and Military

The Canadian Coast Guard (CCG), a branch of Fisheries and Oceans Canada, provides search and rescue, boating safety, environmental response, icebreaking, marine navigation services, marine communications and traffic services, and navigable waters protection services in Canadian waters (Haggarty et al. 2003). The Coast Guard maintains five search and rescue stations (Port Hardy, Fairview, Sandspit, Bella Bella, and Campbell River), one marine communications and traffic service center (Prince Rupert), one base (Seal Cove), one workshop (Port McNeil), 16 lighthouses, and numerous navigational aids in the PNCIMA(see **Figure 66**). Ships operated by the Coast Guard likely contribute ship-based pollutants to the marine environment (see section 11). Historically, staffed lighthouses used large quantities of mercury as a stable base for their beacons, and batteries containing cadmium and mercury were discarded in the marine environment at both lighthouses and navigational aids (Haggarty et al. 2003). Large numbers of discarded lead acid batteries are currently being recovered from the water adjacent to many aids to navigation (Kruzynski 2000). Thus, while the Coast Guard has been responsible for some of the marine contaminant issues on the BC coast, it has since recognized these issues and is working to rectify them (Johannessen et al. 2007b).

Currently, there are no active Canadian forces bases in the PNCIMA. Three military sites on the North Coast have been closed in the time following World War II - CFS Masset, RCAF Alliford Bay, and RCAF Prince Rupert. A variety of discarded chemicals may remain at these sites; however adequate environmental assessments must be completed to develop reliable inventories of these substances (Johannessen et al. 2007b). In a report by the Auditor General of Canada (2003), it was found that the Department of National Defense did not always comply with the provisions of the Fisheries Act, and as a consequence, fish habitat has been lost. In addition, since 1965, lead weights, lithium batteries, and other substances have been deposited into the ocean at the Canadian Forces Maritime Experimental and Test Ranges at Nanoose Bay near Nanaimo (Office of the Auditor General of British Columbia 2003). While this base is located outside of the PNCIMA, the problems associated with it give an indication of the types of pollution issues which may exist at the closed sites in the PNCIMA region. 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 British Columbia 2003).

Figure 66. Coast Guard sites in the PNCIMA (data: DFO 2007a).

18.2. Seafood Processing Plants

There are approximately 40 seafood processing plants in the PNCIMA (see **Figure 67**). Wastes generated by processing plants contain blood, mucus, scales, and other materials generated during the cleaning and packaging of the product. These waste streams have a high BOD and properties similar to sewage effluents (see section 8). The degree of treatment that these wastes receive may vary, ranging from grinding and release through a marine outfall to some form of secondary treatment (either at the plant site, or by addition to the local domestic sewage which is then treated).

18.3. Abandoned Sites

Historically, many activities have taken place in the North and Central Coast regions. These activities have ranged from pre-contact movements of First Nations populations to post-contact industries such as logging, mining, and canning of salmon. As a result of these activities, there are a number of "abandoned" sites along the coast. The pollution impact of these sites ranges from minimal, in the case of old abandoned First Nations village sites, to very significant, in the case of old mine sites (see section 15.1).

Unfortunately, many of these sites have been long forgotten, and are now heavily overgrown with vegetation and difficult to locate. Local knowledge may be useful in identifying, locating, and determining the potential pollution impacts of such abandoned sites.

The history of salmon canneries in British Columbia provides an example of the significance of this issue. Around 1870, the process of preserving salmon by canning was developed. In British Columbia, commercial salmon canning operations grew from 9 in 1880 to 132 in 1920. In total, there have been 223 documented salmon cannery sites in BC. However, with corporate mergers, buyouts, and consolidations, as well as technological advances in fishing and canning which caused many of the jobs in the canneries to become obsolete, the canning industry shrunk to the few factories which are left today (Niho Land & Cattle Company 2007).

Canneries were found at the mouths of many of the inlets on the BC coastline. Due to their remoteness, they had to support as many as 2000 to 10,000 people from May through to September. A large area was required for both the housing of workers and the cannery equipment itself. Each cannery needed a supply of fresh, clean water for the canning process, and was usually located on or near an estuary or the mouth of a river or stream. Each cannery consisted of a cleaning house, a filling room, a soldering department, a cooking room, and a storage warehouse. Other buildings included a net and boat service building, a boiler house, a blacksmith shop, a machine shop, a can-making plant, and a box factory. Administrative buildings included the cannery office, store, post office, and mess house. These buildings were connected by a series of boardwalks which linked houses and offices together. When the canning industry declined, many of the canning communities turned into deserted ghost towns. More than eighty percent of the 223 canneries that existed in the early 1900's are abandoned, burnt down, or reclaimed by the surrounding forest (Niho Land & Cattle Company 2007).

These canneries operated during a time when marine pollution was not considered a significant issue. During the abandonment phase, many materials were left at the cannery sites, including lead solder and roof sheeting, copper piping, grease and other wastes from machine shops, and first aid supplies and other chemicals, since it was cheaper to leave these supplies behind than to transport them out of the remote cannery sites.

Figure 68 shows the locations of some of the salmon cannery sites in the PNCIMA. Many more sites exist, but information on the exact locations will take further research.

Figure 67. Seafood processing plants in the PNCIMA (data: BCILMB 2008).

Figure 68. Some of the salmon canneries located in the PNCIMA (data: GeoBC 2008b, Golden 2007, New York Commercial 1901)

18.4. Liquid Natural Gas

As a result of the Kitimat LNG project at Bish Cove and the proposed Westpac LNG terminal at Ridley Island (which was later dropped due to economic issues), the potential hazards associated with transport and handling of liquid natural gas have become more of a concern on the North Coast. Some of the dangers associated with a large release of LNG include (SENES Consultants Limited 2005):

- The extremely low (cryogenic) temperatures associated with LNG can cause severe freeze burns both to humans and wild animals.
- On contact with some metals, LNG can cause the metal to become brittle and crack. It should be noted however, that modern LNG vessels are designed with steel rated for low temperatures in areas where a leak of LNG might come into contact with decking or internal structures.
- Formation of a pool of released LNG which absorbs the heat from the surface and evaporates, consequently forming a vapor cloud of methane. Ignition of the vapor immediately above the pool can result in a pool fire.
- Formation of a methane vapor cloud. Methane is heavier than air and displaces oxygen. Thus, sustained exposure can lead to asphyxiation.
- Since methane is lighter than water, an LNG stream released underwater will rise to the surface, absorbing heat from the water as it rises, and then evaporate and spread across the water surface.
- Methane can dissolve in the water, with the potential of reaching levels which are lethal to the early life stages of marine organisms.
- LNG vapor clouds, once they reach a concentration of methane between 5 and 15% by volume, are flammable. In the absence of an ignition source, the vapor cloud will disperse in the atmosphere causing no further local damage.

Internationally, the two most significant LNG accidents occurred in the US. In 1944, a tank failure in Cleveland produced a vapor cloud which filled the surrounding streets and storm sewer system. Natural gas in the vaporizing LNG pool ignited, resulting in 128 deaths. At Staten Island in 1973, an industrial incident unrelated to the presence of LNG killed 40 people. During the repairs to a tank, vapors associated with the cleaning process apparently ignited the mylar liner of the tank. The ensuing fire caused the temperature in the tank to rise, generating enough pressure to dislodge a 15 cm thick concrete roof, which then fell on the workers in the tank (SENES Consultants Limited 2005).

From 1974 to 2002, there have been 18 reported LNG incidents worldwide. Fourteen of these incidents involved ships (5 incidents at sea, and 9 incidents while in port). Only two deaths occurred over this time period (SENES Consultants Limited 2005).

Thus, it appears that the safety record of LNG transport and handling operations has improved markedly since 1973. However, the potential exists for very large accidents to occur.

18.5. Methanex

Methanex Corporation operates a methanol and ammonia production plant in Kitimat. Little information exists regarding the pollution potential of this plant. In 2005, Pollution Watch (2005c, d) reported that the primary pollutants released were methanol (18,300 kg) and ammonia (397,500 kg). Pollution Watch gave the methanol and ammonia components of the plant national pollution rankings of 444 and 826, respectively. By comparison, for that same year, Pollution Watch (2005b) ranked the Alcan Kitimat Works plant at 8 nationally. Thus, the Methanex plant is a much less significant pollution issue in Kitimat than Alcan.

19. Conclusions

The North and Central Coast region is a vast, relatively unpopulated, and relatively pristine area when compared with other parts of British Columbia. However, it is not unaffected by marine pollution. Both historical and current pollutants are having an impact throughout the region. Additionally, global pollutants, such as POPs and greenhouse gases, can also affect our region. Thus, if we wish to have a healthy environment in which to live, grow, work, and play, we must act on a number of levels to prevent pollutants from damaging our marine ecosystem:

- **Individually**. Ultimately, most pollution is a result of consumer demand and usage. Consider the products which you buy and use. How were they made? How are they disposed of? If possible, consider purchasing less environmentally damaging products. Practice the three R's – reduce, reuse, recycle. Try to be more efficient in your use of energy and fossil fuels. Even if each of us only makes a small reduction in the amount of pollution we generate, the total impact from everyone reducing is significant!
- **Locally**. Consider the impacts of marine pollution when engaged in community planning. Good community planning can significantly reduce the impacts of sewage systems, marinas, landfills, and other potentially polluting operations.
- **Provincially**. Become informed regarding provincial regulations as they relate to the marine environment (e.g., regulations regarding aquaculture, oil and gas, mining, etc.). Are they providing sufficient protection for the resources which you value? If not, there may be a need for unbiased scientific research, stakeholder discussions, and/or political action.
- **Federally**. Learn about the role that federal agencies, such as DFO and Transport Canada, play in regulation of marine pollution. Are they doing a good job? Are the regulations that they have put in place being enforced adequately? If not, these issues need to be brought forward by the stakeholder's whose resources are suffering.
- **Globally**. The United Nations has set out a number of guidelines on various aspects of marine pollution which member countries have agreed to abide by. However, some countries still cause significant marine pollution. If they are a UN member, it is possible that political pressure can be applied by other member countries; however, often these campaigns need to start at the grassroots (e.g., people who are affected need to contact their member of parliament to start the process).

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Appendix

Table A 1. Census subdivisions located within the PNCIMA for which population data from the 2006 census was available (data: BC Stats 2006a, SC 2007, 2008). CY = City; DM = District Municipality; T = Town; VL = Village; RDA = Regional District Electoral Area; IRI = Indian Reserve; NL = Nisga'a Land; NVL = Nisga'a Village.

Census Subdivision Name	Census Subdivision Type	Population (2006)	Aboriginal Population (2006)
Campbell River	CY	29,370	2,540
Prince Rupert	CY	12,755	4,475
Terrace	CY	11,195	2,380
Kitimat	DM	8,950	755
Port Hardy	DM	3,810	485
Houston	DM	3,160	375
New Hazelton	DM	625	230
Port Edward	DM	520	180
Stewart	DM	495	55
Bella Bella 1	IRI	1,060	1,015
Bella Coola 1	IRI	788	788
Skidegate 1	IRI	780	710
Gitanmaax 1	IRI	725	710
Masset 1	IRI	690	670
Lax Kw'alaams 1	IRI	679	679
Gitsegukla 1	IRI	670	585
Kispiox 1	IRI	615	600
Kitamaat 2	IRI	514	514
Gitwangak 1	IRI	465	455
Tsulquate 4	IRI	435	425
Dolphin Island 1	IRI	414	410
Gitanyow 1	IRI	385	380
Campbell River 11	IRI	380	345
Alert Bay 1A	IRI	303	303
Kitsumkaylum 1	IRI	295	285
Kitasoo 1	IRI	285	275
Kippase 2	IRI	275	250
Quatsino Subdivision 18	IRI	235	230
Hagwilget 1	IRI	230	220
Sik-e-dakh 2	IRI	225	220
Moricetown 1	IRI	225	225
Quinsam 12	IRI	210	180
S1/2 Tsimpsean 2	IRI	185	185
Cape Mudge 10	IRI	175	160
Coryatsaqua (Moricetown) 2	IRI	170	170
Babine 17	IRI	155	155
Kulkayu (Hartley Bay) 4	IRI	155	155
Alert Bay 1	IRI	150	150
Quaee 7	IRI	148	148
Babine 25	IRI	105	105
Katit 1	IRI	85	75
Kulspai 6	IRI	85	85
Babine 6	IRI	80	75
Kitselas 1	IRI	78	78
Gwayasdums 1	IRI	40	40
Bulkley River 19	IRI	36	36
Duncan Lake 2	IRI	10	10
Kshish 4	IRI	10	10
Fort Rupert 1	IRI	5	5
Hope Island 1	IRI	5	5
Jean Baptiste 28	IRI	5	5
Nedoats 11	IRI	5	5
Nisga'a	NL	97	97
New Aiyansh	NVL	805	760
Laxgalts'ap	NVL	474	474

Census Subdivision Name	Census Subdivision Type	Population (2006)	Aboriginal Population (2006)
Gingolx	NVL	340	340
Gitwinksihlkw	NVL	200	195
Bulkley-Nechako A	RDA	5,290	470
Comox-Strathcona D	RDA	4,980	300
Kitimat-Stikine E	RDA	3,995	660
Kitimat-Stikine C (Part 1)	RDA	2,795	290
Bulkley-Nechako B	RDA	2,165	235
Kitimat-Stikine B	RDA	1,610	360
Bulkley-Nechako G	RDA	1,060	70
Mount Waddington A	RDA	1,050	220
Comox-Strathcona H	RDA	750	45
Mount Waddington C	RDA	735	30
Skeena-Queen Charlotte D	RDA	605	20
Central Coast C	RDA	555	55
Central Coast D	RDA	420	20
Skeena-Queen Charlotte E	RDA	400	20
Mount Waddington D	RDA	305	45
Mount Waddington B	RDA	155	0
Central Coast A	RDA	140	10
Central Coast E	RDA	130	60
Skeena-Queen Charlotte A	RDA	55	10
Kitimat-Stikine A	RDA	46	0
Skeena-Queen Charlotte C	RDA	37	0
Kitimat-Stikine C (Part 2)	RDA	5	0
Smithers	T	5,145	765
Port McNeill	T	2,620	150
Telkwa	VL	1,295	155
Masset	VL	940	320
Queen Charlotte	VL	935	135
Port Alice	VL	820	25
Alert Bay	VL	555	260
Port Clements	VL	435	10
Granisle	VL	365	45
Hazelton	VL	345	195
Sayward	VL	340	20

Disclaimer

The findings presented in this report are based upon data collected during the period February 15th to July 15th, 2008. Ocean Ecology has exercised reasonable skill, care, and diligence to collect and interpret the data, but makes no guarantees or warranties as to the accuracy or completeness of this data.

This report has been prepared solely for the use of the North Coast-Skeena First Nations Stewardship Society, pursuant to the agreement between Ocean Ecology and North Coast-Skeena First Nations Stewardship Society. Any use which other parties make of this report, or any reliance on or decisions made based on it, are the responsibility of such parties. Ocean Ecology accepts no responsibility for damages, if any, suffered by other parties as a result of decisions made or actions based on this report.

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