Marine Environmental Quality in the Central Coast of British Columbia, Canada: A Review of Contaminant Sources, Types and Risks

D.R. Haggarty, B. McCorquodale, D.I. Johannessen, C.D. Levings and P.S. Ross

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

Haggarty, D.R., B. McCorquodale, D.I. Johannessen, C. D. Levings, and P.S. Ross. 2003. Marine environmental quality in the central coast of British Columbia, Canada: A review of contaminant sources, types and risks. Can Tech. Rep. Fish. Aquatic Sci. 2507: x + 153 p.

The region known as the central coast of British Columbia (Canada) extends from northern Vancouver Island (approximately 50ºN) to the Queen Charlotte Islands (approximately 53ºN). It encompasses the broad, fjord-strewn mainland region, the open waters of Queen Charlotte Sound, the passages of Queen Charlotte Strait, Johnstone Strait and Discovery Passage, numerous island archipelagos, and offshore waters. The central coast boasts abundant natural resources, stunning land and seascapes, and diverse ecosystems. In comparison to other locations in BC, and indeed the world, the central coast is a relatively pristine environment, at least with respect to environmental contamination. Despite spanning approximately half of British Columbia's coastline, the region is home to only 55,000 residents, or 1.4% of British Columbia's total. This low population density largely explains the relatively pristine nature of the central coast. Nonetheless, pollution and contamination concerns do exist in the central coast. Sources of contamination comprise local, regional and global scales, with timeframes for contaminant impacts varying from short to long-term. Past and ongoing activities which have impacted the environment in the central coast include contamination sources associated with salmon aquaculture, oil pollution, wastewater effluent, marine traffic (shipping, boating and cruise ships), forestry and forest products, and mining, as well as the global atmospheric transport and deposition of "legacy" Persistent Organic Pollutants (POPs), "new" POPs, and metals. Regulations implemented to eliminate the use of many of the POPs, as well as regulations designed to reduce the by-production of dioxins and furans through pulp processes and wood preservative applications, have helped to reduce the inputs of harmful substances into the coastal waters of the central coast. However, emerging issues are likely to reflect new industrial chemicals and pesticides, increasing cruise ship traffic, the expansion of aquaculture activities, and perhaps most significantly, the potential for the development of offshore oil and gas in the Queen Charlotte Basin. This report will provide the reader with an annotated summary of information sources on what is known about this coastal region of British Columbia. However, significant information gaps exist on basic biology and ecology of the species present in this area, making it difficult to conduct a thorough assessment of the state of the environment in the central coast. Basic and applied research is clearly needed to address some of the fundamental information gaps needed for effective management and conservation in this region.

Résumé

Haggarty, D.R., B. McCorquodale, D.I. Johannessen, C. D. Levings, and P.S. Ross. 2003. Marine environmental quality in the central coast of British Columbia, Canada: A review of contaminant sources, types and risks. Can Tech. Rep. Fish. Aquatic Sci. 2507: x + 153 p.

La région connue sous le nom de côte Centrale de la Colombie-Britannique (Canada) s'étend du nord de l'île de Vancouver (soit environ 50ºN) aux îles de la Reine-Charlotte (soit environ 53ºN). Elle comprend la zone continentale parsemée de fjords, la mer libre du bassin de la Reine-Charlotte, les passages que sont le détroit de la Reine-Charlotte, le détroit de Johnstone et le passage Discovery, de nombreux archipels et le grand large. La côte Centrale renferme d'abondantes ressources naturelles, de spectaculaires paysages terrestres et marins ainsi que des écosystèmes d'une grande diversité. Par comparaison avec d'autres parties de la Colombie-Britannique et même du monde, la côte Centrale est un milieu qui est encore, en grande partie, dans son état originel, au moins en ce qui a trait à la contamination de l'environnement. Bien qu'elle englobe environ la moitié du littoral de la Colombie-Britannique, la région abrite seulement 55 000 résidents, soit 1,4 % de la population totale de la province. De plus, les résidents autochtones représentent une proportion élevée de la population locale, et leur bien-être physique, culturel et économique dépend largement des ressources marines. La faible densité de la population humaine explique, en grande partie, la préservation relativement bonne de l'état originel de la côte Centrale. Cela n'empêche pas l'existence d'inquiétudes en matière de pollution et de contamination dans cette région. Les sources de contamination sont liées à des activités locales, régionales et internationales, et les cadres temporels relatifs aux impacts des contaminants varient du cours au long terme. Parmi les activités passées et présentes qui ont eu une incidence sur l'environnement de la côte Centrale, on remarque les sources de contamination reliées à la salmoniculture, la pollution par les hydrocarbures, les effluents d'eaux usées, la circulation maritime (navigation maritime, navigation de plaisance et navires de croisière), l'exploitation forestière et les produits forestiers, l'exploitation minière ainsi que le transport et le dépôt atmosphériques à très grande distance de polluants organiques persistants (POP) dont nous avons hérité, de POP récents et de métaux. Les règlements mis en oeuvre en vue d'éliminer l'utilisation d'un grand nombre des POP, ainsi que ceux qui visent à réduire la création de sous–produits des dioxines et des furanes au sein des procédés de traitement de la pâte et des applications de produits de préservation du bois, ont aidé à réduire les intrants liés aux substances nocives dans les eaux littorales de la côte Centrale. Par contre, des enjeux nouveaux vont probablement entraîner l'utilisation de nouveaux produits chimiques et pesticides industriels, comme l'augmentation de la circulation de bateaux de croisière, le développement des activités aquicoles, et peut-être plus important encore, l'éventuelle exploitation des ressources pétrolières et gazières du bassin de la Reine-Charlotte. Les lecteurs et lectrices trouveront dans ce rapport un sommaire annoté des sources d'information sur ce que l'on sait à propos de cette région littorale de la Colombie-Britannique. Toutefois, il existe des lacunes importantes sur la biologie et l'écologie élémentaires des espèces vivant dans cette zone, ce qui rend difficile toute tentative d'évaluation exhaustive de l'état de l'environnement dans la côte Centrale. Il est évident que la gestion et la préservation efficaces de cette région exigent des recherches fondamentales et appliquées afin d'éliminer quelques-unes des lacunes fondamentales existantes.

Executive Summary

This report is intended as a background paper to educate managers, stakeholders, scientists and public about chemical contamination issues in the central coast. We have used primary and grey literature sources that touch on these issues in the central coast. We have also relied on information sources and studies from outside this region in order to draw inferences when information specific to the central coast was lacking.

The information is presented in a form that we hope is clear and useful. The report is arranged by topic representing the major activities in the central coast that may be introducing chemical contaminants. Each topic is concluded with a "*Synthesis*" section. This section provides a brief summary of the topic, highlights primary issues of concern, and points out information needs, knowledge gaps, and unknowns.

Chemical contamination is but one aspect of marine environmental quality. Numerous other factors could also be considered including biodiversity, habitat alteration and loss, introduced and endangered species, and the health of populations. Moreover, other forms of contamination including biological (i.e. bacteria, viruses, introduced species, toxic algae blooms) and physical (i.e. noise pollution, seismic activity), also effect marine environments. These topics could not be covered in this report on chemical contamination; however, some information sources on related topics are presented in a box at the end of each section. These boxes are not intended as a comprehensive source of information on related topics, but as a starting point for interested readers. The *Boxes* are labelled "*Additional Information and Related Topics*" and also point readers towards useful information sources on primary topics that are covered in the preceding section.

1. **Chemical Contamination:** can be defined as foreign chemicals introduced into an ecosystem, or natural chemicals that are present in unnaturally high concentrations. Pollutants, on the other hand, are substances which have an adverse effect on an ecosystem, or on some component there in. Sources of contaminants, the pathways that distribute them, and the sinks where they accumulate are all important concepts central to an understanding of contamination issues. Chemicals that are persistent, highly toxic, and/or bioaccumulate or biomagnify are of particular concern as they have the greatest potential to affect the health of individuals and perhaps populations, communities and ecosystems.

2. **The Central Coast:** The region known as the central coast of British Columbia roughly extends from northern Vancouver Island, to the bottom of the Queen Charlotte Islands. We have used the proposed boundaries (as of January 2003) for the central coast Large Ocean Management Area (LOMA) as our operational area. The proposed boundaries for the central coast LOMA extend from Campbell River and Discovery Passage, across Vancouver Island to the Northern end of Brooks Peninsula, and northward to Hecate Strait. It encompasses the broad, fjord-strewn mainland region traditionally referred to as the central coast, the open waters of Queen Charlotte Sound, the passages of Queen Charlotte and Johnstone Straits, numerous island archipelagos and offshore waters. Queen Charlotte Island, and surrounding waters, falls just outside of this area.

The central coast is a spectacular part of British Columbia with abundant natural resources, stunning land and seascapes, and diverse ecosystems. The remote nature and low human population of the central coast have resulted in less impact to the natural ecosystem when compared to more urbanized or industrialized areas such as the lower mainland. However, past and ongoing activities have

impacted the environment in the central coast and will continue to leave their mark. A brief overview of the central coast describes the ecological and social setting of this area in order to provide a context for our discussion of contaminant and pollution issues specific to the central coast. A more robust evaluation of the central coast environment can be obtained elsewhere (Johannessen *et al.* 2003a).

3. **Salmon Aquaculture:** is a major industry in the central coast as the majority of all BC salmon farms operate in this region. Chemicals are used in many aspects of salmon aquaculture including intentional use of pesticides to control sea lice, chemical additives in food, antifouling chemicals, as well as inadvertent chemicals found in feed and building materials. Organic enrichment from fish wastes and excess food can result in sediment contamination and changes in the ecological community below salmon net pens.

Most chemical contamination impacts from salmon farms appear to be localized in nature and are relatively short-lived. For instance, ecological communities below net pens often largely recover after a 6-month fallowing period. However, it is uncertain how ecological communities are affected by pesticides, antibiotics, and organic enrichment. In addition, cumulative impacts of multiple farms or net pens is an important issue that must be resolved in order to determine the number of farms that should be located in any given area. Persistent Organic Pollutants (POPs) found in some salmon feed presents a source of harmful contaminants to the marine environment that should be eliminated.

4. **Oil Pollution**: Numerous sources introduce oil and its constituents into the marine environment. These include chronic oil pollution from mixed sources, as well as catastrophic spills associated with oil exploration and transport. Some components of oil, particularly Polynuclear Aromatic Hydrocarbons (PAHs), have widespread toxic effects, particularly to vulnerable species including seabirds, sea otters and marine larvae. Though it is not possible to make overt generalizations about oil-related impacts, the central coast does possess many sensitive environments and species that could be adversely affected by a catastrophic oil spill. A more immanent threat of oil pollution to the central coast is chronic sources of oil pollution that may impact areas such as harbours, marinas, high use areas and shipping routes. More information about the effects of chronic oil pollution is needed. The possibility of oil and gas development highlights the importance of basic research into PAHs/oils in the central coast environment as well as the necessity of collecting baseline data.

5. **Wastewater**: The impact of sewage discharge is site specific and highly dependent on the characteristics of the outfall and the receiving environment such as rate of flushing, type of discharge, level of treatment, and cumulative loadings. All larger communities in the central coast area have some level of sewage treatment, often secondary treatment. Rural areas, especially in northern part of the central coast, have small populations that rely on septic systems. Small amounts of raw sewage, as well as untreated grey water, may be released into marine waters from septic systems, but impacts are likely to be localized. Local inputs of sewage may develop into an issue of greater concern as shellfish aquaculture in the central coast expands. Natural shellfish beds may also be exposed to bacterial contamination. No direct information was found on chemical contaminants in wastewater specific to the central coast.

6. **Pollution from Cruise Ships**: Cruise ships transport over a million people per year through the central coast, generating wastes that include black water, grey water, oil, air emissions and hazardous materials. The great number of people passing through this region on cruise ships dwarfs the resident population of the central coast. Given this high demand, waste generated from cruise ships represents a potentially significant pollution issue for the central coast. Though the cruise ship industry and the Alaskan government have taken steps to regulate and minimize pollution, Canadian regulations and

monitoring have not been harmonized with US regulations. The stricter US rules have the potential to render Canadian waters more vulnerable to the intentional release of pollutants by cruise ships in waters with laxer regulations, monitoring and enforcement. No-discharge zones should be considered for sensitive areas in the central coast including marine protected areas, sponge reefs, clam beds and bird colonies.

7. **Shipping and Boating**: As with all coastal regions of British Columbia, ships and boats are central to transportation, commerce, travel, industry, fishing, and recreation. Pollution forms such as oil, and black and grey water, are associated with all forms of boating as they are with cruise ships. Cumulative impacts from small vessels, such as recreational fishing boats and pleasure craft, may be more difficult to control than pollution from large boats. Impacts of contamination from boats are expected to be greatest where boats are found in the highest concentration, namely harbours and marinas. Consequently, harbours and marinas should be seen as small scale hotspots for some contaminants. Of particular concern are persistent chemicals, such as pentachlorophenol (PCP), tributyltin (TBT) and PAHs, which tend to be found in elevated concentrations in harbours.

8. **Forestry and Forest Products**: Forestry is a major industry in the central coast as it is in all of British Columbia. The forestry sector generates chemical contaminants and has historically been considered a major polluter of coastal environments in BC. Increased regulations on pulp mill effluent and the release of polychlorinated dibenzodioxins (dioxins) and polychlorinated dibenzofurans (furans) has greatly improved this situation; however the legacy of past, persistent contaminants remain in certain areas. Herbicides used in forestry are regulated and represent a poorly understood, yet probably low risk contaminant in BC. Though large-scale risks may prove to be minimal, greater research into contamination from flame retardants, leachates from log storage, and endocrine disrupting chemicals and derivatives from pulp mills should be investigated.

9. **Mining**: Three mines of primary concern in the central coast are the Island Copper Mine (now closed) at the northwest end of Vancouver Island, and the Quinsam Coal Mine and Myra Falls Metal Mines at the southern boundary of the central coast. Other historic mine sites also exist. Good information exists about the environmental effects of the Island Copper Mine due to extensive monitoring programs that ran throughout its operation and after closure. Though copper levels are still elevated in some sediments, the copper is not bioavailable. Biological communities also appear to have been either not affected by mine operations or are recovering now that operations have ceased. Acid Rock Drainage (ARD) is currently not an issue at Island Copper as the passive treatment system, a meromictic lake, appears to be functioning. However, Quinsam and Myra Falls do experience ARD problems. All three mines should be monitored to ensure that environmental effects related to acidic conditions or toxic metal leaching do not occur in downstream areas in the central coast.

10. **Other Chemical Contaminants**: Despite regulatory controls placed on many POPs, harmful pollutants including polychlorinated biphenyls (PCBs), dioxins and furans, PAHs, organochlorine pesticides (e.g. DDT) still exist in the environment. The primary source of many of these contaminants into the central coast is atmospheric and oceanic transport and deposition. New POPs including chemicals in detergents and soaps (surfactants); flame retardants; paints and inks; sealants; oil and gas additives; chemicals in plastics; refrigerants; stain repellants; fire fighting foams; personal care products such as shampoos and perfumes; cleaning products; and pesticides have recently been flagged as potentially harmful substances. Little information about the environmental effects of these poorly regulated POPs is known. Contamination from toxic metals including mercury, copper, cadmium, lead, silver, nickel, and arsenic can be problematic. Most metal contamination in the

central coast appears to be localized (e.g. in harbours); however, extensive monitoring over large areas has not occurred.

The global transport of “legacy” POPs, “new” POPs and toxic metals present health risks for high-trophic level biota such as salmon, birds, seals and whales. Subsistence-oriented humans in the central coast may also be at risk. Understanding how contaminants are distributed among trophic levels, as well as abiotic components of the environment, is important for understanding the transport and fate of POPs and provides a critical foundation for risk assessments on a regional and global scale. The long-range transport of POPs is probably the most critical chemical contamination issue threatening the central coast due to their lasting negative effects and tendency to bioaccumulate.

11. **Additional Contamination Issues**: Some industries or contamination issues prevalent in other parts of BC also affect the central coast, but to a lesser extent.

- Runoff from agriculture and urban areas is a great concern in the Strait of Georgia, but due to the central coast’s small population and limited agriculture, these issues are probably minor in this region.
- There are eight known sites in the central coast where the dumping of waste material has been permitted.
- Sediment contamination does exist in the central coast. We cover this topic in several sections of the report: 3.1, 3.2, 5.1, 7.2, 8.1, 9.1, 10.2, 10.3, 11.3.
- Tourism is a growing industry in the central coast. Most tourism is focused on activities such as nature viewing and sports fishing that require healthy natural resources. Tourists bring with them wastes in the form of wastewater, garbage, increased boat use, and toxic materials such as batteries and electrical equipment.
- Military and naval activities also occur in coastal waters. No historical munitions dumps are thought to be in the central coast.
- The Canadian Coast Guard also operates in the central coast contributing ship-based contaminants. Historical dumps of mercury and cadmium from batteries and contamination from mercury may exist.
- Additional heavy industry is found adjacent to the central coast study area at the head of the Kitimat Arm, near the town of Kitimat. The region is the site of several industries, including an aluminum smelter, a pulp mill and a methanol manufacturing plant (Pierce *et al.* 1998). Contaminants originating in this area may affect the central coast.

12. **Future Risks and Emerging Issues**: Projected risks of chemical contamination in the oceans are often assumed to be a function of increased population growth in the coastal zone. The central coast departs from this international trend: the population of most regions in the central coast, with the exception Campbell River, is projected to decrease or remain stable. Though this may be true of the resident population, transient workers (e.g. from forestry, oil and gas, and construction) may increase, as will tourists. Therefore, pressure placed on the central coast environment will be greater than what the intrinsic population of the central coast would indicate.

The greatest future risk of chemical contamination to the central coast concerns the possible exploration and development of offshore oil and gas. Effects of catastrophic oil spills and chronic oil pollution, particularly on sensitive habitats and species, are of great concern. Other chemical contamination sources exist, particularly chemicals in drilling mud and produced water; however many of the risks are uncertain. Uncertainties as to the effects of these contaminants on the environment of the central coast must be included in risk assessments.

Other emerging human impact issues concern expanded aquaculture and mining, and the potential development of alternative energy industries (wave, tidal, current and wind power). Furthermore, global climate change may affect contaminant transportation pathways which could result in an increase in transportation of contaminants to coastal BC.

The cumulative effect of various contaminants is not a new or emerging issue; however, it is one that we have not yet learned to assess with confidence. Determining the function of cumulative effects (additive vs. synergistic) presents a challenge to modeling such problems. Assessing cumulative effects pertains to several issues in the central coast including salmon aquaculture, effects of different types of contamination and pollution, and synergistic effects of contaminants on wildlife.

13. **Conclusions**: In comparison to other locations in BC, and indeed the world, the central coast is a relatively pristine environment with respect to chemical contamination. Its remote nature and low resident population have helped to preserve environmental quality in the region. Though this may be the case, marine environmental quality in the central coast must be evaluated on its own terms rather than in comparison to other regions. A challenge exists to maintain marine environmental quality to the highest degree in this unique region.

1. Introduction

1.1. Background

The Oceans Act directs Fisheries and Oceans Canada to lead and facilitate a National Oceans Strategy which includes the development of Integrated Management Plans. An integrated management process may be undertaken in the central coast Large Ocean Management Areas (LOMA). As part of this initiative, background documents are being prepared. One such document defines the boundaries of the central coast LOMA (Johannessen *et al.* 2003b). A second document provides a comprehensive ecological overview of the central coast (Paone 2000; Johannessen *et al.* 2003a; Balfry *et al.* 1996; Paone 2001; St-Hilaire *et al.* 2002; Shaw *et al.* 1998). This report accompanies this ecological overview and is a partial summation of marine environmental quality in the central coast as we limit our discussion of environmental quality to sources of contaminants and pollutants. Building upon the central coast Ecological Overview, this report provides a succinct overview of social, biological and ecological characteristics of the central coast to put into context our assessment of components that may be vulnerable to contamination e.g. unique or sensitive species, habitats or areas. We present an annotated collation of available literature (scientific and technical) and unpublished information pertaining to current contaminant issues in the central coast area to educate the readers about current adverse effects of contamination and their ecological significance. Lastly, we evaluate the relative risks of emerging issues that may provide new sources of contamination and pollution, as well as impacting marine environmental quality.

1.2. Contaminants and Pollutants in the Marine Environment

An important first step in the discussion of contaminants and pollutants within the central coast area is a clear understanding of their definitions and the differences between the two subjects (Pierce *et al.* 1998; Macdonald and Crecelius 1994). The following definitions demonstrate this difference.

- **Chemical Contaminants:** Substances which are foreign to an ecosystem, or natural chemicals that are present in unnaturally high concentrations.
- **Pollutants:** Substances which have an adverse effect on an ecosystem, or on some component therein.

An adverse effect can include harm to aquatic life, a hazard to human health, hindrance to human activities (swimming restrictions, invertebrate harvesting closures, etc.) or a reduction of intrinsic value. Factors that determine whether a chemical contaminant poses a risk of harm are its quantity or concentration, the sensitivity of the target organism or habitat, and the duration of exposure. Difficulties in attributing an observed effect to a specific cause can present a considerable challenge to managers (Pierce *et al.* 1998). In this report, we consider major pollutants and chemical contaminants that are affecting or which may affect ecosystem components in the central coast. Though we do not address biological contaminants including bacteria, viruses and exotic species in detail, we do provide the reader with sources of information on these topics.

Contaminating substances can affect marine ecosystems in many different ways and to varying degrees. Effects can be manifested at all levels of biological organization: cellular, organ, whole organism, and population or community levels (Figue 1-1). Important chemical and physical properties of the contaminant include its volatility, solubility, partitioning onto solids, and its stability or persistence (Pierce *et al.* 1998) (Table 1-1). The partitioning of a contaminant between the air, water and solids determines how it will move through the environment or food web. Ultimately, the impact of a contaminant depends on the physical-chemical properties of the substance, its sources, pathways and sinks, as well as the chemical and biological processes of the ecosystem (Figure 1-1).

Terms of note include:

- **Source:** The point of origin of the contaminant.
- **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).

Sources can be further defined as either point or non-point sources:

- **Point Source**: Defined origin such as industrial and municipal effluents.
- **Non-Point Source**: Diffuse origin such as watershed or urban run-off and long-range transport by atmospheric or marine processes.

Uptake of contaminants by biota can be either passive or active. For example, phytoplankton can passively accumulate chemicals by adsorption through their surface while clams can accumulate contaminants by absorption through their gills. Conversely, animals at higher trophic levels actively accumulate contaminants from ingesting contaminated prey rather than through passive absorption.

Once a contaminant has entered an organism, the impact of the substance is, in part, dependent upon the nature of its retention. Two terms that measure the extent by which a contaminant builds up are bioaccumulation and biomagnification.

- **Bioaccumulation:** the process by which chemical substances are ingested and retained by organisms, whether directly from the environment or through consumption of contaminated food (Pierce *et al.* 1998).
- **Biomagnification:** the cumulative increase in the concentration of a persistent substance in successively higher levels of the food chain.

The manner in which contaminants are taken up, distributed among tissues and retained (or metabolized) depends on the physical-chemical properties of the contaminants, length of exposure and the biology of the organism. 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). A contaminant's bioaccumulation and biomagnification potential can be difficult to determine since bioaccumulation is a complex function of the concentration and chemical properties of the contaminant, the trophic level, feeding preferences and rate, and uptake ability, excretion and growth rates, and longevity of the organism in question (Cretney and Yunker 2000).

The chemical and physical properties of a contaminant also determine its transportation pathway. The vapour pressure of a chemical will determine how far a substance will be transported in the atmosphere, and consequently how widely distributed it will be. For instance, trichloroethylene, a compound used in dry cleaning, is highly volatile and remains in vapor phase in the atmosphere and hence is widely distributed throughout the world's atmosphere. Conversely, less volatile compounds that are released into the atmosphere such as dioxins and furans (PCDDs and PCDFs) adsorb more readily to atmospheric particles which settle or are stripped out by precipitation and therefore remain closer to their sources. Solubility in water will similarly influence how far contaminants will be transported by water masses. Chemicals that are readily adsorbed onto particulate matter in the water column (suspended sediment, particulate matter, particulate organic matter) will be transported until they eventually settle onto the bottom through sedimentation. Properties of the particles such as size, surface area, and amount and nature of organic matter determines the adsorption affinity of the chemical and distance the particle will be transported. In summary, chemicals that adsorb onto particles in the water or air will be deposited into sinks relatively close to their sources. The impacts of these chemicals that are not transported as far as volatile or soluble chemicals may be more localized in nature. Volatile and soluble chemicals can be transported great distances on air and water masses thereby having large-ranging or even global distributions and impacts.

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.

1.3. Measuring Effects of Contamination

Effects of chemical contamination can be manifested at all levels of biological organization: cellular, organ, whole organism, population or community levels. Impacts of contamination can be detected at the level of the individual or by changes in population or community structure. A variety of techniques are used to identify and measure the responses.

Biochemical Responses

Organisms may react to toxic contamination with a number of physiological detoxification mechanisms to reduce the harmful effects of substances that cannot be readily excreted. Biochemical responses include changes in enzymatic activity (either induction or inhibition) and are usually measured in fish (Addison 1996). These enzymatic products are often termed molecular biomarkers:

- **Molecular biomarkers** are the products of these physiological responses, such as metallothioneins and mixed function oxygenases. 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).

Impact on the individual
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** can be measured in the laboratory by the median lethal dose (**LD_{50}**), or the amount of a substance which produced death in 50% of a sample population.

Other related measurements are the median lethal time (LT_{50}) and the median lethal concentration, measured over 48 or 96 hours (LC_{50}). Tests are done in laboratory experiments; however, they are not always straightforward (Clark 2001).

Toxicity of a chemical at a low concentration may not produce any lethal effect though sublethal responses may result.

- **Sublethal** responses to toxins vary widely. Examples include major physiological stress, tumours 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 (i.e. ingestion of crude oil by gulls causing damage to the intestine and liver) or by laboratory tests (i.e. sub-lethal concentration of copper sulphate has been shown to cause the production of abnormal larvae in 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** describes 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 they 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.

Population Change
Measuring the toxicity of a contaminant to an individual, even if it causes mortality to that individual, is not sufficient to show that the contaminant will cause a change at the level of the population.

Mortality that results in a prolonged reduction in the population of a species is often regarded as a serious a loss. The abundance of a species is measured by the population density or biomass. Monitoring changes to a population can be extremely difficult. The problems involved with showing population changes caused by the Exxon Valdez oil spill are discussed elsewhere (Hilborn 1996). Good, baseline pre-impact data to compare to post-impact population estimates are rarely available, as was the case with most seabirds. Even if good baseline data exists, as was the case for herring and pink salmon, great population fluctuations may mask the effects of the impact if a complete understanding of the natural variability is not understood. Comparisons of populations in oiled versus non-oiled areas are also made difficult by confounding factors. Different sources of information can be used in conjunction to strengthen the case that a population change is attributable to pollution (Hilborn 1996).

Certain species are often focussed on in studies of population change. They may be species of high conservation value (seabirds, marine mammals), commercial species (salmon, shellfish), key species (dominant herbivores, important predators), or indicator species (*Capitella*, mussels). Population changes of certain species, may have a greater impact on the community they are part of; therefore, the pollution impact may also be measured at the level of communities.

Community Response

Though more complicated, another approach is to measure community responses. Many statistical methods exist to look at community change, including diversity and dominance; graphical representations including rarefaction curves; and multivariate analysis such as non-metric multi-dimensional scaling (MDS), cluster analysis, and principal component analysis (PCA) (Clark 2001). Though statistical techniques exist, collection of the data can be burdensome. Nonetheless, this is one method to assess aquaculture impacts (Clark 2001). Sampling methodology must also be carefully designed in order to have the power to demonstrate changes to community structure that 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).

Ecosystem Effects

Ultimately, one would like to be able to measure the impacts of various activities on the ecosystem as a whole. This represents a considerable challenge and we often do not possess the necessary information about the structure and function of an ecosystem in order to achieve this. In addition, impacts would likely 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.

Regardless of our ability to measure ecosystem effects, we can discuss the ecological relevance of the various levels of impacts caused by different types of pollution. Figure 1-2 shows the ecological relevance, specificity and timeline of the biological effects measurements discussed above. This figure depicts how the specific biochemical responses may be very rapid, whereas community response, which may be to unspecific causes, may change only after prolonged stress. Another way to look at this is that biochemical measurements can be anticipatory of ecological change whereas community responses may be retrospective (Addison 1996).

Table 1-1. The transport and fate of contaminants in the environment vary as a function of their chemical and physical properties.

Property	Definition	Effect	Example
Volatility	Defined by the chemical's vapour pressure. Volatility describes how a chemical is distributed between the solid/liquid phase and the air.	Affects the magnitude of atmospheric transport. Chemicals with high vapour pressures are likely to become widespread.	The highly volatile trichloroethylene is widely distributed throughout the world's atmosphere.
Solubility	A chemical's solubility in water or lipid can determine its transportation by water as well as its uptake by biota. Chemicals with low water solubility and high lipid solubility, or an attraction to particulate materials tend to attach to particulates and are said to be hydrophobic.	Chemicals with high affinity for lipids are prone to accumulate in aquatic animals. Hydrophobic chemicals that attach to particulates can partition onto solids. Chemicals with high solubility in water can be transported by water currents.	Organochlorine compounds, such as DDT, have high lipid solubility biomagnify and bioaccumulate.
Partitioning onto Solids	Movement from liquid or gaseous phases on to particles. Unlike fluids and air that are in motion, particles tend to settle out and create sinks of contaminants.	Chemicals end up in sediments and soils near the source. Particle size and organic content of sediments enhances the attachment of many chemicals.	Chemicals that attach strongly to particles include lead, PAHs, PCBs, dioxins and furans.
Stability or persistence	Chemicals that do not degrade rapidly in the environment.	Chemicals that both persist and can be uptaken by biota have the greatest potential to cause toxic effects.	Metals such as methylmercury, as well as PCBs and PAHs.

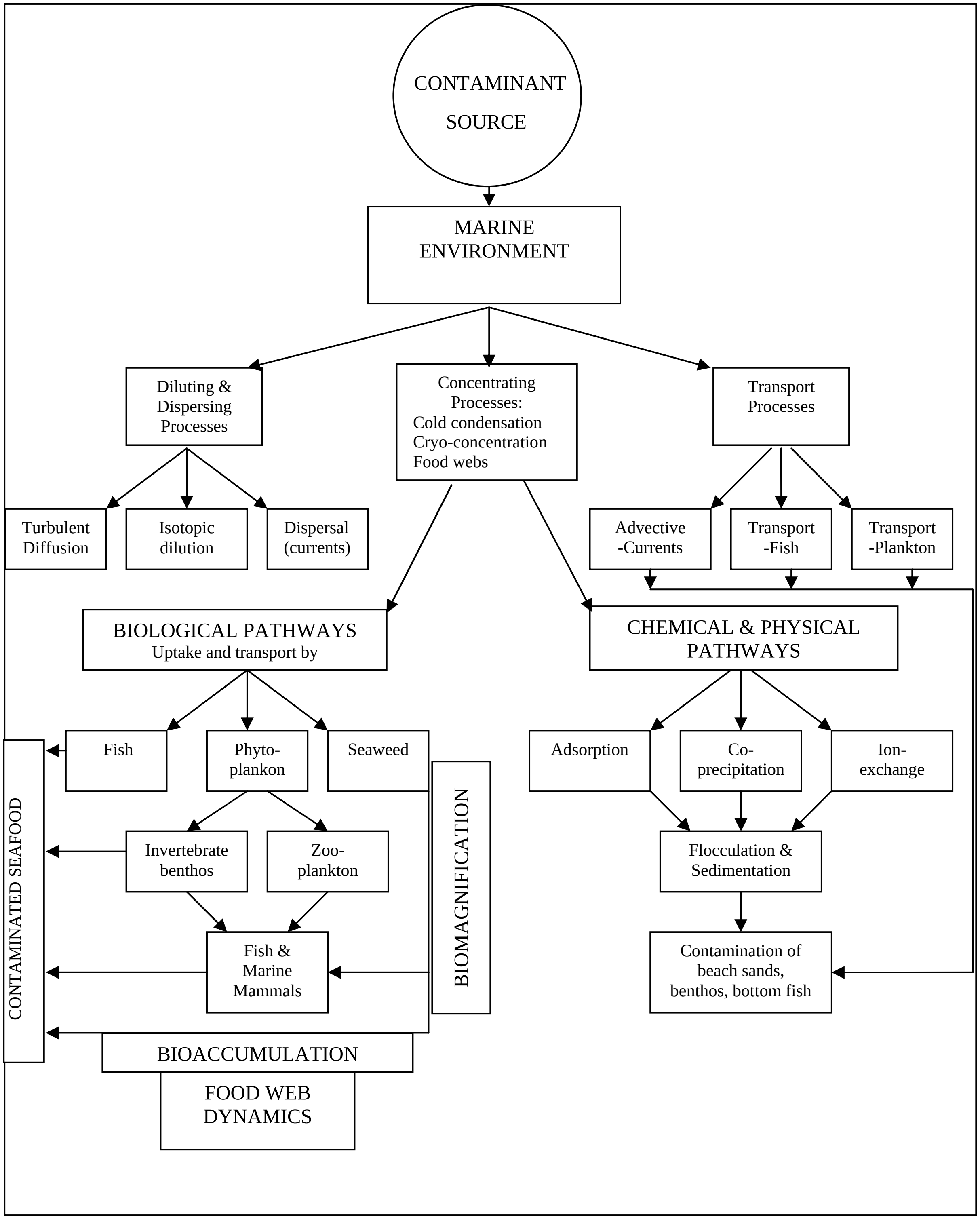

Figure 1-1. The fate of a contaminant in the marine environment reflects its interactions with a variety of abiotic and biotic components (modified from Waldichuk 1983).

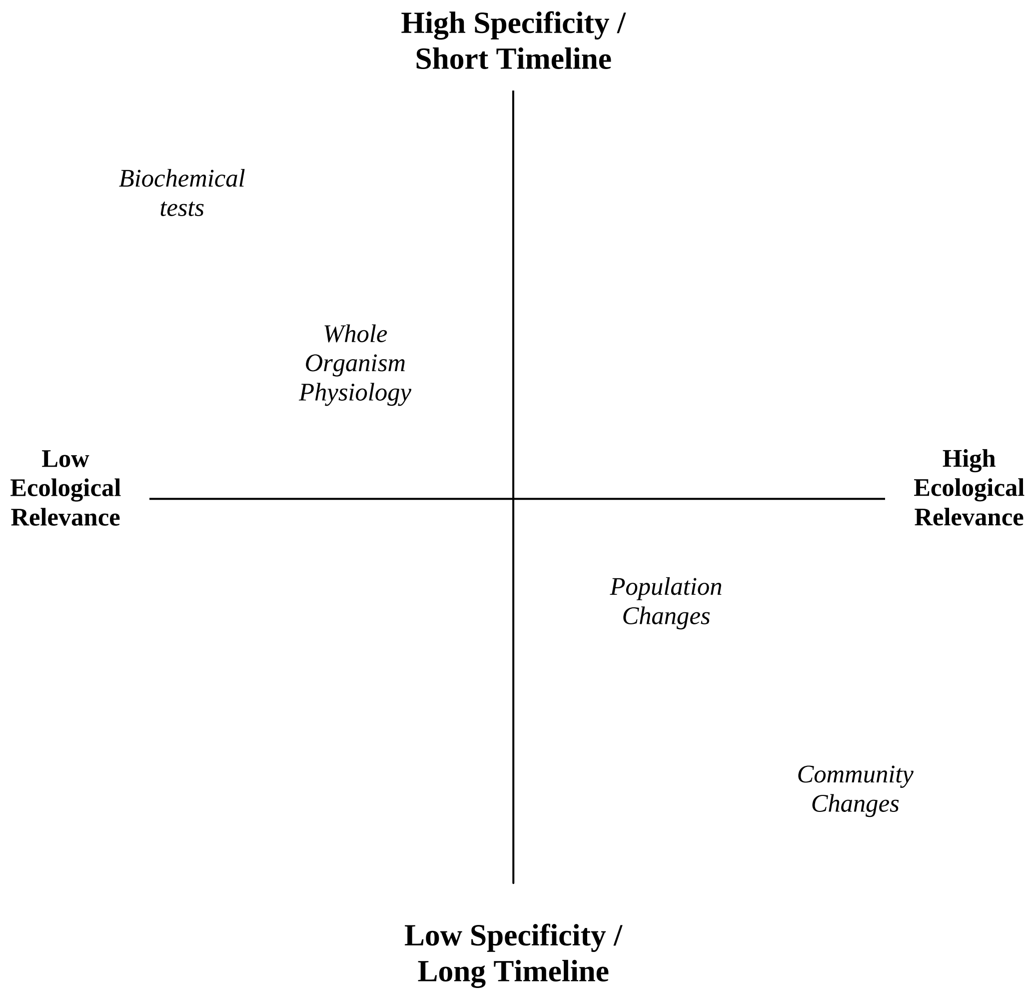

Figure 1-2. Ecological relevance, specificity and timelines of biological effects measurements (modified from Addison 1996).

2. Overview of Central Coast Environment

The proposed boundaries (Johannessen *et al.* 2003b) for the central coast Large Ocean Management Area (LOMA) are shown with community place names and major coastal features for reference in Figures 2–1, 2–2, and 2–3. The central coast is a spectacular part of British Columbia with abundant natural resources, stunning land and seascapes, and diverse ecosystems. The remote nature and low human population of the central coast have resulted in less impact to the natural ecosystem when compared to more urbanized or industrialized areas such as the lower mainland. However, past and ongoing activities have impacted the environment in the central coast and will continue to leave their mark. This brief overview of the central coast will describe the ecological and social setting of this area in order to provide a context for our discussion of contaminant and pollution issues specific to the central coast. A more robust evaluation of the central coast environment can be obtained elsewehere (Johannessen *et al.* 2003a).

2.1. Physical Environment

The central coast of British Columbia has a varied physiography that was strongly shaped by the Quaternary Glaciations (Booth 1998). The central coast is flanked by the Coast Mountains on the mainland side, and the Pacific Ocean or Queen Charlotte Islands on the Western side. The area includes such features as Johnstone Strait, Queen Charlotte Strait, Queen Charlotte Sound and portions of the Vancouver Island Shelf (north of Brooks Peninsula), the North Coast Fjords/Hecate Strait and Continental Shelf Ecosections (Johannessen *et al.* 2003a). The coastline of the central coast can be categorized as open coast, archipelago, fjord, strait and channel (Ardron *et al.* 2002; Booth 1998):

Open coasts: Open coasts are defined as areas with high wave fetches and moderate to high wave exposure. These characteristics are found on the open shores in the Queen Charlotte Sound, Queen Charlotte Strait as well as parts of Hecate Strait and the Vancouver Island Shelf. The salinity is marine (i.e. >30 ppt) and the nearshore biota tend to be high-exposure marine communities (Booth 1998). Queen Charlotte Sound is a major part of the central coast and considered to be open coast. Three major troughs, with depths to 400 m, cut across Queen Charlotte Sound. Much shallower banks, such as Cook Bank, Goose Island Bank and North Bank, are found between these troughs and in the case of the eastern edge of Goose Island Bank are as shallow as 31 m. In Hecate Strait, Laskeek Bank is a shallow area of less than 40 m located between the Queen Charlotte Islands and Moresby Trough which is a deep (50-300 m) submarine valley on the mainland side of Hecate Strait running south and westward until opening to Queen Charlotte Sound (See Figure 2–3).

Archipelagos: Archipelagos are groupings of 10 or more islands in a relatively small area. Most archipelagos are near the open coast and are therefore dominated by marine-type salinity. The numerous small islands produce a long shoreline length and a variety of habitats including highly exposed areas, protected shoreline, and channels exhibiting high tidal current velocities. The high diversity of habitats and productivity caused by tidal mixing often leads to very high biodiversity and biological productivity. Many of these channels are renowned for their high biodiversity (e.g. Browning Passage in the Goletas Channel Islands). Some island archipelagos are also well known seabird colonies (e.g. Triangle Island in the Scott Islands) and boast high densities of eagles’ nests (e.g. Broughton Archipelago). The most significant archipelagos in the central coast are the Broughton Archipelago (a provincial park), the Goose Group (in Hakai Recreational area) and islands of Goletas Channel (Nigei, Hope, etc.) (Booth 1998).

Fjords: Fjords are elongate, steep-walled channels that were carved by glaciers and are typical features in the Central and North Coasts. They generally run perpendicular (E-W) to the major coastline orientation (NW-SE) (Booth 1998). Fjords can be classified by their depth (which can exceed 500 m), the height of their sill, the degree of stratification of the water column, and if they tend to covered by ice in winter (Ardron *et al.* 2002; Booth 1998). The water column of most fjords is highly stratified at certain times of the year, and shows estuarine circulation due to fresh water input at the head of the inlet. The estuary and associated mud flats at the head of the fjords are often highly productive habitats with high salmon, eulachon, waterfowl, bird and wildlife values (e.g. Knight Inlet) (Ardron *et al.* 2002; Booth 1998). Fjords are often much deeper than adjacent waters and show life-forms reminiscent of the deep-sea. The steep vertical walls often have a rich and endemic fauna (Booth 1998), and others cited within). Major fjords in the central coast LOMA are Quatsino, Loughborough, Knight, Kingcome, Seymore, Belize, Smith, Rivers Inlets, Bentick Arm, Burke and Dean Channels (Booth 1998).

Straits and Channels: Both are open-ended passages dominated by currents rather than waves, where the maximum fetch direction is parallel to shore. High mixing in channels tends to make the water more marine than estuarine. The main straits and channels are found in the Johnstone Strait Ecoregion. Passages can be classified by the amount of mixing that occurs. Many of them, particularly in the Johnstone Strait system, show well mixed or almost vertically homogenous water columns due to extreme tidal mixing (Ardron *et al.* 2002; Booth 1998; Zacharias *et al.* 1998).

Queen Charlotte Strait is an approximately 90 km long and between 13 and 26 km wide. It is characterized by a shallow passage with numerous islands, and a broken, shoal-infested coastline with a comparatively low relief. Shoals and reefs are especially numerous within the broad seaward entrance that flanks the mainland shore and within the Broughton Strait to the south of Malcolm Island. Greatest depths are found at the narrow, eastward end of the Queen Charlotte Strait (Thomson 1981).

Johnstone Strait and Discovery Passage are the narrowest of the major channels in the Johnstone Strait Ecosection. The width between Alert Bay and Kelsey Bay ranges from 3.5-4.5 km, and from Kelsey Bay to Seymour Narrows, it rarely exceeds 2.5 km. Within Discovery Passage and the more constrained eastern half of Johnstone Strait, the bottom is characterized by a highly irregular profile with numerous sills and shoals with maximum depths of approximately 250 m. These narrow channels are characterized by rapid tidal streams, constricted passages, numerous shallow sills, and well mixed and highly oxygenated water (Thomson 1981).

The other main straits and channels of the central coast are those that make up the "inside passage" on the central coast. They include Fitz Hugh Sound, Fischer Channel, Mathieson/Finlayson/Princess Royal Channels and a host of smaller connecting channels. Collectively they are as long if not longer than the Johnstone/Queen Charlotte Straits; however, almost nothing is known about the oceanography of these channels as they are mostly unsampled.

Nearshore Marine Habitats: A variety of nearshore marine habitats are found within these broad physiographic types. Nearshore habitats in British Columbia have been classified into along-shore units according to their substrate, sediment type, slope and shore-zone width (Howes *et al.* 1993). The zones are further described with indicator species (such as eelgrass (*Zostera marina*), urchin barrens, bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis integrifolia*)) and levels of exposure to ocean currents (exposed, semi-exposed and protected). The distribution of shoreline substrates in the Queen Charlotte Sound Marine Region (QCSMR), which represents one part of the central coast

LOMA, is estimated to be mainly composed of rock substrates, followed by sediment coastline (boulder, cobble, and pebble beaches or sand/gravel beaches) (Booth 1998). Sand beaches, estuaries and mudflats are rare compared to Vancouver and Queen Charlotte Islands. The four most common shore types in the QCSMR are rock cliff (27%); narrow rock ramp with gravel beach (16%); narrow gravel beach (9%) and narrow rock ramp (8%). Mapping of the nearshore shallow subtidal habitats in Queen Charlotte and Johnstone Straits have revealed that eelgrass (5%) and bull kelp (30-35%) are found along the coast. Giant kelp was found only in exposed portions of Queen Charlotte Strait (3% of coastline) while the distribution of kelps, particularly giant kelp, was more extensive in Queen Charlotte Sound (Ardron *et al.* 2002) and along the west coast of Vancouver Island (Booth 1998). Urchin barrens were found to be more predominant in Queen Charlotte Strait compared to Johnstone Strait (12% vs. 2 %), possible due to stronger currents in Johnstone Strait.

Continental Slope: Offshore benthic habitats are often classified according to depth and substrate; however, their distributions in the central coast have only been crudely characterized. Depths between 20-200 m are considered to be "shelf" and to have the greatest benthic productivity. Rock and gravel substrates tend to support more diverse biological communities than do soft sediments. Other offshore habitats include reefs, areas of high relief, banks, troughs and seamounts. Banks are important areas for the commercial groundfish fishery, particularly in areas adjacent to troughs that may show higher productivity due to increased water exchange (Booth 1998). Cook Bank, Goose Island Bank and North Bank are three major banks in the central coast.

Anadromous Waterways: The central coast contains hundreds of salmon producing systems located on both the mainland and on Vancouver Island. The extent of this can be seen in the Central Coast Land and Coast Resource Management Plan (CCLCRMP), which covers only a portion of the central coast LOMA. The management plan documents a total of 537 known salmon producing systems and 6276 km of known anadromous fish habitat (Ministry of Employment & Investment (Economics Branch) *et al.* 2000). All five salmon species: pink, chum, chinook, coho and sockeye; as well as steelhead, cutthroat, Dolly Varden Char, brown trout and Eulachon are found in the central coast. Some of the major steelhead producing systems include Nimpkish, Eve, Salmon, Marble, Mahatta, Nahwitti, Tsitika, Dean, Wakeman, Kingcome, Bella Coola, Glendale, Ahnuhati, Kakwiken, Atwaykellesse and Whapeeto Rivers. There are nine primary systems producing eulachon: Dean, Kimsquit, Taleomey, Asseek, Bella Coola, Kingcome, Wannock, Chuckwalla/Kilbella and Klinaklini/Franklin Rivers (Ministry of Employment & Investment (Economics Branch) *et al.* 2000).

Upland: The upland portion of the central coast LOMA is mainly defined by watershed boundaries (Johannessen *et al.* 2003b). Much of the upland relief in the central coast is quite steep. A Parks Canada report found that 25% of the coastal ecounits were mountainous (defined as relief within 5 km of the coast that is greater than 1,000 m in elevation) and 53% were hills (between 500 m and 1,000 m in elevation) (Booth 1998). The upland boundaries are similar to those of the central coast LOMA such that we may assume that approximately 75% of land in the central coast LOMA within 5 km of the coast has a relief of 500 m in elevation or greater. The four primary biogeoclimatic zones found in the central coast are described as follows:

- Coastal Western Hemlock: BC's rainiest biogeoclimatic zone, occurring at low- to mid-elevations (0-800 m) along most of the BC coast.
- Mountain Hemlock: Found at subalpine elevations (400-1000 m) in the coastal mountains. It is characterized by short, cool summers and long, wet winters with heavy snow cover.

- Engelmann Spruce-Subalpine Fir: Occurs mainly at high elevation (900-1700m) in interior mountainous terrain that can be steep and rugged. It has a relatively cold, moist and snowy climate with cool and short growing seasons and long and cold winters.
- Alpine Tundra: is found at the highest elevations (1000-1500 m) in the region. It is characterized by a cold, snowy and windy climate, short growing season and stunted vegetation.

A more complete description of the biogeoclimatic zones and subzones/variants is described elsewhere (Johannessen *et al.* 2003a; Ministry of Employment & Investment (Economics Branch) *et al.* 2000). British Columbia has been divided into hierarchical ecological provinces, regions and sections (termed ecoprovinces, ecoregions and ecosections). The central coast LOMA is found in the Coast and Mountains Ecoprovince and includes the following Ecoregions: Pacific Ranges, Hecate Continental Slope, West Vancouver Island, and Coast Gap. The terrestrial Ecosections found in these Ecoregions are described as follows (see Figure 2-4):

- Hecate Lowland Ecosection: An area of low relief, consisting of islands, channels, rocks and lowlands adjacent to Hecate Strait and Queen Charlotte Sound.
- Kitimat Ranges Ecosection: An area of subdued, yet steep-sided mountains, east of the Hecate Lowlands Ecosection.
- Northern Pacific Ranges Ecosection: An area of steep, rugged, often ice-capped, mountains located in the northern portion of this Ecoregion.
- Outer Fjordland Ecosection: An area of rugged, low relief, consisting of inlets, sounds, islands and peninsulas, east of Johnstone Strait and Seymour Narrows
- The Nahwitti Lowland Ecosection is an area of low to rolling topography, with high precipitation located at the north end of Vancouver Island.
- The Northern Island Mountains Ecosection is a partial rainshadow of wide valleys and mountains located in the northern portion of Vancouver Island.
- The Windward Island Mountains Ecosection is the area of lowlands, islands, and mountains on the western margin of Vancouver Island (Ministry of Employment & Investment (Economics Branch) *et al.* 2000).

For a discussion of the marine Ecosections in the central coast LOMA see (Johannessen *et al.* 2003a).

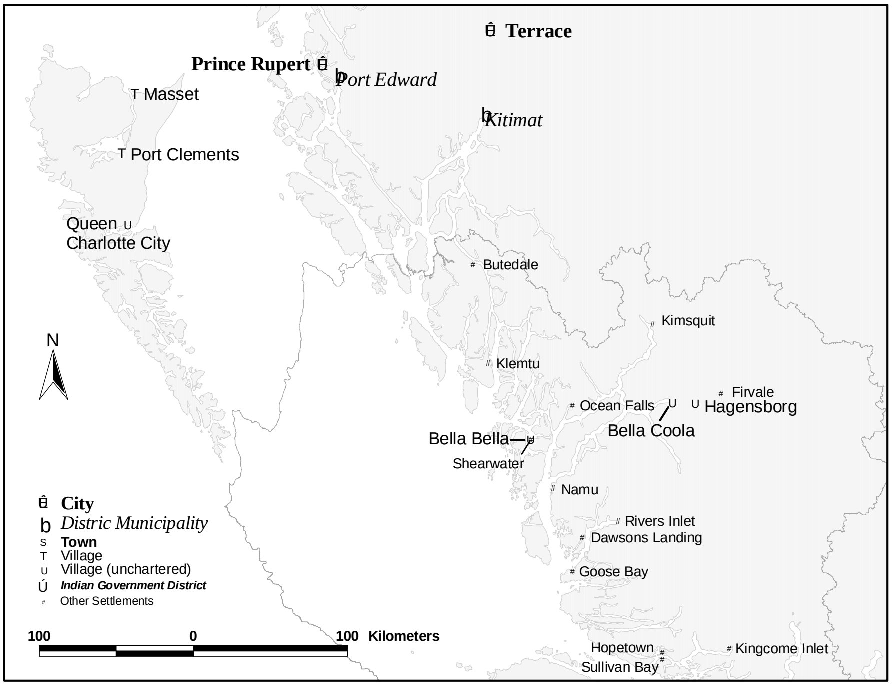

Figure 2-1. Place names and settlements for the northern portion of the central coast. Also shown is the proposed boundary for the central coast LOMA.

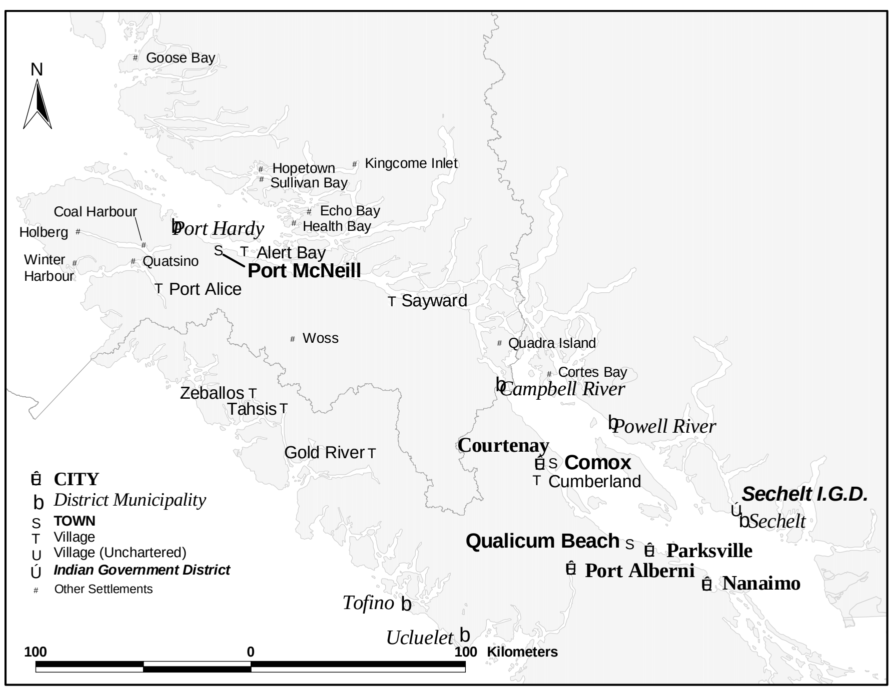

Figure 2-2. Place names and settlements for the southern portion of the central coast. Also shown is the proposed boundary for the central coast LOMA.

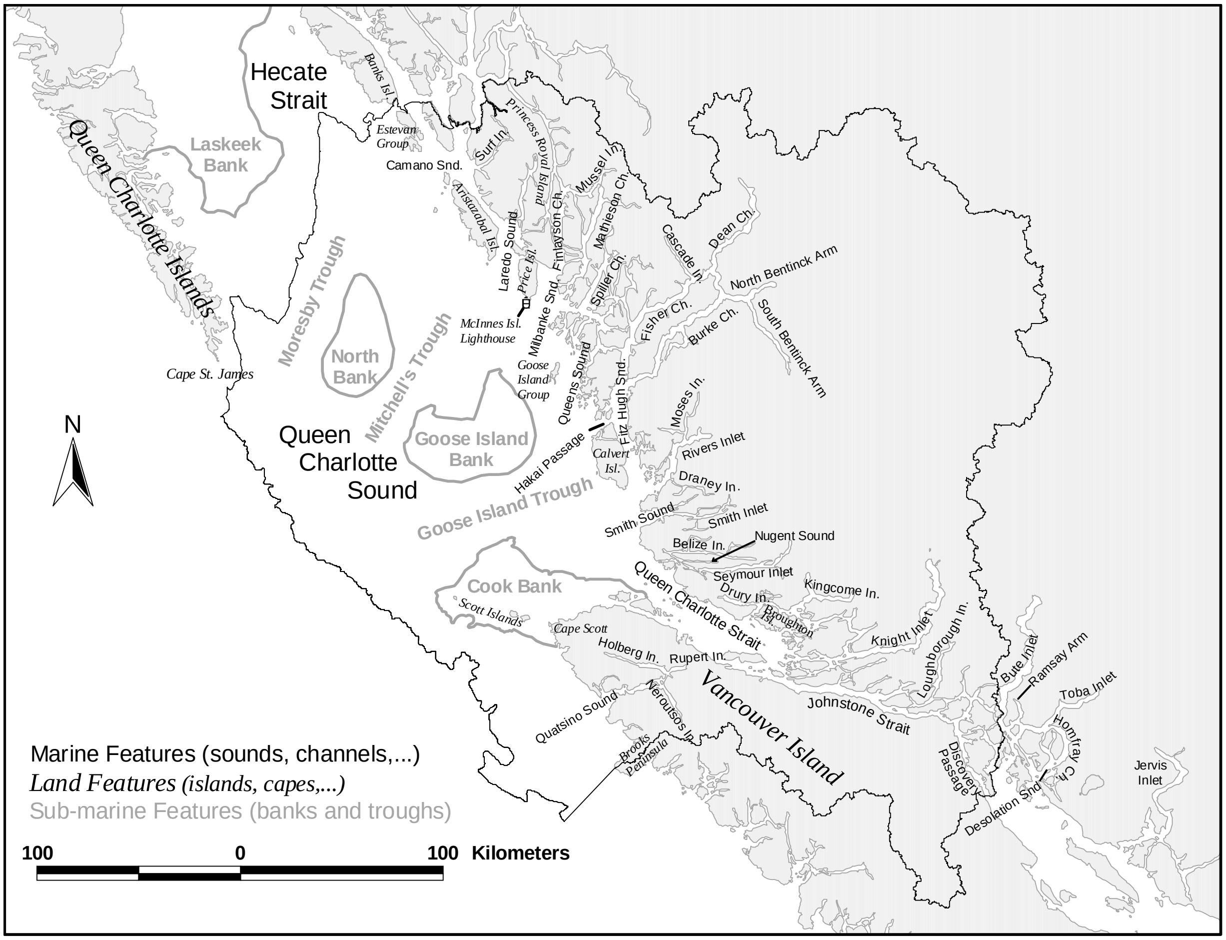

Figure 2-3. Major geographic features of the central coast with the proposed central coast LOMA boundary.

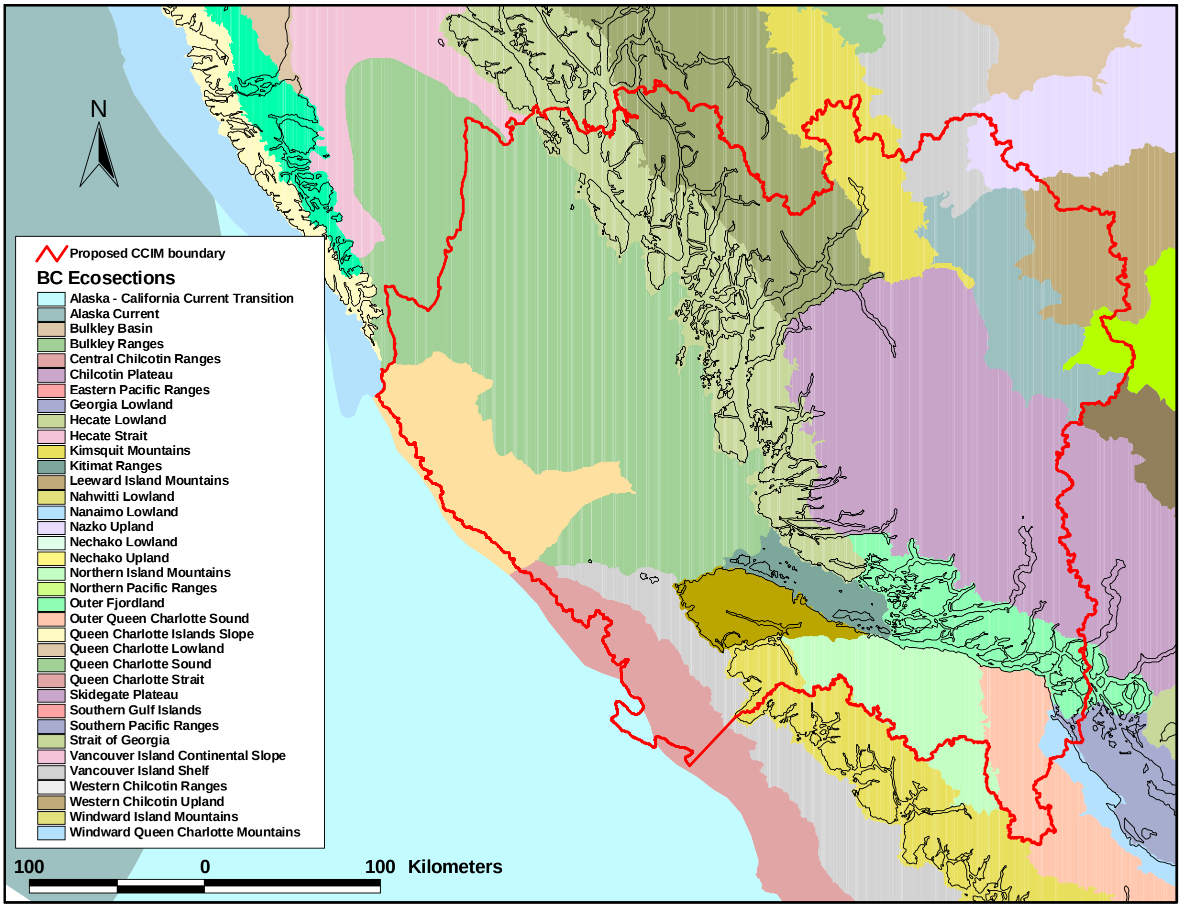

Figure 2-4. **BC Marine and Terrestrial Ecosections in the central coast (Johannessen *et al.* 2003a).**

2.2. Oceanography

Currents and tides have a significant impact upon the ecosystems contained within the central coast LOMA as they affect the movement of water into and out of the area, resulting in varying salinity, temperature and dissolved oxygen and nutrient levels which have direct impacts on the marine ecosystem

Currents and Tides: Three main oceanic currents affect the British Columbia coast. They are the Alaska Current, the California Current and the Davidson Current:

- **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.

Currents affecting circulation in the central coast are mainly generated by tidal and wind influences and fresh water supply (Thomson 1981).

Tides in the northern portion of the central coast are mixed, predominantly semi-diurnal and co-oscillate with the tides in the adjacent North Pacific Ocean. Mean tidal ranges in Queen Charlotte Sound are about 3 m and increase to about 4.8 m midway up Hecate Strait. Mean tidal range is often amplified to 4.9 m as it moves up the deep narrow inlets of the central coast. Tides produce semi-diurnal tidal streams that dominate the water motion in the Queen Charlotte Sound-Hecate Strait region so that clockwise-rotary tidal streams that alter direction and speed over a tidal cycle of approximately 12.5 hrs dominate. Principal floods are to the northeast and ebbs to the southwest. Strong winds, freshwater runoff and coastal topography modify these surface currents.

Tidal, estuarine and wind currents exist in the southern central coast. The strength of tidal currents is affected by the earth's rotation, channel curvature, bottom topography, and cross-sectional area of the channel. Swift, rectilinear tidal currents are found in Johnstone Strait and Discovery Passage. These currents become even faster in constricted narrows and over shallow sills. The strength of the tidal current varies over 15 days with tidal and ebb currents tending to be stronger than floods. Though tidal currents in Queen Charlotte Strait are weaker than in Johnstone Strait due to less constricted passages, the surface currents are still strong enough to make a short, steep chop more than a meter or two high when winds rise above 10 m/s (20 knots). Wave activity in Queen Charlotte Strait can be higher than in Johnstone Strait due to its greater width and the remnants of low, eastward propagating oceanic waves. Wave height in Johnstone Strait is greatly limited by the limited fetch and narrow, winding channels (Thomson 1981).

Estuarine Circulation: Large quantities of freshwater entering coastal regions create an oceanographic region known as an estuary. 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. There are two main types of estuaries in BC: salt-wedge estuaries, typical of larger rivers with large runoff and little mixing (none of which are found in the central coast); and partially mixed estuaries, typical of most inlets and sounds where there is enhanced mixing between fresh and marine water layers because of tidal action and lower runoff. River runoff alters current patterns in coastal basins and inlets creating what are known as estuarine circulation. Because freshwater is lighter than saltwater, it floats on the surface of marine water. This thin, fresh surface layer mixes with and entrains 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 compensate for the brackish surface outflow. 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 river entrains an equal amount of water that has been replaced with deep water. This two-way circulation is particularly well established during periods of large river runoff and when strong down-inlet winds aid the entrainment process (Thomson 1981). Further information can be found in a study of the Bella Coola River Estuary that was completed in 1980 (Leaney and Morris 1981).

Salinity, Temperature and Dissolved Oxygen: Salinity levels in Queen Charlotte Sound and Hecate range from 30-34 % with bottom salinity being relatively homogenous at 34‰. Surface salinity shows more variability (between 30-32.5%) due to factors such as freshwater runoff, sea surface evaporation, downwelling, upwelling and lateral mixing. Surface water temperature varies with the seasons and location but tends to be between 8-16^{o}C in summer and 4-9^{o}C in winter (Strong *et al.* 2002).

Vigorous tidal mixing in Johnstone Strait means that the water at its southern end is well mixed. The northern end of Johnstone Strait is usually weakly stratified. Water temperatures therefore increase very slightly inward along Johnstone Strait and Discovery Passage and stay low all year (<10°C in summer, around 7°C the rest of the year). Salinity is also nearly uniform in Johnstone Strait and Discovery Passage due to mixing with a slight increase in salinity in the seaward direction and with depth. Mixing also leads to almost uniform oxygen content so benthic organisms are not O_2 deprived (Thomson 1981).

The water column in the Queen Charlotte Strait is more highly stratified than Johnstone Strait. Winter temperatures range between 7°-10°C at the surface and 7°-8°C at depth. Summer surface temperatures can be greater than 10°C due to a thin brackish layer in peak runoff and can reach 15°C in some protected embayments. Surface salinities in Queen Charlotte Strait range from 31 to 32 ppt and are lowest in winter. Highest salinities occur in summer due to prevalent NW winds and estuarine circulation that drives surface water out of the strait and makes oceanic water spill over sills. Dissolved Oxygen (DO) is higher at the surface and lower at depth than in Johnstone Strait due to less intense tidal currents and the denser, low oxygenation of oceanic water that spills over sills (Thomson 1981).

Seasonal variations in DO levels in the Queen Charlotte Strait have been investigated (Stucchi *et al.* 2002). They constructed a climatology based model on approximately 500 water profiles collected over the last 50 years and found a clear seasonal signal in the DO concentrations. DO concentrations are lowest in late summer (~3 to 4 mg/l) and highest (8 to 9 mg/l) during the winter months. The vertical structure of the DO profiles also has a distinct seasonal signal. During the winter, the waters of Queen Charlotte Strait are well mixed or weakly stratified. The opposite is true in the summer months, when increased runoff and thermal heating result in a stratified water column with the lowest DO levels present near the bottom. In the late summer and early fall, low DO waters are brought onto the continental shelf by the upwelling favourable offshore winds. The active estuarine flow in

Johnstone and Queen Charlotte Strait then draws these low DO waters into the region (Stucchi *et al.* 2002).

Haida Eddies: These are anti-cyclonic meso-scale eddies that form during the winter off the west coast of the Queen Charlotte Islands and generally propagate westward. The life cycle of these eddies has only been known for the past few years as they can now be detected and tracked with satellite imagery since the surface of these eddies is approximately 1/3 of a metre above surrounding sea levels (Crawford 2002). The characteristics of the Haida Eddies are described elsewhere (Crawford 2002); (Mackas and Galbraith 2002); (Whitney and Robert 2002). Haida Eddies can be 200 km or greater in diameter, extend to a depth of 1000 m, and contain warmer water that is normally less saline than surrounding waters (Crawford 2002). In addition to being warmer and fresher, the water is also higher in nutrients and contains zooplankton communities characteristic of the coastal waters and the continental shelf, rather than oceanic communities (Mackas and Galbraith 2002; Whitney and Robert 2002). This indicates that coastal water, and the nutrients and organisms found therein, are being transported offshore. Whitney and Robert (2002) calculated that the eddies transport between 3,000 to 6,000 km^3 of coastal water up to 1,000 km westward. The area of Hecate Strait and Queen Charlotte Sound is approximately 55,000 km^2 and a total volume of 6,800 km^3 (Whitney and Robert 2002). Therefore a significant amount of water, nutrients and organisms can be transported out of the central coast LOMA, particularly during years when large Haida Eddies form. This newly recognized phenomenon likely has important consequences for ecosystems in Queen Charlotte Sound and Hecate Strait.

2.3. Climate

The central coast has a temperate climate regulated by prevailing onshore flow of marine air. Frontal systems from the Pacific Ocean rise over the coastal mountains depositing high levels of precipitation on the western slopes, making it one of the rainiest regions in Canada (e.g. some areas can receive up to five times the precipitation of Vancouver!). The waters around the Queen Charlotte Islands as well as the central coast area are also some of the windiest in Canada. In the summer, the North Pacific High pressure system dominates, producing north to northwesterly winds along the coast. In the winter, the Aleutian Low pressure system dominates, producing winds from the south to southeast which pump moist, mild air onto the central coast. The prevailing winds are modulated by coastal topography and interrupted by eastward bound high and low pressure systems which can produce 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. As such, these currents present one of the major challenges to understanding the fate and dispersal of contaminants discharged or spilled into the marine environment. It should also be noted that high winds as well as the combination of strong currents interacting with the shallow bottom topography so characteristic of many parts of Queen Charlotte Sound and Hecate Strait can produce considerable surface waves in the region (Strong *et al.* 2002).

Winds in Queen Charlotte and Johnstone Straits run primarily along the length of the channel in a westerly direction in summer and easterly in winter. High winds can generate significant surface currents in some of the long narrow channels in Johnstone Strait and Discovery Passage. The timing and strength of the currents in the various passages of the Johnstone Strait/Discovery Passage are complex (Thomson 1981).

2.4. Biology

The central coast is a region with significant biodiversity. It supports a large diversity of marine flora and fauna including productive fish stocks, a diverse array of invertebrate species, important sea bird colonies and numerous marine mammals. There are several provincial parks, ecological reserves, and recreational areas in the central coast, as well as rockfish protection areas. That said, the marine environment is under-represented in terms of protected areas and no permanent, fully-protected areas exist to date. Parks Canada and the Living Oceans Society have both performed analyses to identify representative and unique areas in the central coast/ Queen Charlotte Sound Marine Region (Ardron *et al.* 2002; Booth 1998). Representative marine areas identified by Parks Canada include: the southern Queen Charlotte Strait and Tribune Channel; the entrance to Queen Charlotte Strait and the North West coast of Vancouver Island; the Goose and Bardswell Group Islands, Hakai Pass, Goose Island Bank and Roscoe Island; and Aristazabel Island, Moody Bank and Douglas Channel. The Living Oceans Society's "Conservation Hotspots" identified areas that should be incorporated into a network of Marine Protected Areas in the central coast. Many of these "hotspots" coincide with areas that are of interest to Parks Canada (Ardron *et al.* 2002). The Living Ocean Society's "Conservation Hotspots" in the southern central coast include: Scott Islands; the entrance to Queen Charlotte Strait; Broughton Archipelago; the head of Knight Inlet; and the Narrows (narrow passages in the Johnstone Strait). Some northern areas include the Goose Group Islands and the Hexactinellid sponge reefs.

2.4.1. Habitat Types

The Hexactinellid sponge reefs are of particular interest being globally unique biological structures. Found at depths of 165-230 m in the Queen Charlotte Sound and Hecate Strait, these structures 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).

Other important biological structures that form habitat which supports a number of species include kelp forests and eelgrass beds. Both are considered to be highly productive nearshore habitats supporting fish communities, invertebrates and algae that contribute to productive fish habitat. Eelgrass beds are particularly sensitive to habitat alteration and destruction through dragging, dredging or construction. They are also sensitive to shading, sedimentation and increased temperature. The structure of kelp forests is strongly influenced by abiotic and biotic factors such as nutrients, light, storms, temperature, salinity, and 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.

Rocky reefs provide stable surfaces for the attachment of invertebrates including anemones, polychaetes, ascidians, corals and sponges, and support diverse communities of invertebrates, fishes and algae. Rocky reefs and walls in nutrient-rich current swept passages, such as Browning Pass, are particularly productive. Rocky habitats are characterized by rocky reef fishes, such as rockfish, greenlings, sculpins, and wolfeel as well as numerous epilithic (attached to rock) invertebrates. Fifteen species of rockfish (*Sebastes* sp.) have been reported from the hook and line fishery in the central coast. Lingcod (*Ophiodon elongatus*), an economically important species caught in rocky habitats, use crevices for egg incubation. Rockfish are known to feed on small demersal and pelagic fishes and crustaceans. Some dominant epilithic invertebrates documented in Tribune Channel in the Broughton Archipelago include serpulid polychaete worms, brachiopods, cup corals, sponges and stylasterine coral (*Allopora verrilli*). Rocky habitats in the central coast also support prawns (*Pandalus platyceros*) which are caught in commercial trap fisheries (Levings *et al.* 2002a).

Sand and gravel beds can represent important habitat for many commercial species such as Dungeness crab (*Cancer magister*) as well as adult groundfish such as English sole (*Pleauronectes vetulus*), rock sole (*Pleuronectes bilineata*) and Pacific cod (*Gadus macrocephalus*). Nearshore sandy and gravel habitats are particularly important nursery habitats for juvenile fishes such as English sole. Infauna sampling and stomach content analysis of fishes and crabs from sand and gravel reveal some components of the food web. Important prey items include sandlance (*Ammodytes hexapterus*), herring (*Clupea harengus pallasi*), demersal fishes (cottids, gobies, pricklebacks and gunnels) and various types of shrimp, crabs, amphipods, polychaete worms and mollusks. Sand and gravel bottoms are particularly important for sandlance, a major prey item of fishes and seabirds.

Muddy sediments in the central coast are known to be important rearing and adult habitats for several species of pandalid shrimps (humpback shrimp, spiny pink shrimp, pink shrimp, sidestripe shrimp). Bottom fish that use this habitat include flathead sole (*Hippoglossoides elassodon*), pollock (*Theragra chalcogramma*), Pacific tomcod (*Microgadus proximus*) and the dwarf wrymouth (*Lyconectes aleutensis*). These species feed on invertebrates, including pandalid shrimp. Heart urchin (*Brisaster latifrons*) is a dominant infauna species in muddy fjord habitats including Kingcome Inlet (Levings *et al.* 2002a).

2.4.2. Biota

There are over 200 species of marine fishes in the central coast including pink, chum, chinook, coho, and sockeye salmon, steelhead, cutthroat trout, eulachon, herring, ground fish (i.e. halibut, sole, rockfish, lingcod, Pacific cod, walleye pollock, hake etc.) and numerous fishes in shallow habitats such as rocky reefs, eelgrass beds and kelp forests. Long-lived nearshore rockfish species of the genus *Sebastes* have recently been protected from commercial fishing pressure in rockfish protection areas due to conservation concerns. Herring and other small pelagic fishes such as sandlance are important components of marine food webs as they support populations of predatory fishes, marine mammals and seabirds. Herring spawn along shorelines and in nearshore vegetation each spring. Due to the commercial significance of herring, the spawning areas have been well documented (starting in 1928). The deposition of eggs is not only significant to maintain herring populations, but also results in seasonally productive habitats that attract a wide diversity of species to feast on the eggs and emerging young. These species include other fishes, invertebrates, mammals and birds. Numerous commercial and ecologically important invertebrates are found in the central coast. Commercial fisheries for shrimp, prawns, crabs, urchin, clams, geoducks, sea cucumbers, and octopus exist (Ardron *et al.* 2002; Booth 1998).

Many islands in the central coast support nesting colonies of seabirds including storm petrels, auklets, puffins, murrelets, common murres and pigeon guillemonts. Important seabird nesting colonies in the central coast include the Scott Islands, Pine and Storm Islands at the entrance to Queen Charlotte Strait and Aristazabel Island. Marbled murrlets, an endangered seabird that nests in coastal old growth forests as well as foraging and rearing young in nearshore habitats, are mostly concentrated in Millbank Sound and the associated Spiller-Matheson Channels, Kynoch Mussell, Knight and Kingcome Inlets (Booth 1998). Species of shorebirds such as plovers, surfbirds, turnstones, and sandpipers are found along the coastline of the central coast while black oystercatchers, killdeers and spotted sandpipers are known to breed in the area (Booth 1998). Blue herons and bald eagles, both important predators, are also found in the central coast. The highest concentration of bald eagle nest sites in the central coast is found in the Queen Charlotte Sound, in and around the Broughton Archipelago, and along the shores of Hope and Nigei Island. Waterfowl such as swans, geese, dabbling ducks, sea ducks (harlequin, long-tailed duck, scoters, bufflehead, goldeneye, merganser) and divers (loons, grebes, cormorants) are also found throughout the central coast though it is generally not considered to be of "prime" importance for waterfowl (Booth 1998). Other types of significant bird habitats include estuaries at the heads of some inlets, exposed sites used by post-moulting sea ducks in late summer as well as sheltered mainland inlets and archipelagos which are important wintering habitats (Booth 1998). There are twenty-six species of pelagic seabirds found in the region, eight of which also breed in the region. Of the pelagic seabirds, shearwaters, albatrosses, fulmars, petrels, phalaropes and gulls are found over Cook, Goose Island, and Moody Banks in Queen Charlotte Strait in high concentrations.

Marine Mammals

The central coast is home to many resident and migratory species of marine mammals. Since most marine mammals are high on the food chain, some even being apex (top-level) predators, they are of interest from a contamination perspective since they are known to biomagnify contaminants. The marine mammals with the highest profile in the central coast are the northern resident killer whales (*Orcinus orca*). They are the subject of much research and attract many whale watchers from Telegraph Cove, Port McNeill, and Alert Bay. Beaches in the Robson Bight area of Johnstone Strait are repeatedly used by killer whales as "rubbing" beaches. In addition, transient and offshore populations of killer whales are also found in the central coast though considerably less is known about them. All three are on the provincial 'blue list' (http://srmwww.gov.bc.ca/atrisk/red-blue.htm), as well as being listed as species at risk in regards to the federal *Species at Risk Act (SARA)* (http://www.pac.dfo-mpo.gc.ca/sara/default_e.htm).

Grey whales (*Eschrichtius robustus*) are another common cetacean in the central coast. An estimated 25,000 migrate along coastal BC between their winter breeding grounds in Baja California to summer feeding grounds in the Bering Sea. An estimated 150 grey whales are known to be "resident" in BC throughout the winter, but it is unknown how many may reside in the central coast.

Many other species of whales are also found, and were once hunted in the central coast. The number of humpback whales (*Megaptera novaeangliae*) seems to be slowly increasing and they are more commonly encountered in BC than they once were. Blue (*Balaeanoptera musculus*), fin (*Balaeanoptera physalus*), sei (*Balaeanoptera borealis*), sperm (*Physeter catodon*) and northern right whales (*Eubalaena glacialis*) were all hunted in the past though presently sightings are infrequent. Minke whales (*Balaeanoptera acutorostrata acutorostrata*), another whale formerly hunted, are more commonly sighted but are rarely studied. Sperm whales may also be more common than their sighting frequency would indicate due to a lack of directed research on this species.

Smaller, toothed whales are more common. The Pacific white-sided dolphin (*Lagenorhynchus obliquidens*) is believed to be one of the most abundant species. Dall's porpoise (*Phocoenoides dalli*) and harbour porpoise (*Phocoena phocoena*) are also present however no population estimates for the central coast exist.

Harbour seals (*Phoca vitulina richardsi*) are a common marine mammal in BC that are found in the central coast. They are non-migratory and tend to show site-fidelity to haul-outs, which for the most part have not been surveyed on the central coast.

California and Steller sea lions (*Zalophus californianus* and *Eumetopias jubatus*) are also found in the central coast. While California sea lions do not breed in BC, they have become relatively common in the southern part of the coast. Steller sea lions breed in five colonies on the western edges of central coast and traditional post-breeding haul-outs are found on offshore islands in Queen Charlotte Sound and Outer Queen Charlotte Strait. Their numbers have been slow to recover from a dramatic population decrease resulting from culls between the years 1913-1968. Populations in Alaska are still declining and they are listed as endangered.

Sea otters (*Enhydra lutris*), extirpated from British Columbia in 1929, were re-introduced between 1969 and 1972 to the West Coast of Vancouver Island and their population is now recovering with total estimates at 3,000 individuals. The Vancouver Island population has expanded their range and are now found at the northern end of the island and hence within the central coast LOMA. A second population of sea otters, approximately 135 animals, is found around the Goose Group Islands in Queen Charlotte Sound. Sea otters are voracious predators of invertebrates and have been considered to be keystone predators that control the population of grazing invertebrates like sea urchins, thereby enhancing kelp forests. While the biggest threat to sea otters is oil spills, they are also susceptible to conflicts with fishermen, diseases and the concentration of environmental toxins (Booth 1998; Ministry of Employment & Investment (Economics Branch) *et al.* 2000).

Approximately 1.5 million Northern fur seals (*Callorhinus ursinus*) migrate to the Pribilof Islands in the Bering Sea during June to October to give birth and mate. After leaving the rookery, northern fur seals disperse widely throughout the eastern North Pacific but tend to be concentrated over the continental shelf. Most female adults and juveniles migrate to California though some remain in BC waters during winter and spring, though are rarely seen closer than ten-miles from shore. This species was hunted for its fur in the later 1700s to the 1980s. Recent population declines may be related to mortality related to entanglement in discarded debris, packing rings and nets (Olesiuk and Bigg 1988).

2.5. Human Population

Approximately 54,000 people live in the central coast area (Table 2-1). The central coast is sparsly populated, in comparison to the rest of British Columbia (Figure 2-5). The primary population base is the municipality of Campbell River, in the Comox-Strathcona Regional District (Figure 2-6). The human population generally decreases as one travels northward. Small population centres are found in and around the Mount Waddington Regional District and the communities of Port Hardy, Port McNeill, Sointula, Alert Bay and Telegraph Cove. Most of the northern population from the Central Coast Regional District is based in Bella Bella and Bella Coola. Most other communities are very small with fewer than 1,000 residents. The population for the northern portion of the region is considered to be stable but no growth is forecasted for the next 25 years due to out-migration and an aging population (Ministry of Employment & Investment (Economics Branch) *et al.* 2000). The population in the Mount Waddington Regional District declined by 11% between the years of 1981-2001; most of the decline occurred after 1996. This drop is attributed to the closing of the Island Copper Mine, timber harvesting reductions, and a down-turn in salmon fisheries with the associated vessel buybacks (Ministry of Sustainable Resources Management Coast and Marine Planning Branch 2002). The population of the Comox-Strathcona Regional District is relatively stable.

2.5.1. First Nations

Much of the central coast is comprised of First Nation traditional territory (Figure 2-7). There are 18 bands belonging to 5 Tribal Councils as well as 2 independent Kwakiutl Nations in the central coast

LOMA. Nearly 5000 people live on reserves in this area (Figure 2-8). In 1996, 53% of the population, or 2455 people, were First Nations living on-reserve in the CCLCRMP plan area (Ministry of Employment & Investment (Economics Branch) *et al.* 2000). First Nations represent 17% of the Waddington Regional District northern Vancouver Island.

First Nations continue to exercise legal Aboriginal rights which include fishing, shellfish harvesting and marine plant collection. Many of these activities take place on a seasonal basis and in locations reflecting traditional divisions of management within and between specific First Nations. Aboriginal food harvesting continues to be of huge economic significance 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 (Ministry of Sustainable Resources Management Coast and Marine Planning Branch 2002).

There is major concern by the Gwawaenuk, Tsawataineuk and Namgis, in the North Island Straits region, about coastal uses that can cause contamination or reduction of harvestable marine resources (Ministry of Sustainable Resources Management Coast and Marine Planning Branch 2002). Concerns that subsistence-oriented consumer groups may be exposed to elevated levels of POPs and heavy metals (e.g. mercury) present in aquatic foods have been raised elsewhere. Groups of special concern include First Nations, Inuit, sportfishing families and some immigrant communities since their diets all consist of a high proportion of aquatic foods (Mos *et al.* 2003; Kuhnlein 1995; 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 breastmilk 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 central coast, 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 central coast may rely on an even greater proportion of traditional food items due to the remote nature of many of their communities (see Figure 2-8). This highlights the necessity to integrate contamination risks to human health with wildlife and ecological risk assessments (Ross and Birnbaum 2003).

Table 2-1. Population of central coast LOMA (Statistics Canada 2003).

District/ Municipality/ Indian Reserve Town/Community within District	Population in 1996	Population in 2001
North Central Coast		
Central Coast Regional District A	244	143
Denny Island, Ocean Falls, Oweekeno, Calvert Island, Rivers Inlet		
Central Coast Regional District B	1,211	1,253
Bella Bella		
Central Coast Regional District C	883	697
Hagensborg, Firvale, Stuie, Saloompt area		
Central Coast Regional District D	439	516
Nuxalk Nation reserves (Four Mile and Townsite)		
Central Coast Regional District E	205	167
Bella Coola (townsite)		
Bella Coola Indian Reserve	873	909
Klemtu Indian Reserve	311	295
Central Coast Regional District (Census Area)[1]	**3,921**	**3,781**
South Central Coast		
Port Hardy	5,283	4,574
Port McNeill	2,925	2,821
Port Alice	1,331	1,126
Alert Bay Indian Reserve	204	281
Alert Bay	612	583
Kingcome Indian Reserve	130	95
Hope Island	0	5
Fort Rupert Indian Reserve	20	36
Mount Waddington Regional District A	1,052	886
Sointula, Echo Bay, Kingcome, Gilford		
Mount Waddington Regional District B	206	169
Holberg, Winter Harbour		
Mount Waddington Regional District C	916	829
Hyde Creek, Quatsino, Coal Harbour		
Mount Waddington Regional District D	510	401
Telegraph Cove, Woss, Beaver Cove		
Mount Waddington Regional District (Census Area)[1]	**14,601**	**13,111**
Comox-Strathcona Regional District		
Campbell River	33,849	33,872
Comox-Strathcona Regional District H	849	785
Sayward		
Comox-Strathcona Regional District J	2,671	2,548
Quadra Island		
Total Comox-Strathcona Regional District in CC LOMA[2]	**37,369**	**37,205**
Total Central Coast[3]	**55,891**	**54,097**

[1] Numbers quoted from 2001/1996 census. Numbers from table do not sum to census total.

[2] Only part of the Comox-Strathcona Regional District is found in the CC LOMA. Not all Regional District sub-areas used for census purposes align with CC LOMA boundaries. These numbers are estimates as some of the population may lie outside CC LOMA boundaries.

[3] Best estimate.

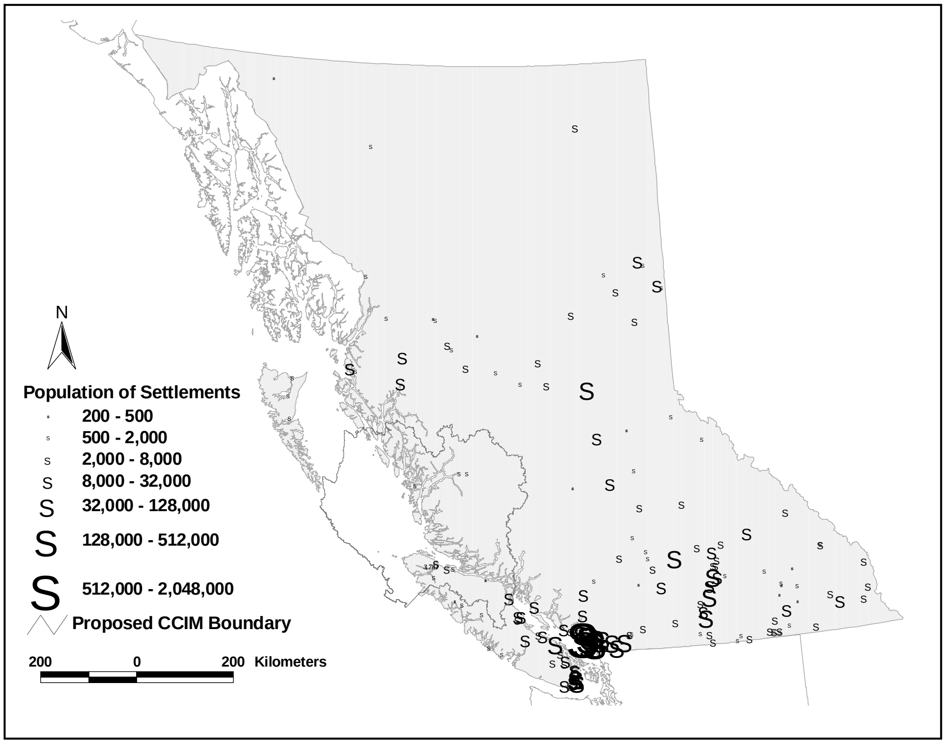

Figure 2-5. Population of settlements in BC. The central coast is sparsely populated in comparison with the rest of central and southern BC. Data from the 1996 Statistics Canada Census using populations projected to the year 2000.

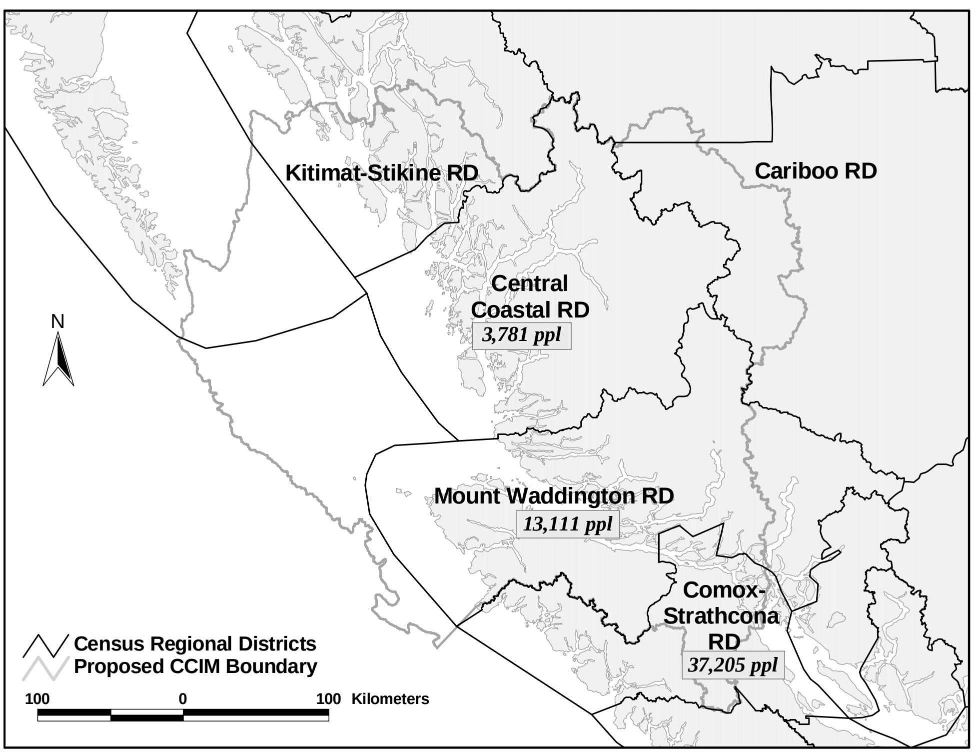

Figure 2-6. 2001 Population totals for Statistics Canada Census Regional Districts in the central coast. Data from Table 2-1.

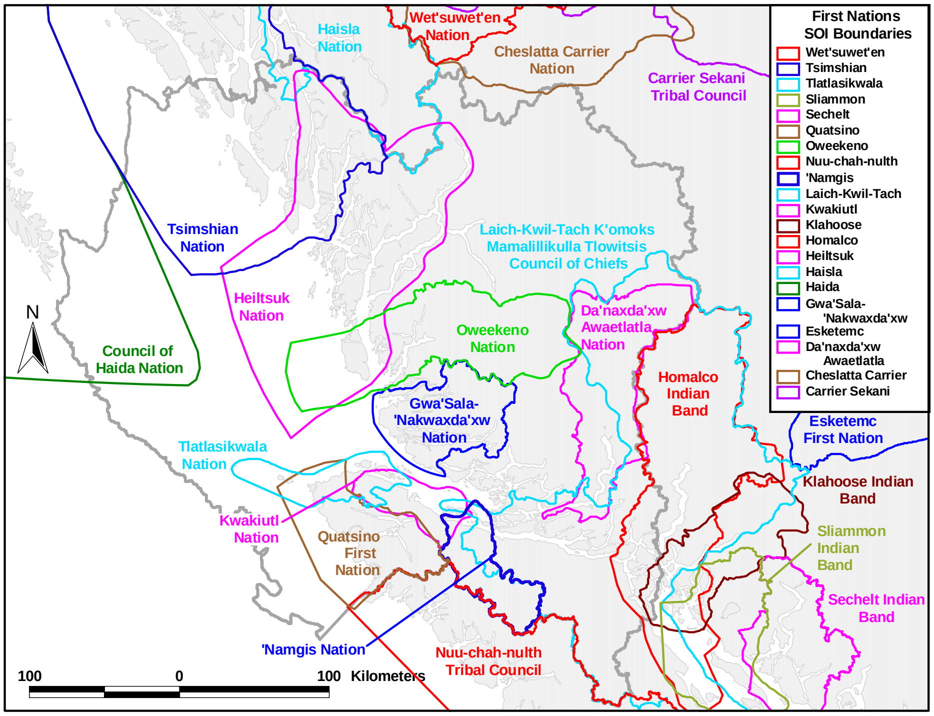

Figure 2-7. Statement of Intent (SOI) boundaries of some central coast First Nations along with the proposed central coast LOMA boundary in grey. These boundaries are not finalized and not all First Nations have yet entered into this process. Data from the Department of Indian and Northern Affairs as of 2001.

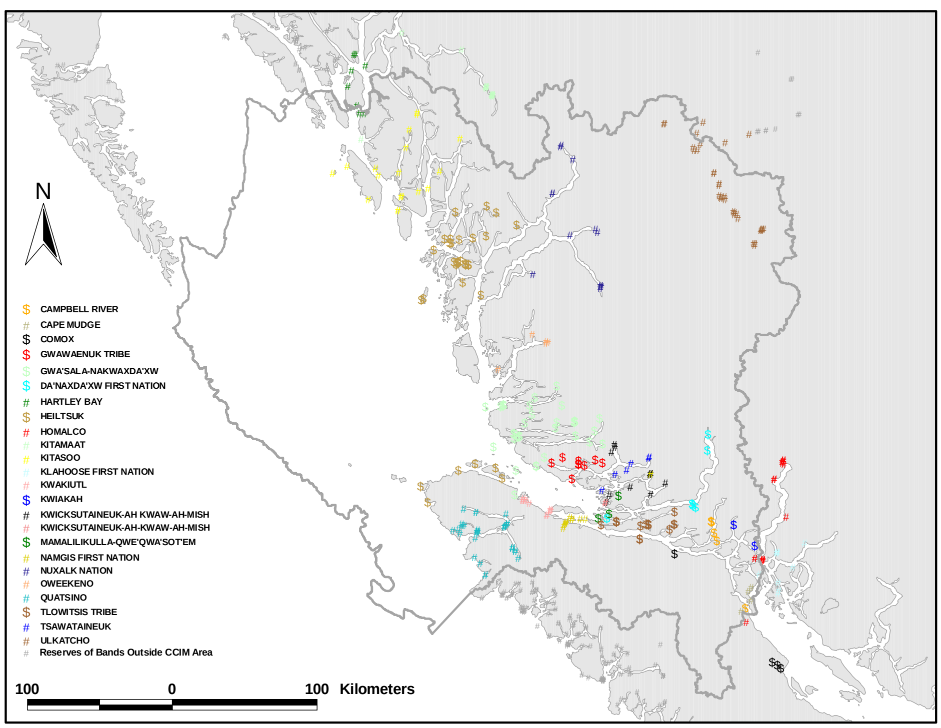

Figure 2-8. Location of First Nations Reserves within the proposed central coast LOMA. Data from the BC Ministry of Sustainable Resource Management, updated in 2002.

2.6. Industry

The central coast has traditionally been and is still a resource-based economy. The main economic drivers are forestry, fishing, tourism, aquaculture, and the public sector (Ministry of Employment & Investment (Economics Branch) *et al.* 2000). With recent declines in industrial forestry and commercial fisheries, many people have been turning to other forms of employment such as aquaculture and tourism. The North Island Straits area supports the majority of BC's salmon aquaculture industry. The industry is looking for expansion and relocation opportunities within the region (Ministry of Sustainable Resources Management Coast and Marine Planning Branch 2002). Tourism, especially ecotourism, is another growing industry for the central coast. High profile tourist destinations in the region include the Broughton Archipelago, Telegraph Cove, God's Pocket Dive Resort, the Cultural Centre in Alert Bay, Knight Inlet, Cape Scott, and numerous fishing lodges. Many of these tourist opportunities rely on natural resources as such as healthy fish populations, killer whales and other wildlife for viewing opportunities, and picturesque and natural sea and landscapes. Many cruise ships pass through and visit the region every year. Other forms of marine transportation, including log transportation, ferries, cargo ships, fishing boats and recreational vessels, compete for foreshore facilities, anchorages, and open passages (Ministry of Sustainable Resources Management Coast and Marine Planning Branch 2002).

Despite the down-turn in the forestry and fishing, these industries still dominate the economy and culture of the central coast. The area is one of the most important timber producing regions in Canada with 350 truckloads of wood produced each day in the Mount Waddington Regional District (http://www.rdmw.bc.ca/). In 1996, timber harvesting accounted for 26% of the income and 21% of local employment of the residents in the CCLCRMP area. The CCLCRMP area also supported the equivalent of 4,400 full-time jobs; however 96% of workers had permanent residences outside of the plan area. In addition, forestry supplies the income of 34% of the people on the North Island.

Other economic activities tied to forestry are two pulp mills located in the central coast LOMA, with the Port Alice mill having operated since 1917, as well as the numerous log handling and storage tenures of which 139 are sited in the North Islands Straits region alone (Ministry of Sustainable Resources Management Coast and Marine Planning Branch 2002). Over the past decade, significant internal and external stresses in BC's coastal forestry industry have occurred relating to global economics, international trade and transitioning to more sustainable forest practices. The central coast has seen reductions in Annual Allowable Cuts (AACs) as Timber Supply Reviews for Coastal BC indicated the AACs were above long-term harvest levels. Coastal BC has also been the site of protests over the protection of old growth forests that have garnered international attention. Most notable in the central coast is the campaign to protect intact old growth watersheds in the area termed the "Great Bear Rainforest." Attempts have been made to resolve these conflicts through planning exercises such as the CCLCRMP and the Vancouver Island Land and Resource Management Plan (VILRMP). Harvesting in the North Island Straits region is subject to adopting new silvicultural techniques and helicopter logging so as to minimize the impact of "visually sensitive areas" as well as merging the goals of conservation and economic development.

Tourism and recreation in the central coast are focused around the natural environment as the central coast offers high quality outdoor recreation opportunities such as sports fishing, boating and kayaking, backcountry hiking, hunting and wildlife viewing. Tourism/business travel accounted for 16% of the resident employment and 10% of the income in 1996 for the CCLCRMP area. A further 850 jobs are generated by tourism in the North Islands Straits Region (Ministry of Sustainable

Resources Management Coast and Marine Planning Branch 2002). The tourism industry experienced 26% growth between 1986 and 1996; growth is expected to continue but has generally been dependent on the health of the sports fishing sector (Ministry of Employment & Investment (Economics Branch) *et al.* 2000).

Commercial fisheries account for 12% of the jobs in the central coast LOMA, spread between fishing and fish plants, which also receive fish from aquaculture. More than 80 marine species including, salmon, herring, groundfish and shellfish in the central coast, are commercially harvested with a variety of fishing methods. As such, commercial, recreational and First Nations food fisheries are very important activities in the central coast. First Nations in the area have historically utilized most of the available marine resources including finfish, (salmon and eulachon in particular), octopus, crabs, squid, clams, mussels, scallops, barnacles, sea urchins, cockles and abalone. These resources are still very important for food, social, economic and ceremonial purposes (Mos *et al.* 2003). Salmon fishing, mostly chum and sockeye, was historically the most important non-native fishery in the region. Declines in salmon abundance, conservation concerns for many stocks, changing global seafood markets, weak Asian economies, and biological uncertainty required a fundamental shift in the structure of the salmon fishery. In a report commissioned by the federal government, Gislason found that small coastal communities, such as Port Hardy, Alert Bay, Sointula, Kitkatla, Bella Bella, Bella Coola, and Klemtu are especially vulnerable to long-term declines in salmon stocks (Fisheries and Oceans Canada 2003). These coastal communities are in the process of diversifying their economies. Herring spawn-on-kelp and invertebrate resources have become increasingly important in providing income and employment for residents of the central coast. Though they make contributions to the local economy, many other fisheries such as herring roe and groundfish are primarily owned and operated by people living outside of the region. Historically, many fish processing and packing plants existed along the coast. With the advent of improved freezing and transportation, most processing has centralized in larger centres outside of the central coast (Ministry of Employment & Investment (Economics Branch) *et al.* 2000). Some smaller processing plants do still exist and are often associated with finfish aquaculture.

There are 71 salmon farms and in the central coast. This represents approximately 60% of all the salmon farms in BC (Ministry of Agriculture 2001). The salmon farming industry is due to expand since the moratorium on new tenures has been lifted. The outlook for the global demand of products produced by aquaculture is strong. Many individuals, environmental groups, and First Nations have concerns over environmental impacts of aquaculture. Recent protests have focused on the Broughton Archipelago and Ocean Falls. Shellfish aquaculture has not been as strong as salmon farming in this area (only 5% of the total shellfish leases in BC) (Johannessen *et al.* 2003a). New shellfish operations in the central coast are also proposed.

2.7. Land Use and Foreshore Tenures

As is apparent in Figure 2-9, forest cover accounts for the majority of landuse in the central coast. Few other landuse types are visible at the scale necessary to view the entire region.

Mining is another form of landuse that is reviewed in this report. A major decommissioned mine in the region is the Island Copper Mine and operating mines include the Quinsam Coal Mine and the Myra Falls Metal Mines, at the extreme south of the central coast. Other historical mine sites also exist.

Agriculture contributes very little to overall land use in the central coast. In 1996, agriculture contributed to 2% of employment and 1% of personal income in the CCLCRMP area. There are 400 ha of Agricultural Land Reserve and 6 grazing tenures (~2200 ha) in the Bella Coola Valley (Ministry of Employment & Investment (Economics Branch) *et al.* 2000). Additional agricultural areas are found on Vancouver Island, especially around Campbell River, but this still represents a minor proportion of the total landuse in the central coast.

Foreshore uses covered in this report include salmon aquaculture (Section 3), marinas and harbours (Section 7.2), log storage tenures (Section 8.5), and ocean dumping sites (Section 11.2).

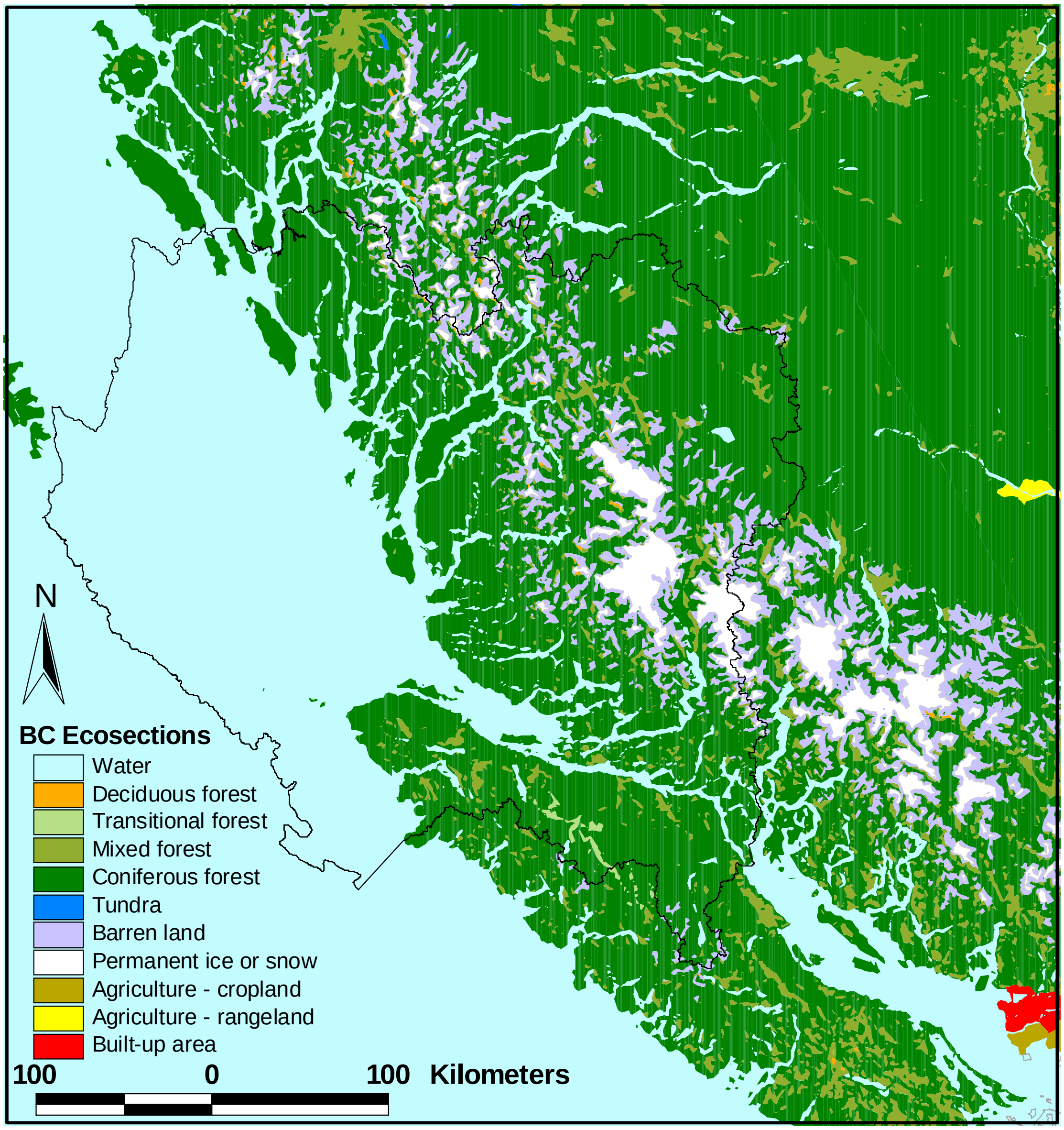

Figure 2-9. **Land cover/land use in the central coast is heavily dominated by forest cover. However, this map is based on satellite data (AVHRR land cover data) with a resolution of 2km^2 which was further simplified in the conversion to vector format. This results in the omission of many significant land use features (even cities the size of Campbell River). Data from the Government of Canada via Geogratis: http://geogratis.cgdi.gc.ca/clf/en.**

3. Salmon Aquaculture

Salmon aquaculture (fish farming) is an important industry in coastal British Columbia. The total revenue and tonnes of salmon produced per year in BC increased significantly between the years 1991-2001 (Figure 3–1). The industry has seen steady growth in terms of value and tonnage over this time period, despite a moratorium on the expansion of fish farming between 1995 and 2002. 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 2000).

Salmon farming is also a major source of employment and represents an important part of the economy in the central coast. There are 71 salmon farm leases in the central coast representing approximately 60% of all the salmon farms in BC (Ministry of Agriculture 2001) (Figure 3–2). The Broughton Archipelago, in the southern half of the central coast, has the highest concentration of salmon farms (~30 farms) in the central coast. Numerous salmon farms are also found in the Queen Charlotte Strait (Ministry of Sustainable Resources Management Coast and Marine Planning Branch 2002) (Figure 3–3). Fewer salmon farms are found in the north, however salmon aquaculture is expected to expand in the northern central coast (Ministry of Employment & Investment (Economics Branch) *et al.* 2000).

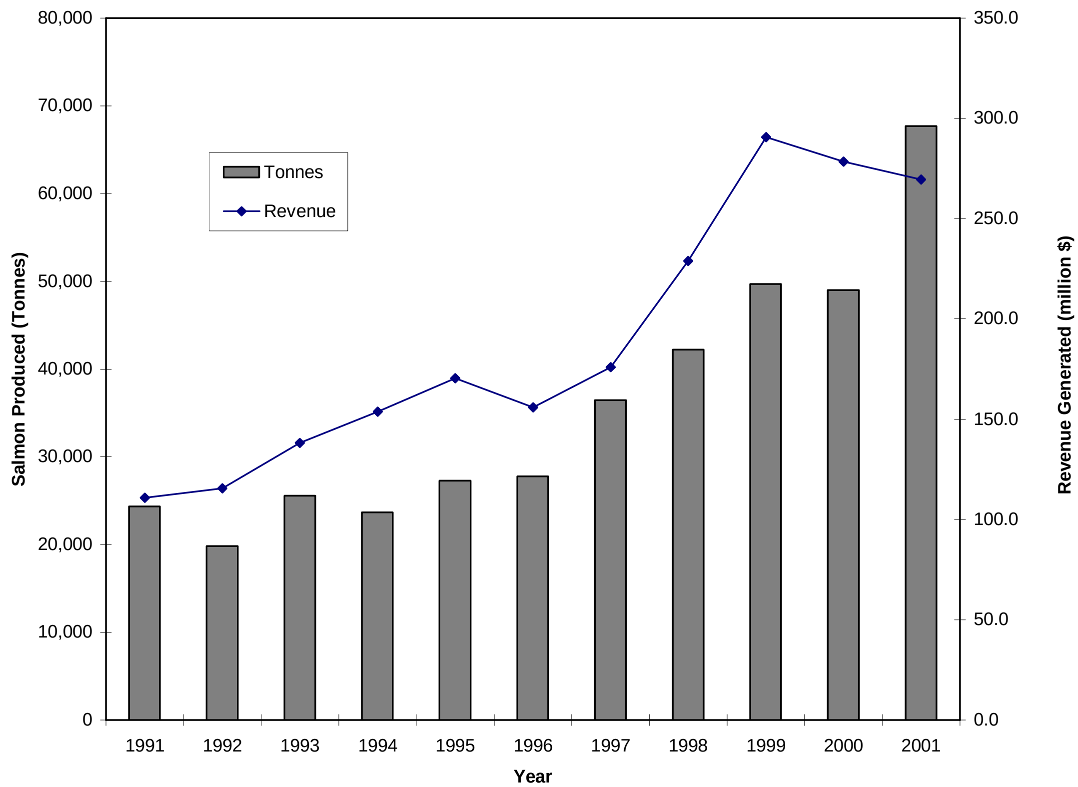

Figure 3-1. Amount of salmon produced (metric tonnes) and revenue generated (million $) by BC salmon farming industry, has increased between 1991-2001. Data from: http://www.dfo-mpo.gc.ca/communic/statistics/aquacult/aqua_e.htm.

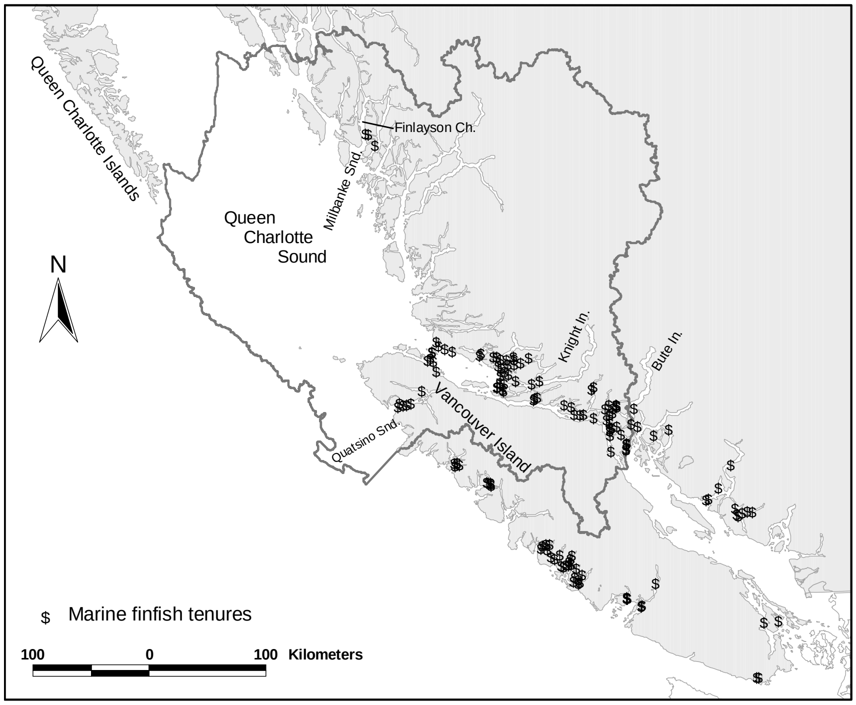

Figure 3-2. Locations of salmon farms in part of BC. The majority of salmon farms in BC are found in the central coast particularly in the waters of Queen Charlotte and Johnstone Straits (see Figure 3-3).

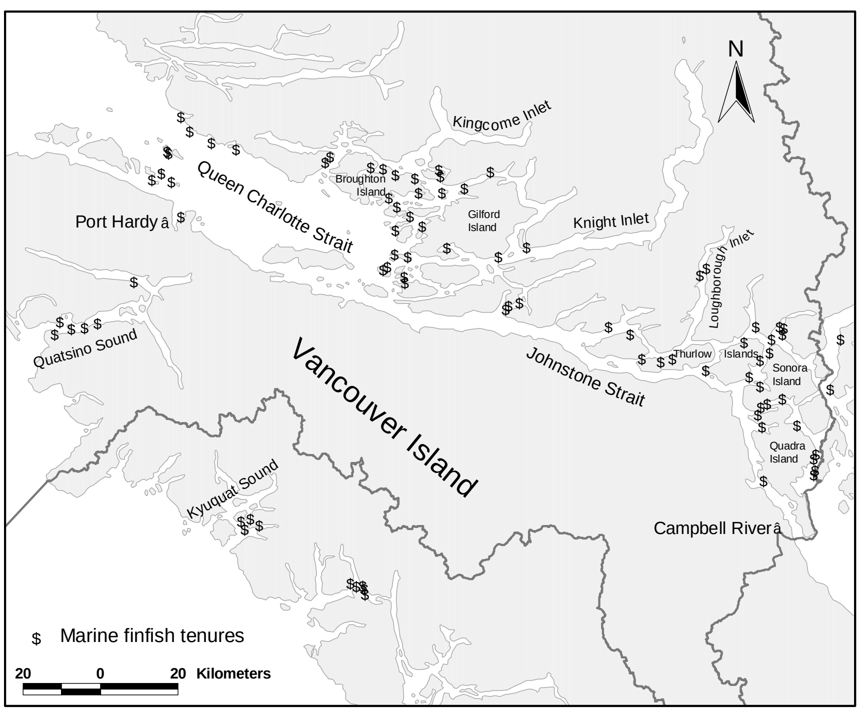

Figure 3-3. Finfish farm tenures in the Queen Charlotte and Johnstone Straits. The Broughton Archipelago, between Knight Inlet and Broughton Island, has the highest concentration of fish farms in the central coast. Data from BC Ministry of Food and Fisheries as of January 2003.

Salmon aquaculture is not, however, without its environmental concerns. Salmon aquaculture leads to several sources of contamination that can be grouped as organic and chemical wastes. Organic and chemical contamination will be discussed below.

Other pollution issues include biological contamination related to the transfer of disease and parasites from farmed to wild fish; the potential introduction of non-native species through the escape of Atlantic salmon; the pollution of the wild salmon gene pool by the escape of farmed salmon; and noise pollution associated with anti-predatory devices. (See Box 3.1 for sources of information on these and other related issues.)

Other forms of aquaculture, such as shellfish aquaculture also exist in the central coast; however they are not as predominant as fish farming. Twenty-seven shellfish farms are found in the central coast, mostly located in the southeastern end of Johnstone Strait. Currently, shellfish aquaculture is not considered to produce any chemical contaminants (Jamieson *et al.* 2001). (See Box 3.2 for sources of information on shellfish aquaculture.) In addition to shellfish aquaculture, there is also an abalone hatchery on Malcolm Island as well as some proposed offshore finfish farming.

3.1. Organic Wastes

A primary contamination concern related to aquaculture involves the organic wastes produced by salmon farms. Types of waste include excess feed, fish feces and urine, fish carcasses and biofouling. Of these, the types that have received the most attention in the literature include excess feed and fish feces. Organic wastes produced by salmon farms are difficult to quantify since there are multiple sources such as uneaten food, undigested carbohydrates, and excretion of phosphorous and nitrogen (Levings *et al.* 2002a). Recent improvements made to food composition to increase assimilation by the fish as well as more efficient feeding techniques have lowered amounts of organic wastes associated with excess food and feces. Approximately 5% of food is estimated to go uneaten and approximately 4% of the feed is ejected as feces (Nash 2000). These figures are considerably lower than earlier estimates of organic loading (Wu 1995; Nash 2000). Suspended particulate matter surrounding a salmon net pen in the Broughton Archipelago was studied during feeding (Sutherland *et al.* 2001). They found a greater flux of particulate matter in sediment traps at the farm site than at the control site. Elemental analysis of the feed and of the sediment from the traps showed all of the major elements were observed in both feed and sediment trap material, while only a few of the minor elements were observed in feed pellets and not sediment trap material. Therefore, the authors concluded that though some elements were removed in the net pen system; other elements in the sediment trap material were in higher proportions that those observed in the feed. One result was that the carbon isotope specific to the feed pellets was not evident in sediment traps. The authors attributed this to three possibilities: 1) isotopic fractionation occurred during digestion; 2) feed pellets lacked critical mass to allow for detection; and 3) the feed signal was diluted by other sources of organic matter (Sutherland *et al.* 2001).

The organic wastes lead to relatively localized impacts, usually found directly under or adjacent to the cages. Enriched sediments are quickly degraded through enhanced microbial activity. This has important consequences for sediment biogeochemistry. Sulphur reduction, an important mineralization process in the marine environment, is stimulated by organic matter leading to an increase in the production of sulphides. Sulphides can accumulate to levels that are toxic to benthic fauna (Holmer *et al.* 2001). Increased levels of sulphides results in dramatic changes to the macro and meiobenthic communities (Pohle *et al.* 2001; Heilskov and Holmer 2001; Levings 1994). A typical ecological succession that occurred in infaunal communities under net pens of salmon farms was characterized in the Broughton Archipelago (Brooks *et al.* 2003). Their study tracked community and chemical changes in sediments under several farms (and a reference site) as they completed a production cycle including maximum production, harvesting, and a fallowing period. When organic loading was at its highest, during maximum production, the community was dominated by opportunistic species tolerant of high total organic carbon and sulphide levels including the polychaete *Capitella capitata*. Once harvesting began and the total organic carbon levels began to decrease, pioneer species such as the polychaetes *Armandia brevis* and *Phyllodoce maculata* began colonizing the sediments. This group was followed by an intermediate group of deposit feeders including the polychaetes *Nephtys ferruginea, Ophelina acuminata*, and the bivalves *Macoma carlottensis* and *Psephidia lordi*. Late colonizers consisted of a more persistent group including the polychaete *Leitoscoloplos pugettensis* and the bivalve *Axinopsida serricata*. The rate at which the infaunal community recovered (as compared to the reference site) varied due to current speed, dissolved oxygen in the overlying water column, depth of accumulated organic matter, sediment grain size and recruitment rates; however, most sampling sites had reached the late colonizer stage six months after the fish were harvested. Although the communities resembled the reference sites, some rare species including the polychaetes *Exogone naidina* and *Phyllochaetopterus prolifica*, and the urochordate *Styela gibbsi* were notably absent by the end of the 20.5 month study (Brooks *et al.* 2003). The changes in the infaunal community, which were related to organic content and sulphide levels, were observed primarily under the net pens and decreased with distance downstream from the pens; however, changes were observed up to 225 m downstream.

Due to changes in infaunal communities related to organic content and sulphide levels, provincial regulations require sulphide levels be monitored; however, Levings *et al.* (2002a) argue that there is an insufficient understanding of how sulphides at different concentrations affect biodiversity, particularly in environments other than mud bottoms. As a result, it is difficult to prescribe meaningful sulphide standards. Community structure, in addition to contaminants, should be monitored by using multivariate analysis, univariate analysis such as species diversity, and indicator species that are sensitive or resistant to organic loading as in Pohle *et al.* (2001). In addition to toxicological effects of sulphides on biota, sulphides can also interact with other elements exacerbating hypoxia, anoxia, and influencing the bioavailability of metals such as cadmium, copper and nickel which may cause metal toxicity (Levings *et al.* 2002a). The anoxic and reducing condition caused by excess organic content in the sediments can also lead to the production of toxic gases other than hydrogen sulphide, such as ammonia and methane (Wu 1995).

Organic wastes are also released into the water column. Salmon excrete ammonia (NH_3) and ammonium (NH_4^+) across their gill epithelia and as concentrated urea (Nash 2000). The total discharge of nitrogen (N) and phosphorus (P) from pen-raised salmon has been estimated to be 20.5-30.0 g N and 6.7 g P per kg of Atlantic salmon produced (Nash 2000). Given a total production of 68,000 metric tonnes of salmon produced per year in BC (Figure 3-1), this amounts to approximately 1400-2000 metric tonnes N and 400 metric tonnes P released into the marine environment per year by all salmon farms in BC. Nitrogen is considered to be a limiting nutrient for marine phytoplankton; therefore, excess nitrogen can lead to increased levels of primary production or eutrophication (under localized conditions). Phosphorus is not considered to be limiting in marine systems, though it can be in brackish and freshwater systems. It is feared that increased levels of nutrients may lead to toxic algal blooms that are both detrimental to the environment, as well as the health of the farmed salmon. Phosphorus levels have been implicated in a toxic bloom of *Prymnesium parvum* in a brackish fjord in Norway (Levings 1994). No toxic algal blooms in British Columbia or Washington State have been attributed to increased nutrients from salmon farms (Levings 1994; Nash 2000). In general, tidal currents in BC and Washington are considered strong enough such that nutrients are dissipated or mixed in the water column and do not reach harmful concentrations (Nash 2000). Hypernutrification due to salmon farming may, therefore, only be problematic in poorly flushed fjords or bays.

3.2. Chemical Contamination

Many chemicals are used, both intentionally and unintentionally, in salmon aquaculture in Canada. Sources of intentional chemicals include feed additives, chemotherapeutants, disinfectants and, sometimes, pesticides. Unintentional chemicals in feed include persistent chemicals and heavy metals. Chemicals are also found in construction materials such as plastics, paints, metals, antifouling chemicals and wood preservatives (Haya *et al.* 2001).

3.2.1. Chemicals in Feed

Additives:

Zinc is added to fish feed pellets as it is an essential element in fish diets to prevent cataracts in juvenile fish (Sutherland *et al.* 2001). A detectable influx of zinc was detected in sediment traps during feeding; however, the observed levels fell within natural background levels reported for another inlet in BC (Sutherland *et al.* 2001). Elevated levels of zinc at some salmon farms have been observed (Brooks 2001). The toxicity of zinc in sediments below fish farms is difficult to assess because the speciation of the metal, and hence the toxicity, varies with factors such as interactions with sulphides, dissolved oxygen and pH (Levings *et al.* 2002a). Elevated zinc levels under net pens in the Broughton Archipelago were observed when farms were at maximum production levels but noted that zinc was not bioavailable due to the concurrently high sulphide levels (Brooks *et al.* 2003). They also found that zinc levels dropped after harvesting and throughout the fallowing period. The authors concluded that as long as chemical remediation is reached (approximately 6 months) during one fallowing period before the next production period begins, zinc will not accumulate in sediments (Brooks *et al.* 2003). Cumulative effects of numerous pens in a localized area were not addressed.

Chemicals are also added to the feed to produce the characteristic red flesh of salmon that consumers expect. Wild salmon come by their orange flesh colour through the consumption of red and orange-coloured crustaceans such as euphausiids. Commercial feeds use colour additives such as astaxanthin; though carotenoid and canthaxanthin are sometimes used (Nash 2000). No information was found on the environmental or health effects of these pigments.

Vitamins such as Biotin and Vitamin B_{12} are also added to fish feed. Though laboratory experiments have shown that certain vitamins stimulate the growth of some phytoplankton species such as the dinoflagellates *Gymnodinium aureoles* and *Heterosigma akashiwo*, and the algae *Chrysochromulina polylepis*, there is no scientific evidence relating these red-tide causing plankton to fish farm wastes (Wu 1995). Little information about possible environmental effects of the use of vitamins is available (Nash 2000).

Antibiotics are included in medicated feed that is occasionly fed to fish. Drugs used in fish farms in the Pacific Northwest include oxytetracycline (OTC), Romet ® 30 (composed of sulfadimethioxine and ormetoprim) and occasionally amoxycillin (an aminopenicillin). These antibacterials are administered as medicated fish feed after clinical signs are observed for vibrosis, furunculosis or bacterial kidney disease in salmon. Some of the antibiotics do not reach the salmon and are released into the environment as uneaten medicine or undigested in the feces. OTC is the most commonly used and most studied antibiotic used by salmon farms (Herwig *et al.* 1997). OTC is poorly absorbed though the intestinal tract of the fish. It must therefore be administered at high dosage rates for a period of 10-15 days causing excretion of large amounts of this antibiotic (Miranda and Zemelman

2002). The use of antibiotics is of concern because it can lead to the development of antibiotic-resistant strains of bacteria. This, in turn, impairs our ability to treat fish diseases. It may also negatively impact the treatment of human infections as a consequence of either direct transmission of resistant pathogens to humans, or indirectly though the transfer of resistant genes from environmental bacteria to human pathogens (Miranda and Zemelman 2002). There are two environments wherein resistant bacteria may develop. One is the intestinal flora of the fish treated with the antibiotics; the other in the sediments under the net pen. Antibiotic resistant bacteria were studied in surface sediments near salmon farms which used a range of antibiotics in Puget Sound (Herwig *et al.* 1997). The authors found that levels of resistant bacteria tightly correlated with the amounts of antibiotics used. In addition, bacteria resistant to OTC were also resistant to Romet ® 30. Strains of resistant bacteria are not thought to be permanent as long as antibiotic use is terminated. A regular genetic structure of bacteria returns after a few months (Miranda and Zemelman 2002). Antibiotic use also decreases the total amount of bacteria under the net pens and may change the structure of microorganism communities. Microorganism communities in the marine environment are poorly understood, rendering it difficult to predict the impact of such antibiotic-induced alterations. The use of antibiotics has decreased substantially over the last decade as vaccines against common diseases have been developed (Gardner and Peterson 2003).

Inadvertent Chemicals:
Persistent chemicals such as dioxins and PCBs have been found in commercial fish feeds, particularly if the fish meal and oils in feed originated from Europe (Nash 2000). Fish meal and oils that originate in less-industrialized parts of the world have lower rates of contaminants. A recent pilot study conducted in British Columbia found that commercial feed used in salmon farms as well as salmon hatcheries had significant concentrations of PCBs, organchlorine pesticides, brominated diphenyl ethers, PAHs and mercury (Easton *et al.* 2002). Persistent contaminants in fish food are of concern since these chemicals are known to bioaccumulate. Easton *et al.* (2002) also tested a limited number of farmed and wild salmon and found relatively high levels of contaminants in the farmed fish. Though this study was a preliminary investigation with so few samples that statistical analysis could not be performed, it does highlight possible risks to fish health as well as to those who consume the fish, including humans and wildlife. It also points to a potential pathway for the introduction of contaminants from other parts of the world into the central coast region. A major study is currently underway at the Institute of Ocean Sciences, Sidney, BC, and it will hopefully provide more concrete results about this issue.

3.2.2. Pesticides

Farmed salmon are susceptible to a variety of parasites such as parasitic worms, myxosporean parasites, and crustaceans in the family Caligidae (parasitic copepods, also called sea lice). We could find no information on pesticides, herbicides or fungicides that may be used apart from those used to treat sea lice. Epidemics of parasitic copepods (mainly *Caligus elongatus*, *Lepeophtheirus salmonis*, and *Ergasilus labracis*), have caused significant losses to the industry and have been implicated in transferring sea lice to wild smolts, particularly in the Broughton Archipelago (Haya *et al.* 2001; Gardner and Peterson 2003). 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). It therefore represents an important parasite to control. Infested fish are treated with a variety of chemicals (Table 3-1) administered as a bath or given orally as medicated feed. If treated in a bath, fish are isolated with a tarpaulin and sufficient chemicals are added to the water to give the desired treatment concentration. After a bath of 30-60 minutes, the tarpaulin is removed and the solution is released into the environment (Haya *et al.* 2001). Two unintentional exposure pathways for these pesticides exist: non-target organisms may actively eat excess medicated pellets, or they may be exposed to dissolved chemicals in the water column. Azamethiphos, an organophosphate insecticide, is currently the only product approved for use in Canada by the Pest Management Regulatory Agency (Haya *et al.* 2001); however, Ivermectin and Emamectin Benzoate (SLICE®) and others are also available for use in salmon farms in BC (Gardner and Peterson 2003; Nash 2000).

There is little or no information on the lethal and sublethal effects of the chemicals used to treat sea lice on marine organisms (Haya *et al.* 2001). These authors studied the effects of azamethiphos, a neurotoxin, on various invertebrates in the laboratory. They found azamethiphos was toxic to crustaceans including lobster and shrimp but not to bivalves. Also, earlier larval stages of lobster were more resistant to the chemical than later stages, and lethal concentrations were unlikely to be achieved by a single treatment. They also investigated sub-lethal effects on lobster and found a significant reduction in spawning by female lobster exposed to azamethiphos. Some of the exposed lobsters that did not spawn died while others reabsorbed their eggs. Those that did spawn produced normal amounts of eggs and all clutches reached the eyed stage. No studies on the effects of pesticide baths on non-target organisms or the environment have been performed *in situ*.

Dichlorvos (Cyprimethrin®) is under temporary registration in Canada and is also administered in a bath. It is adsorbed by 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 (Nash 2000). Dichlorvos is considered to be less toxic than azamethiphos (Nash 2000).

Ivermectin, a pesticide delivered in fish feed, was also found to be consumed by the non-target Atlantic sand shrimp (*Crangon septemspinosa*). When the feed was consumed by the shrimp, mortality occurred. It was determined that Ivermectin was 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 2000).

Emamectin benzoate (SLICE®) is less toxic than Ivermectin and has been approved for use in many countries, including Canada. SLICE® is also delivered to fish in medicated food pellets. It accumulates in sediments and has a half life of 175 days but no adverse effects were found on the infaunal community after treatment in a Scottish study (Nash 2000). Van Aggelen (2002) studied the effects of SLICE® on Dungeness crabs and prawns from BC in the laboratory. No toxic effects were observed for either crabs or shrimp since they both avoided feeding on the medicated pellets. No other species were tested and no field trials were performed.

Calicide® (teflubenzuron), a chitinase inhibitor that is administered as a coating on food, is being licensed for use in Canada. 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 (Nash 2000). No adverse effects were detected on the benthic community in a study by the Scottish Environmental Protection Agency. Calicide® inhibits chitinase and may therefore be toxic to phyla other than arthropods; however, many forms of residual teflubenzuron do not seem to be bio-available (Nash 2000).

More information is needed in order to access the risk of these pesticides on the environment. Nash (2000) noted that all are non-specific, at least within the class Crustacea, and that many are broad-spectrum biocides that may affect several phyla. Though studies that have been performed have not detected widespread adverse effects, caution must be used when these pesticides are applied (Nash 2000). Particular information gaps include *in situ* lethal and sublethal effects on important commercial benthic crustaceans including crabs, prawns, and shrimp, as well as other benthic organisms such as polychaetes. Another important area of research is the effect of these chemicals (both bath and medicated pellets) on zooplankton and zoobenthos, particularly on orders that are closely related to sea lice such as other copepods, amphipods, isopods and euphausids. Mortality or contamination of these important prey species may affect local food web dynamics.

Table 3-1. Selected characteristic of chemicals used for treatment of sea-lice infestations in farmed salmon (modified from Davies *et al.* 2001).

Compound type	Medicine	Product name®	Treatment	Properties/environmental fate
Organophosphate	Dichlorvos	Cyprimethrin	Bath	Diluted
	Azamethiphos	Aquaguard	Bath	
		Salmosan	Bath	
Hydrogen peroxide		Salartect	Bath	Degrades rapidly to O_2 and H_20
		Paramove	Bath	
Synthetic pyrethroid	Cypermethrin	Excis	Bath	Strongly adsorbed to soil and sediments
Semi-synthetic avermectin	Ivermectin	Ivomec	Oral	Low solubility, strong affinity to lipid, soil, organic
	Emamectin benzoate	SLICE	Oral	Strong affinity to soil, probably to sediment
Benzoylphenyl ureas	Diflubenzuron	Lepsidon	Oral	Low solubility: sediment
	Teflubenzuron	Ektobann	Oral	Low solubility: sediment
		Calicide		

3.2.3. Antifouling Chemicals

Nets and other structures in the water are subject to biological fouling as sedentary biota such as mussels, barnacles, ascidians, bryozoans, polychaetes, and anemones colonize available surfaces. These structures must be periodically cleaned of fouling, as it weighs down nets and restricts water flow (Nash 2000). Scraping the fouled surfaces is one means of cleaning; however this can be one more source of increased organic wastes. Nash (2000) recommends that waste from bio-fouling should be retained and disposed of on land rather than dumping it into the water. Another common alternative to scraping is to treat nets and other surfaces with chemicals that reduce the amount of subsequent growth. Several antifouling paints and solutions with various brand names are approved for the use in the marine environment and are used on salmon farms. A common antifouling paint, tributyltin (TBT), was once used on the hulls of boats, but was banned in British Columbia fish farms in 1988 due to toxic environmental effects. It was detected in salmon tissue as well as in oysters and clams in proximity to the farms (Levings 1994). No long-term effects attributed to the use of TBT in salmon farms have been reported although severe reproductive impacts have been described in shellfish and gastropods adjacent to harbours (Stewart and Thompson 1994) (see section 7.3). Copper compounds are now used as an antifouling treatment for nets in many BC fish farms (Gardner and Peterson 2003). Copper anti-fouling solutions inhibit the settlement of organisms (Nash 2000). Though copper is a micro-nutrient necessary for growth of most organisms, the cupric ion (Cu^{2+}) is toxic to marine organisms at moderately low levels. The gametes, embryos and larval stages of invertebrates are particularly sensitive to copper (Brooks 2001). The cupric ion is highly reactive and forms various copper complexes and precipitates. Some forms of copper are not bio-available and are therefore not toxic. The many forms of copper are maintained in a dynamic equilibrium that depends on temperature, salinity, pH, alkalinity, dissolved oxygen, sediment physiochemical characteristics and the presence of other organic and inorganic substances (Brooks 2001). Thus, measuring copper concentrations and determining toxicity is no simple matter. Maximum cupric ion levels are regulated in Canada and the US and many studies have been completed to measure copper toxicity on various organisms.

Lewis and Metaxas (1991) monitored dissolved copper concentrations in and adjacent to salmon farms using copper-treated nets in Jervis Inlet, BC. They measured ambient copper concentration in two time periods: two days vs. one month post treatment. Though copper levels appeared elevated relative to background levels, the differences were not statistically significant nor were they viewed as biologically significant. Copper leaching off the nets was not measured prior to two days following placement in water, and current speeds were not calculated. In a separate study and modeling exercise, Brooks (2001) found that initial levels of leaching declined exponentially with time. The model suggests that the total number of nets, their configuration, and the current speed are important factors in determining whether or not copper water quality criteria will be met or exceeded (Brooks 2001).

Brooks (2001) also measured copper concentrations in sediments at different salmon farms which used ®Flexgard XI to treat their nets. Mean concentration of copper in the sediments of 117 samples from six unidentified farms was 48.24 ± 27.00 µg Cu/g. This was not significantly different for values from 10 reference samples (12.01 ±2.77 µg Cu/g) or from 39 samples from farm sites not using copper-treated nets (26.27 ±2.77 µg Cu/g). Though no statistically significant differences were found, there were large variations in copper concentrations in the sediments of farms using treated nets. Two of the 117 samples exceeded Washington State’s standard of 390 µg Cu/g and 13 samples exceeded the mean screening benchmark used in British Columbia. These high levels may have been due to activities such as net washing rather than copper leaching. When net washing is carried out on a barge or float as opposed to on land, latex paint chips containing copper can be washed over the side of barges with fouling organisms. This may be a source of elevated copper concentrations in the sediments (Brooks 2001). Therefore, this author concluded that all nets should be removed and washed in upland stations and all debris should be disposed of at approved land fill sites. Net cleaning and antifouling chemicals can also be replaced in some cases by net drying practices as are in place in Norway (Gardner and Peterson 2003).

Copper concentrations have also been assessed in the tissues of salmonids. Though copper concentration in the muscles of chinook salmon positively correlated with the size of the fish, there was no difference in copper concentrations between fish of comparable sizes raised in copper-treated and un-treated pens (Lewis and Metaxas 1991; Peterson *et al.* 2001).

3.2.4. Other Chemicals

Pentachlorophenol (PCP) is a persistent chemical used as a wood preservative in lumber and wooden structures such as wharves and in wooden structures at salmon farms (Levings 1994). Its use is relatively widespread in British Columbia (Kay 1989). Concentrations of PCP in the livers of copper rockfish living near a salmon farm in BC were elevated but did not differ from a control site as the control site also had sources of PCP contamination such as abandoned log storage sites (Levings 1994).

3.3. Synthesis

Many of the environmental impacts of salmon farming can be minimized or mitigated with appropriate siting of the farms. Much work has been written on this subject (See Box 3.1). Technical improvements such as improved feed composition and delivery, and the development of vaccines, have helped to reduce pollution caused by salmon farms. Further advances and refinement of regulations and monitoring criteria will also reduce impacts.

Much of the chemical contamination and organic pollution associated with salmon farms seems to be generally limited to a localized area and is probably relatively short lived. We do not, however, have a good understanding of the cumulative impacts of various stresses nor the collective effect of multiple farms situated in close proximity to each other. More information is also needed on how chemical contamination and organic enrichment affects biodiversity and ecosystem function. More research should be conducted on the community level effects of antibiotics, pesticides, and organic enrichment.

Persistent organic chemicals are a notable exception to the relatively short lived and localized nature of most contamination issues related to salmon farming. Persistent organic chemicals are used in construction materials and contaminate some of the food given to salmon. Not only could this pose a human health risk, but it also represents a pathway for toxic persistent chemicals, produced far away from here, to be transported into marine ecosystems in British Columbia. Levings (1994) commented that filter feeding organisms and fishes around salmon farms may benefit from organic enrichment, in part from excess food. Contaminants in food thereby have the potential to work themselves into local food webs. Indeed, copper rockfish (*Sebastes caurinus*), a relatively sedentary fish, caught near fish farms had significantly higher levels of PCBs in the liver tissue as well as significantly higher levels of DDT, DDE, and DDD than at a control site (Levings 1994). These persistent chemicals are known to bioaccumulate and biomagnify. Escaped farmed fish present another pathway for these chemicals to end up in marine food webs. If escaped salmon have high levels of toxins, predators such as seals, sea lions and killer whales could also accumulate these toxins, just as they accumulate toxins present in wild salmon and other food items. These predators could potentially consume a significant number of fish in the event of a large escapement because farm-reared salmon may be naïve to predation and so would be an easy meal. In addition, some net pen farms have reported considerable losses of penned salmon to predatory seals and sea lions (Nash *et al.* 2000). Therefore, to protect environmental and human health, fish farms should use feed that is free of persistent chemicals.

Box 3.1. Additional Information on Salmon Aquaculture and Related Topics

- Habitat impacts: Productive capacity of fish habitat can be impacted by salmon aquaculture, particularly due to organic enrichment. Though impacts are thought to be localized, cumulative area of seafloor habitat impacted may be substantive. Proper siting of farms is essential to minimize habitat impacts. For further information, refer to: (Levings 1994; Levings *et al.* 1995; Levings *et al.* 2002a).
- Effects of salmon farming on wild stocks:
    - Introduced Atlantic salmon: (Gardner and Peterson 2003; Volpe 2002; Fisheries and Oceans Canada 2000);
    - Genetically modified salmon: (Fisheries and Oceans Canada 2000);
    - Parasite transfer: (Gardner and Peterson 2003);
    - Disease transfer: (Balfry *et al.* 1996; Gardner and Peterson 2003; Paone 2000; Paone 2001; Totland *et al.* 1996);
    - Pollution of gene pool by escaped farmed Pacific salmon or salmon hatcheries (Noakes *et al.* 2000).
- Interactions with salmon farming and marine mammals:
    - Predation/Predator control: (Jamieson and Olesiuk 2001);
    - Noise pollution and displacement of whales: (Morton and Symonds 2002).
- General information of salmon farming/useful reports:
    - http://www.fish.bc.ca/
    - http://www.salmonfarmers.org/library/studies5.html
    - http://www.farmedanddangerous.org/reports.htm
    - http://www.agf.gov.bc.ca/fisheries/Finfish_main.htm
    - http://www.nwfsc.noaa.gov/pubs/tm/tm49/Tm49.pdf
    - http://www.salmonfarmers.org/library/studies5.html

Box 3.2. Additional Information for Shellfish Aquaculture

- Shellfish farming is another important form of aquaculture in BC. Although clams and oysters are most commonly cultured, scallops, mussels, and abalone farming are also being developed. Minimal issues related to chemical contamination exist. On the contrary, shellfish aquaculture has stringent water quality needs and also monitors contamination levels in the tissues to ensure they are safe for consumption. There is no present use of pesticides in BC shellfish aquaculture (Jamieson *et al.* 2001); however, environmental issues such as habitat loss, introduced species, and predator control do exist. For further information, refer to:
    - (Jamieson *et al.* 2001);
    - BC Government. 2002. BC Shellfish Aquaculture Code of Practice. BCMAAF Environmental Code of Practice. http://www.agf.gov.bc.ca/fisheries/Shellfish/FinalCOPSubmission%2002July03.pdf;
    - Introduced Species in BC (Levings *et al.* 2002b).

4. Oil

4.1. Sources

There are many potential sources of oil in the oceans including natural inputs and seepages, chronic pollution and catastrophic spills (Table 4-1). Though catastrophic spills garner much attention, they actually contribute relatively little to the total global oil pollution. Atmospheric emissions, atmospheric fallout, municipal and industrial wastes and runoff as well as oil from boat operations and bilges contribute more oil than spills. Nonetheless, an oil spill contributes much more oil on a local, short term scale than do chronic sources. Natural sources of oil also exist. Oil deposits close to the Earth's surface naturally seep out in places. Oil deposits are produced by fossilized plant remains. Living plants also produce hydrocarbons. Estimates of annual production of hydrocarbons by marine phytoplankton and land plants that are eventually deposited in the sea are vague; however, they are believed to dwarf the input of fossil hydrocarbons by several orders of magnitude; however, recent and fossil hydrocarbons possess different constitutive characteristics and may have very different effects on marine ecosystems (Clark 2001).

Table 4-1. Estimated world input of petroleum hydrocarbons to the sea (Clark 2001).

Source	**million t year-1**	**Total**
Transportation		4.630
Tanker operations	0.163	
Tanker accidents	0.162	
Bilge and fuel oil	0.524	
Dry Docking	0.009	
Scrapping of ships	0.002	
Non-tanker accidents	0.020	
Atmospheric emissions	3.750	
Fixed installations		0.180
Coastal refineries	0.100	
Offshore production	0.050	
Marine terminals	0.030	
Other Sources		1.380
Municipal wastes	0.700	
Industrial waste	0.200	
Urban run-off	0.120	
River run-off	0.040	
Atmospheric fall-out	0.300	
Ocean dumping	0.020	
Natural inputs from seepages		0.250
Total		6.440
Biosynthesis of hydrocarbons		
Production by marine phytoplankton		26,000
Atmospheric fall-out		100-4,000

4.2. Chronic vs. Acute Oil Pollution

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 1.3). 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. Chronic and sublethal effects may prove to be harmful over the long-term. Though there are considerably more sources of chronic oil in the oceans, the effects of acute oil spills have been studied to a much greater extent. Far less is known about the effects of chronic oil pollution.

4.3. Threats of Oil Pollution to the Central Coast

Chronic sources of oil in BC's central coast include natural seepages, shipping, boating, sewage, atmospheric input, and run-off from land. No estimates of the input of chronic oil specific to the central coast exist; nor do any studies investigating the effects of chronic oil.

There is also the risk of oil spills from tankers and fuel oil from other ships traveling through the central coast. Oil tankers are not allowed in the inside passage; however, they do go past the central coast as they travel between Alaska and the rest of the United States. After the *Nestucca* oil spill of 1988 off the coast of Washington and BC and Alaska's *Exxon Valdez* oil spill of 1989, the US Pacific States of Alaska, Washington, Oregon, California and Hawaii and British Columbia signed a memorandum of cooperation in 1989 to form the Pacific States/British Columbia Oil Spill Task Force. The task force represents a shared commitment to protecting marine resources. This task force analyzed vessel routing and shifted it offshore to reduce the risk of spills from grounding. Other activities of the task force include mutual aid for spill response and reporting, salvage, awards programs for risk reduction, and risk analysis studies.

The task force released a final report for the West Coast Offshore Traffic Risk Management Project (BC MWLAP2003b). They modeled several risk scenarios and developed recommendations based on these scenarios. The following factors affecting risk of oil spills were evaluated:

- 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 and transiting coastwise anywhere between Cook Inlet and San Diego should voluntarily stay a minimum distance of 50 nautical miles offshore, termed a Tanker Exclusion Zone. The Bowie Seamount lies just west of the Tanker Exclusion Zone off of the Queen Charlotte Islands and rises to a peak of 25 m below the surface. Though it represents a risk, tanker companies reported that they recognize it as a navigational risk and stay tens of nautical miles away from Bowie Seamount (Ministry of Water, Land and Air Protection2003b).

Fortunately, there have been no large oil spills in the central coast to date. Much information on the effects of spilled oil exists for a similar environment in Prince William Sound, Alaska, due to the *Exxon Valdez* Oil Spill (EVOS). One major oil spill has affected the central coast. 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 the 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 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. Overall, the impact of the spill, though widespread, was of low intensity. No effects on other mammals, or fishes were reported. Some fisheries were closed due to gear fouling; however, herring roe and salmon aquaculture were spared from impacts. No follow-up studies of possible long-term effects have been conducted (Addison 1998).

Following the *Nestucca* spill, the crab fishery in Clayoquot was shut down for several weeks because they were unmarketable due to oil spots on their claws. The crabs were apparently eating or contacting dead oiled birds on the bottom (Harding and Englar 1989).

Chronic pollution and episodic oil spills are also associated with offshore oil and gas development, an industry that may develop in the central coast. See Section 12.2 for a discussion of oil and gas exploration and development.

Most information on effects of oil pollution originates from outside the central coast.

4.4. Oil Properties

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). Different crude oils contain different chemical mixtures that reflect the different geological history of the area they were extracted from (Spies *et al.* 1996; Clark 2001). In addition to hydrocarbons, crude oils also contain other organic and inorganic components such as nitrogen, oxygen, sulphur, vanadium, nickel, and iron, which differ from one crude to another (Doerffer 1992).

The number of carbon atoms of the major products of oil refining is shown in Table 4-2. Products with 5 carbon atoms per molecule are usually gases at room temperature, while those with 5-15 are liquids, and straight chain alkanes with more than 15 carbon atoms are solids. The various petroleum hydrocarbons differ in their toxicity and their physical properties:

- molecular weight (which increases with the number of carbon atoms);
- solubility;
- vapour pressure;
- density;
- oil-water partitioning coefficient;

- hydrocarbon solubility;
- viscosity;
- surface tension;
- specific gravity.

Temperature greatly affects the physical-chemical properties of oil components; therefore, oil spilled into the environment in Northern waters will react very differently from oil spilled in warm waters (Doerffer 1992).

When crude oil or petroleum products are introduced into the environment they are subjected to a wide variety of weathering processes that can change their composition. These include (Doerffer 1992):

- spreading and drift;
- evaporation;
- dissolution and advection;
- dispersion of whole oil droplets into the water column;
- photochemical oxidation;
- water-in-oil emulsification;
- microbial degradation;
- adsorption onto suspended particulate material (SPM);
- ingestion by organisms;
- sinking and sedimentation.

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 that are degraded by bacteria. High molecular weight fractions tend to form tar balls. Figure 4-1 shows the fate of the oil from the Exxon Valdez oil spill in Alaska.

The complex chemical composition of crude oil in conjunction with weathering processes and variable environmental properties including temperature, salinity, wind and waves, makes predicting effects of oil on the environment very difficult.

4.5. Toxicity of Petroleum Hydrocarbons

General toxic effects are difficult to characterize as different oil components produce different effects and different organisms have various abilities to metabolize hydrocarbons. The soluble components of oil are generally the most toxic to marine organisms. These are termed Water Soluble Fractions (WSF) and can 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; therefore, they tend to cause chronic effects and are probably more significant in the long-term. Though the volatile fumes from the very low molecular weight compounds are thought to be of little concern, they can pose a risk to animals that breathe just above the surface of the water such as marine mammals and seabirds. For instance, oiled seals in the *Exxon Valdez* spill behaved lethargically and may have suffered brain damage from inhalation of volatile fumes (Sloan 1999).

Many studies underestimate the harmful effects of oil by not considering the importance of sublethal effects. Sublethal physiological and behavioural effects on organisms that produce population-level changes are likely to have more lasting effects. Sublethal effects include carcinogenic and cytogenic effects, as well as physiological effects involving reproduction, growth, respiration, excretion, chemoreception, feeding, movement, responses to stimuli, and susceptibility to disease. However, sublethal effects are difficult to measure due to complications in measuring chronic oil exposure, confounding results caused by acute oil effects, and the lack of information on biomarkers and the exposure to oil from food.

Table 4-2. **The major products of oil refining (Sloan 1999).**

Fraction	No. of Carbon Atoms	Product Name
Natural gas	1-6	Natural Gas
Petrol and Naptha	4-12	Gasoline, feedstock for petrochemical industry
Medium distillates	10-20	Kerosene, light gas oil, aviation fuel, diesel fuel
Heavy distillates	18-45	Heavy gas oil, feed for “cracking” process, wax, lubricating oil
Residue	>40	Heavy fuel oil, asphalt, coke

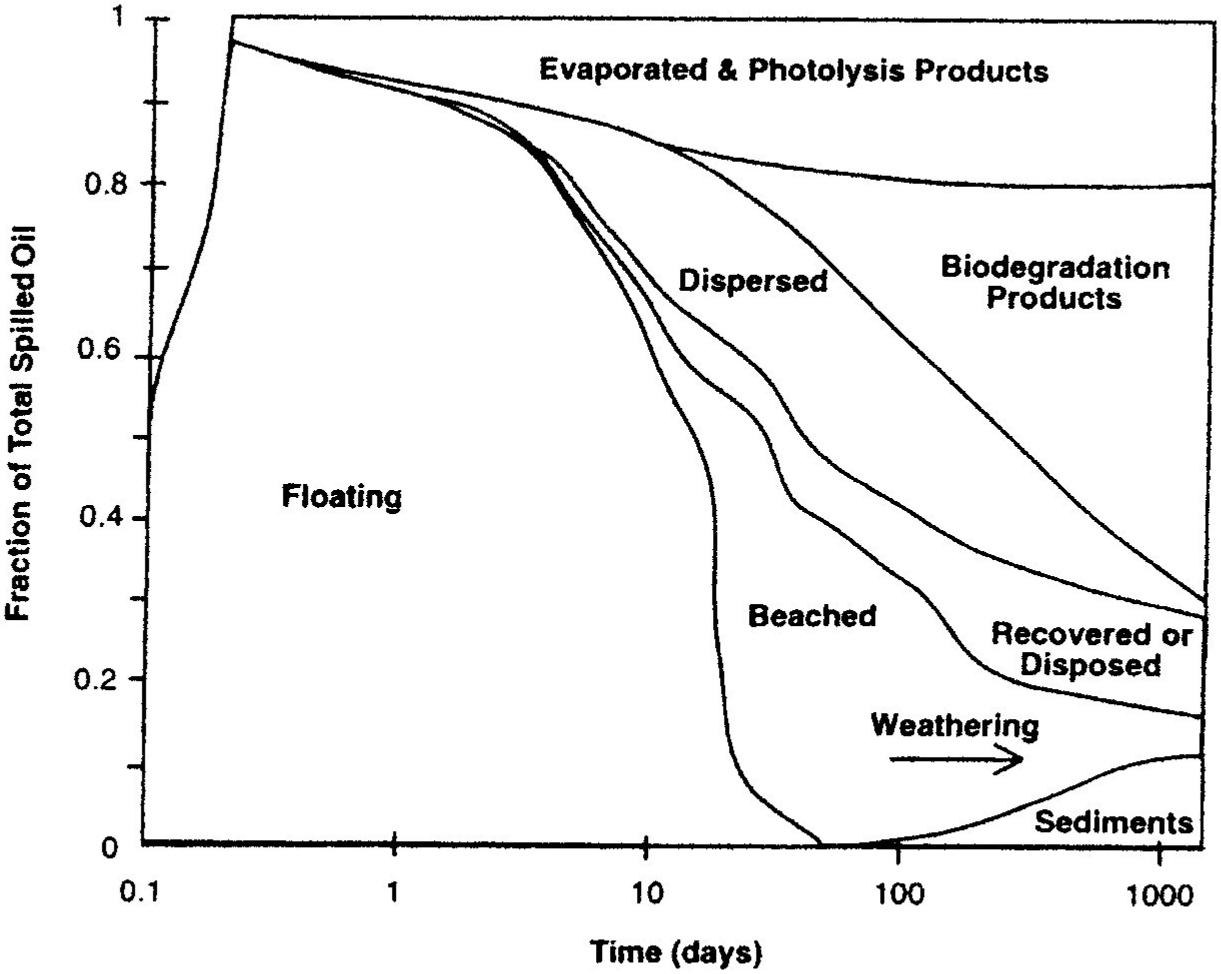

Figure 4-1. Fate of oil spilled from the *Exxon Valdez* (Spies *et al.* 1996).

4.6. Effects of Oil Spills

Oil spilled into the marine environment has widespread effects. Probably the best studied oil spill was the Exxon Valdez oil spill (EVOS) that spilled 75 million litres of crude oil into Alaska's Prince William Sound in 1989. Information on environmental effects of oil spills gleaned from the EVOS is also relevant to the central coast due to its similarity to the environment of Prince William Sound (PWS). PWS is characterized by highly convoluted shorelines composed of deep fjords and large islands with tides as great as 6 m (Irons *et al.* 2000). Environmental conditions such as water temperature and storm events are also similar to what we would expect in the central coast and the species and communities likely to be affected are also the same. Species in the central coast that are sensitive to oil spills include sea otters; sea birds, particularly those around important nesting colonies; intertidal communities; other marine mammals such as harbour seals and killer whales; and fish populations such as salmon and herring populations.

Sloan (1999) cautioned that scientific studies of catastrophic events have considerable limitations with regard to how studies are designed. Limitations include hasty sampling designs due the urgency of the situation; environmental and weather limitations; politics; and decisions that are made regarding the important areas to study. The sampling design as well as the statistical analysis used directly affect whether impacts will be detected (Hilborn 1996; Irons *et al.* 2000; Peterson *et al.* 2001). Sampling must be conducted at scales appropriate to the subjects of the study in order to correctly detect effects (Irons *et al.* 2000; Jewett *et al.* 2002). Literature must therefore be viewed critically. More information about effects of the EVOS can be found elsewhere (Spies *et al.* 1996; Rice *et al.* 1996; Irons *et al.* 2000; Sloan 1999).

Habitat is considered to be the single most important influence on the impact of oil as different habitats come into contact with oil at different rates, and contain different species with separate oil tolerance or sensitivity. Intertidal habitats are more sensitive than subtidal habitats; benthic habitats are generally more affected than pelagic habitats (Sloan 1999). See Box 4.1 for a ranking of intertidal habitats.

Following the EVOS, seabirds, eagles, marine mammals and intertidal and nearshore subtidal communities suffered immediate, acute effects (Spies *et al.* 1996). Many species suffered from physical aspects of oiling such as hypothermia, suffocation and drowning; however, this review will only focus on chemical contamination caused by oiling. See Box 4.1 for sources of information on related topics. Though oil spills are a catastrophic or acute incident, both immediate acute effects as well as chronic and sublethal effects can occur as a result.

4.6.1. Birds

Seabirds are one of the groups most at risk to oil spills. Birds coated with oil are not only physically impaired and die from drowning, hypothermia or an inability to fly or forage, but they will also ingest oil when attempting to preen coated feathers. Physiological effects of ingested oil have been studied in the laboratory. Effects include greatly lowered red blood cell counts (anemia) that reduces the bird's ability to recover from stress, reduced body weight, and liver damage. Estimates of seabirds killed in the EVOS range between 100,000-645,000, based on carcass recovery and modeling (Spies *et al.* 1996). Irons (2000) looked at bird populations for nearly a decade following the spill. They observed that several species of marine birds showed population declines, and these negative effects continued through 1998. Cormorants, goldeneyes, mergansers, Pigeon Guillemots, and murres all had lower than expected densities in oil areas than in unoiled areas. Black oystercatchers and harlequin ducks also exhibited negative effects in 1990 and 1991. Marbled murrelets, an endangered species in BC, also suffered acute losses estimated to be 8,000 birds or 5-10% of the local population (Spies *et al.* 1996). Irons (2000) found that taxa that dive for their food were negatively affected while taxa that feed at the surface were not.

Bald eagles also seemed to be affect by the spill. Though the number killed is uncertain, about 150 dead eagles were found and it is estimated that this number could be doubled. Surveys in the spill area indicated a decline of nesting success in 1989; however, this did not occur in 1990 and the population had probably recovered by 1992 (Spies *et al.* 1996).

4.6.2. Marine Mammals

Marine mammals are another group that are acutely affected by spilled oil. In particular, sea otters suffer severe mortalities from oiling as it causes hypothermia as well as many toxic effects. Sea otter mortality was estimated between 2,800-10,000; however, a precise estimate cannot be made primarily because of a lack of prespill data (Loughlin *et al.* 1996). It was estimated that the population dropped by 28% (Spies *et al.* 1996). Tissue lesions and interstitial pulmonary emphysema were the most common lesions found during histological analysis. Gastric erosion, and damage to the liver and kidneys were also found in oiled otters (Loughlin *et al.* 1996). Chronic or sublethal effects were reported until 1993, at which time it was speculated that populations were recovering. Chronic damage was thought to arise from tissue pathology (especially liver and kidneys), and continued exposure to oil from prey, especially for juvenile otters feeding on mussels.

As a result of the EVOS, between 300-2,200 harbour seals were thought to be lost, amounting to a 13% population decrease (Spies *et al.* 1996). Both harbour seals and Steller sea lions were found swimming in oil and did not avoid it. Harbour seals also continued to use oiled haul outs. It is likely that seals died from a combination of toxic fumes and of stress resulting from ingestion of oil. There were elevated levels of petroleum related hydrocarbons in tissues and PAHs in blubber of seals in oiled areas. Chronic contamination likely continued for at least a year as hydrocarbons were found in the bile of seals up to one year after the spill (Loughlin *et al.* 1996).

A lack of information did not allow researchers to evaluate the effects of the EVOS on killer whales. Several whales from AB pod were recorded missing after the spill; but no carcasses were found to allow for study. Loughlin *et al.* (1996) speculate that the first seven whales that went missing may have succumbed to immediate stress from toxic vapours resulting in sudden death. Six additional whales that went missing afterwards may have suffered complications associated with mucus membrane damage, including damage to airways. No conclusive information exists on killer whales or any other cetaceans (Loughlin *et al.* 1996).

4.6.3. Fishes

The extent to which fishes are affected by oil depends on their life histories and the likelihood of contact with oil. Water surface, intertidal habitats, and sediments represent zones of potential impact from oil spills; fishes at any lifestage which depends on such zones may be vulnerable (Sloan 1999). Adult fishes can ingest oil or oiled food, and take up oil compounds through skin and gills; as well eggs and larvae can be affected. Acute effects in fishes include death or debilitation due to central nervous system disruption, osmoregulatory dysfunction, metabolic dysfunction, and tissue damage. Increased stress levels can also increase susceptibility to disease, and reduced ability to feed and avoid predators. Organs including liver, gills, gut, brain and ovaries are known to show histological damage. Heavy oil fractions (i.e. PAHs) are also known to bioaccumulate in fish, particularly when the ability to metabolize the compounds is exceeded.

Following the EVOS, concern existed as to the health of pink salmon and herring as their life histories put them both at risk, and both support important local fisheries. At the time of the spill and shortly thereafter, herring were spawning and juvenile pink salmon fry were emerging. 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. In 1989, spawning occurred just weeks after the spill. 40 to 50% of the PWS eggs spawned were estimated to be in the trajectory of the spill and exposed to oil during incubation. Mortality was observed among larval herring, as were sublethal effects such as premature hatching, low weight, decreased growth, and morphological and genetic abnormalities (Brown *et al.* 1996). Brown *et al.* (1996) estimated a reduction of 50% in larval production in 1989. Sublethal impairment from oil may have affected adult herring in subsequent years (Spies *et al.* 1996). Increased levels of PAHs were found in adult herring from oiled areas as were hepatic necrosis and viral hemoragic septicemia (Marty *et al.* 1999).

Herring populations in PWS crashed in 1993, the first year the 1989 cohort recruited as four-year old adults, with a 75% reduction in spawners. Unfortunately, recruitment processes are not well understood in fish such as herring that exhibit very large year-to-year variation; causes of population changes are therefore difficult to determine. Subsequent studies of herring biomass found that herring population changes from the spill area did not deviate from population patterns in the rest of Alaska and that the crash of 1993 and again in 1994 were not attributable to the EVOS but to some larger-scale phenomenon (Williams and Quin 2000b; Pearson *et al.* 1999). The herring decline may have been caused by ocean conditions that affected food availability and ocean temperature (Williams and Quin 2000a; Norcross *et al.* 2001).

Pink salmon spawn in the upper intertidal near creeks in PWS and fry emerged shortly after the EVOS. An estimated 31% of streams were impacted from oil, placing many juvenile pinks at risk from contaminated habitats. Approximately 1.9 million fewer spawners than estimated returned in 1990; however, it was still a record year with very strong runs (Spies *et al.* 1996). Long-term impacts of the EVOS on pink salmon populations between 1989-93 were reflected by reduced egg densities and survival (Bue *et al.* 1996). However, Brannon *et al.* (2001) have recently criticized the sampling design of this study and refuted the findings. Birtwell *et al.* (1999) performed an experiment in which tagged pink salmon fry were exposed to the water-soluble fraction of North Slope crude oil for 10 days and then released to complete their life cycle at sea. The experiment was replicated in 1990, 1991 and 1992. Tagged adult pink salmon were recaptured and collected from the fishery as well as from the Quinsam River, near Campbell River. The exposure to oil did not result in a detectable effect on pink salmon survival to maturity as compared to control groups.

Other intertidal and subtidal fishes were also affected by the EVOS. Fluorescent aromatic compounds (FACs; metabolites of PAHs) among fishes were highest in the bile of Dolly Varden char. Biomarker evidence of oil exposure was found in nearshore benthic species including rock, yellowfin and flathead sole more than 2 years after the EVOS. Walleye pollock, a bathypelagic fish that feeds in the water column also had increased levels of FACs following the spill; levels dropped by 1991 (Collier *et al.* 1996). Ten years after the spill, there was still evidence of chronic contamination in some fishes. Levels of cytochrome P4501A, a protein induced by PAHs, were higher in nearshore fishes (gunnels and greenling) at heavily oiled sites than non-oiled sites. There were also increased FAC levels from gunnels and greenling near oiled mussel beds (Jewett *et al.* 2002). Sol *et al.* (2000) note that the long-term impact of oil exposure on endocrine processes is not fully understood and more research is required to better understand the impacts of oil on reproductive processes and fish populations.

4.6.4. Intertidal

Oil deposited in the intertidal environment remained largely in the high intertidal zone, where it penetrated cobbles and soft sediments. Widespread effects were observed in many intertidal habitats. Fewer invertebrates, mussels, barnacles, limpets and rock weed (*Fucus garderneri*) were found in oiled versus non-oiled habitats (Spies *et al.* 1996). In addition to immediate mortality caused by the spill, recolonization of affected shorelines by invertebrates and algae was also inhibited by the oil coatings on rocks (Duncan and Hooten 1996).

A number of weaknesses in study design made it difficult to clearly document the impacts of the EVOS on the rocky intertidal zone (Peterson *et al.* 2001). These included a lack of baseline data and an inability to find adequate control sites to compare with oiled sites. A continuous monitoring of oiled and un-oiled sites over time can partly resolve these problems. If the impacted communities begin to track or parallel the control site profiles, then recovery can be shown, and initial impacts inferred. This is the Parallelism hypothesis. Skalski *et al.* (2001) used this method to show that temporal patterns of numerous taxa showed a recovery two to three years after the spill. The temporal patterns were also consistent with the hypothesis of acute mortality after the spill followed by eventual recovery (Skalski *et al.* 2001). In addition to intertidal impacts from oil, there were also negative effects from cleaning actions such as high-pressure hot water treatments (See Box 4.1).

Recovery of some intertidal habitats was much slower. Data presented in Downs *et al.* (2002) indicate that bivalves exposed to 10-year old residual oil from the EVOS continue to show signs of cellular physiological stress relative to bivalves from un-oiled sites. Results of biomarker studies show that at least one of the environmental stressors is a PAH (Downs *et al.* 2002). High concentrations of oil also remained in mussel beds until at least 1994 (Spies *et al.* 1996). Contaminated mussels were identified as a source of hydrocarbons to juvenile sea otters (Sloan 1999).

4.6.5. Subtidal

Subtidal environments are generally less affected than intertidal ones, as they do not as readily come into contact with the oil. Oil can, however, be transported to the subtidal environment by adsorption to sinking particles or by ingestion and transport of plankton such as copepods (Sloan 1999). Two epibenthic invertebrates showed decreased densities following the EVOS: the sea star, *Dermasterias imbricata* and the helmet crab *Telmessus cheiragonus* (Spies *et al.* 1996). Numbers of these species had recovered by 1993 at shallower sites but had not at deeper sites (Spies *et al.* 1996). Jewett *et al.* (2002) reported a large die-off of invertebrates in a fjord in 1989; however, a second die-off occurred in 1993 after oil had decreased by 95%. Large die-offs of invertebrates in a fjord in 1989 and 1993 may have been related to low oxygen levels caused by periodic hypoxia of the poorly flushed fjord rather than to oil toxicity although oil toxicity may have exacerbated hypoxic stress in 1989 (Spies *et al.* 1996).

4.7. Chronic Oil Pollution

Though considerably more information is known about the effects of oil spills, low levels of chronic oil pollution actually contribute more hydrocarbons into the marine environment than do acute spills (Table 4-1). Much of what we know of chronic effects of oil results from post-oil spill monitoring. Other studies focus on chronic effects of offshore oil and gas development. Chronic effects are usually measured by biomarker techniques; however, we often lack an understanding of how the sublethal effects of chronic oil pollution will affect an individual or populations. It is thought that chronic, low-level pollution from ship operations may have a greater effect on bird populations than episodic spills do (Sloan 1999).

Most studies of chronic oil pollution focus on heavy and/or toxic components of oil that are known to persist and accumulate such as PAHs. PAH uptake and accumulation by blue mussels (*Mytilus edulis*) and juvenile turbot has been studied (Baussant *et al.* 2001b; Baussant *et al.* 2001a). Baussant *et al.* (2001b; 2001a) found that chronic exposure to PAHs affected different species in different ways. Factors included bioavailability related to feeding habits or lifestyles; uptake pathways (i.e. through ingestion as with mussel or across gills as with fish); and the species' physiological ability for enzymatic degradation of PAHs. Both species showed lower concentrations of PAHs than expected due to decreased bioavailability. The authors recommended that bioavailability of PAHs to various species as well as the fate of PAH metabolites (that may be more toxic than parent compounds) and their toxic effects be considered when assessing risk of chronic oil pollution.

Though most studies of chronic oil pollution focus on PAHs, Rowland *et al.* (2001) studied another component present in oil: unresolved complex mixtures (UCM). Aromatic UCM are present in very high proportions in oil particularly when the oil is weathered. They have largely been ignored as tests to measure PAHs in the environment often filter out the UCMs. However, aromatic UCMs are widespread in the environment. Rowland *et al.* (2001) tested the toxicity of aromatic UCMs on the indicator species, the blue mussel. A 40% reduction in feeding rate for the test mussels compared to controls indicated sublethal toxic effects and a lower scope for growth. They also found higher levels of UCMs in mussel populations from polluted sites on the east coast of the UK as compared to an unpolluted reference site. Polluted mussels also showed decreased health as measured by a lower scope for growth (Rowland *et al.* 2001).

4.8. Synthesis

Numerous sources introduce oil and its constituents into the marine environment. These include chronic oil pollution from mixed sources, as well as catastrophic spills associated with oil exploration and transport. Crude oil consists of a complicated mixture of hydrocarbons and other elements. Different oil constituents have differing properties, toxicities, and degrees of persistence. Many species can degrade hydrocarbons and many microorganisms can use hydrocarbons as a fuel source. Regardless, some components of oil, particularly PAHs, have widespread toxic effects, particularly to vulnerable species including seabirds and sea otters. Though it is not possible to make overt generalizations about oil-related impacts, the central coast does possess many sensitive environments and species that could be adversely affected by a catastrophic oil spill.

Many species can metabolize PAHs; however, metabolites may be just as, or more toxic than the parent compound. The effects of metabolites of PAHs are largely unknown and represent an area requiring more research.

Chronic sources of oil pollution may impact certain areas such as harbours, marinas, high use areas and shipping routes. More information about the effects of chronic oil pollution is also needed. The possibility of oil and gas development highlights the importance of basic research into PAHs/oils in the central coast environment as well as the necessity of collecting baseline data.

Box 4.1 Additional Information on Oil Pollution and Related Issues

- **Habitat Sensitivity:** 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.

Vulnerability Index of Shores (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

- The *Marine Oil Spill Response Information System* (OSRIS): is a computer-based, shoreline sensitivity project using an information system with 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.
    - Completed Atlases: Strait of Georgia and southern west coast of Vancouver Island.
    - Additional data to be compiled in an Atlas: Johnstone Strait (Quadra Island to Cape Caution), Mid Coast (Cape Caution to Princess Royal Island), north west coast of Vancouver Island (Esperanza Inlet to Mexicana Point).
    - For more information, refer to: http://wlapwww.gov.bc.ca/eeeb/osris/osris.html.

- Information on BC's Oil Spill Strategy:
    - http://wlapwww.gov.bc.ca/eeeb/strategy/oilstrat.html
    - http://wlapwww.gov.bc.ca/eeeb/oilfacts/oilfacts.html.

- Impacts of oil spills can also be caused by action taken to clean up oil.
    - i.e. high pressure hot water and oil-dispersant chemicals
    - Refer to (Doerffer 1992).
- More information on EVOS: (Rice *et al.* 1996).
- More information on oil in BC and cold water climates: (Sloan 1999).

5. Wastewater

Wastewater discharged from urban and industrial sources directly into the ocean contains various biological and chemical contaminants. Sewage contributes to five types of pollution problems (Waldichuk 1983):

1. bacteriological-viral contaminants
2. bio-chemical oxygen demand
3. organic solids deposition
4. nutrient enrichment
5. other chemical contamination.

An important issue concerning the environmental affects of wastewater is the behaviour of the aquatic environment receiving the wastewater since different aquatic environments (i.e. rivers, lakes or marine waters) have different abilities to disperse, dilute and assimilate sewage. Coastal environments, characteristic of the receiving water of communities in the central coast, have high flushing and mixing rates. As such, over-enrichment from the input of nutrients is unlikely to occur in marine systems with the exception of poorly flushed fjords or bays (Waldichuk 1984). Therefore, pollution types 2, 3 and 4 are unlikely to be significant issues in the central coast.

Bacteria and viruses do, however, pose risks to human health as well as to the health of wildlife, and represents a major reason for the closure of shellfish beds. Such problems have often been the impetus for increased sewage treatment. For instance, 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 1984). Although this issue is significant, particularly in light of the desire to expand shellfish aquaculture in the central coast, our review will focus on the fifth issue, chemical contamination.

5.1. Chemical Contamination in Sewage

Municipal wastewater can contain domestic, industrial and commercial wastes, as well as storm water runoff. Hundreds of chemicals including metals (Cd, Hg, Cu, Pb), synthetic organic chemicals (PCBs, dioxins, furans, pesticides, nonylphenols), chlorine, solvents, oils, bleaches, as well as pharmaceuticals are released into the marine environment through wastewater.

Street runoff, industrial wastes from small industries such as photographic processing, laboratories, hospitals, dental clinics, and other operations, as well as household wastes, represent sources of trace metals in municipal sewage (Kay 1989; Waldichuk 1983). Elevated levels of trace metals have been found in sediments, water, and shellfish near municipal outfalls (Kay 1989). Environment Canada monitors trace metals near outfalls in Campbell River, Port McNeill, and Port Hardy (Kay 1989). Kay (1989) reports that metal concentrations in sediments in Nanaimo have been increasing steadily since the installation of a sewage outfall, and that highest levels of zinc, mercury and copper in mollusks occur around Victoria outfalls. No information about metal contamination related to sewage outfalls is available for the central coast (Personal communication, Walter Hagen, Environment Canada, 2002).

Toxic contaminants such as PCBs, dioxins, furans, PAHs, and chlorinated phenols are released into marine environments by various sources including, but not limited to, municipal wastewater. These chemicals are of concern because they persistent and accumulate in biota and sediments. Many of these substances bioaccumulate in aquatic organisms; however, it is difficult to determine the proportion of persistent substances that are attributable to sewage discharges due to the variety of sources (Pierce *et al.* 1998). A preliminary mass balance model of PCBs in the Strait of Georgia indicated that PCBs entering the Strait of Georgia through sewage were a minor source as compared to other inputs (Personal communication, Sophia Johannessen, Fisheries and Oceans Canada, 2003).

Chlorine can be introduced into the sewage effluent to act as a disinfectant in order to reduce bacterial and viral contamination; however, chlorine is toxic to many marine organisms. Chlorine also reacts with other substances to create chlorinated substances that can also be very toxic. The BC government discourages the use of chlorine for effluent released into the marine environment. Where chlorine is used to decrease the risk of contamination of shellfish, drinking water and recreational sites, dechlorination is required (People for Puget Sound and Georgia Strait Alliance 1995), suggesting that this process does not represent a significant concern in the central coast.

Various contaminants are found in household cleaning products and personal care products that are washed down drains and introduced into marine environments. Household cleaning products can contain bleach, solvents, surfactants and nonylphenols. Many of the impacts of such products are unknown however acute toxicity and endocrine disruption have been documented for some products (Daughton and Ternes 1999).

Pharmaceuticals and natural or artificial hormones consumed or 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 (Barnes *et al.* 2002). The most commonly detected substances included antibiotics, reproductive hormones, and various prescription drugs. These products are most likely found in wastewater in Canada as well.

5.2. Sewage Treatment

Various levels of sewage treatment exist, ranging from no treatment (the release of raw sewage into the environment), to tertiary treatment. Each level of treatment progressively removes greater amounts of solids, metals, and some contaminants (Grant and Ross 2002):

- Pre-treatment: screening of effluent to remove solids.
- Primary treatment: removal of solids through settling of solids, and skimming of floating materials (oils, grease). Sludge is removed and disposed of elsewhere; liquid effluent is discharged. This removes approximately 40-50% of total suspended solids, 50% of metals, and a small proportion of organic contaminants.
- Secondary treatment: following primary treatment, biological breakdown of organics in effluent is assisted by supplying oxygen to microorganisms through aerated settlement ponds, trickling filters and filtration. This process removes 85-95% of the suspended solids, 75% of the metals, and 70-80% of the organic contaminants.
- Tertiary Treatment: removes nutrients and sometimes organic contaminants by various methods. No tertiary treatment exists in the central coast (Table 5-1).

Some smaller communities and rural areas do not have sewage treatment facilities and rely on private sewage treatment or septic systems. Septic systems are tantamount 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).

5.3. Synthesis

The impact of sewage discharge is site specific and highly dependent on the characteristics of the outfall and the receiving environment such as rate of flushing, type of discharge (shallow, deep) and level of treatment, and cumulative loadings (Macdonald *et al.* 2002). All larger communities in the central coast area have some level of sewage treatment, often in the form of secondary treatment. Rural areas, especially in northern part of the central coast, have small populations that rely on septic systems. Small amounts of raw sewage, as well as untreated grey water, may be released into marine waters from septic systems. Any impacts of sewage effluent are likely to be localized. Local inputs of sewage may develop into an issue of greater concern as shellfish aquaculture in the central coast expands. Natural shellfish beds may also be exposed to bacterial contamination. No direct information exists on chemical contaminants in wastewater specific to the central coast.

Table 5-1. Sewage treatment in the central coast. 1^o = primary treatment, 2^o =secondary treatment.

District/ Town	Population	Sewage Treatment
Central Coast Regional District A	143	Septic / Raw
Central Coast Regional District B	1,253	1^o or 2^o
Central Coast Regional District C	697	Septic / Raw
Central Coast Regional District D	516	Septic / Raw
Central Coast Regional District E	167	Septic / Raw
Bella Coola Indian Reserve	909	Septic / Raw
Klemtu Indian Reserve	295	Septic / Raw
Central Coast RD	3,781	Mostly Septic / Raw
Port Hardy	4,574	2^o Contact Stabilization
Port McNeill	2,821	2^o
Port Alice	1,126	2^o
Alert Bay	583	2^o
Sointula,		2^o
Echo Bay	886	Septic System
Holberg, Winter Harbour	169	Septic/Raw
Quatsino,		Raw
Coal Harbour	829	2^o
Telegraph Cove,		2^o
Woss,		2^o Aeration Lagoon
Beaver Cove	401	Industrial 2^o, residential septic
Mount Waddington RD (Census Area)	13,111	Mostly 2^o
Comox-Strathcona Regional District		
Campbell River	33,872	2^o Hi Rate Activated Sludge
Sayward	785	2^oAeration Lagoon
Quadra Island	2,548	Septic / Raw
Total Comox-Strathcona RD in CC LOMA	37,205	Mostly 2^o

Data Sources:
Coast Regional District information: (Personal communication, Janet Poole, Central Coast Regional District 2003; Personal communication Dean Wilson, Heltsik First Nation, 2003).
Mount Waddington and Comox-Strathcona Regional Districts: (Ministry of Environment 1991), updated with Personal communication, Bernie MacKay, BC WLAP, 2003.
Population data from Table 2-1.

Box 5.1 Additional Information on Wastewater Treatment and Related Issues

- Shellfish Closures: Shellfish beds can be closed to harvesting because of bacterial contamination. Parts of the Central coast are closed to shellfish harvesting:
    - http://www.ecoinfo.org/env_ind/region/shellfish/shellfish_e.cfm.
- Canadian food inspection agency guidelines to maintain water quality for shellfish:
    - http://www.inspection.gc.ca/english/anima/fispoi/manman/cssppccsm/chap2annce.shtml.
- Nutrient enrichment and organic wastes can lead to:
    - Increased oxygen demand by aerobic bacteria that degrade the organic waste. This may result in oxygen depletion.
    - Eutrophication, and increased algal blooms, including toxic blooms.
    - Positive effects such as enrichment of biota (i.e. tubifex worms, a major food item of seabirds).
    - Refer to: Marine Pollution in the United States; (Clark 2001); and http://www.pewoceans.org/reports/022701report.pdf.
- Sewage effluent in the Georgia Basin/Puget Sound:
    - Puget Sound Georgia Basin Sewage Report: http://www.pugetsound.org/sewage/report/default.html;
    - (West *et al.* 1994).
- An historical perspective on sewage pollution in BC: (Waldichuk 1984).
- National evaluation of sewage in Canadian Cities:
    - Sierra Legal Defense Fund: http://www.sierralegal.org/reports/Sewage.pdf.
- Guide to environmentally friendly house hold cleaning products:
    - Georgia Strait Alliance: http://www.georgiastrait.org/toxicguide.php.
- More information on pharmaceuticals in the environment:
    - (Environmental Research Foundation 1998);
    - (McLeay 2002).

6. Pollution from 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 central coast LOMA. A typical cruise ship route is shown in Figure 6–1.

Between 1988 and 2000, 193-309 voyages per year were made from the Port of Vancouver alone. Each cruise ship carries an average of 2,000 people (Nowell and Kwan 2001). Additional cruises also departed from Seattle or San Francisco and may have docked in Victoria rather than Vancouver, so these figures may slightly underestimate the number of cruise ships traveling up the coast. The number of trips, and consequently passengers, have been increasing steadily; over 1 million passengers and crew now travel through the central coast each year (Figure 6–2) (Transport Canada 2003).

The cruise ship industry contributes greatly to BC's economy; passenger spending plus spending by the cruise industry for supplies and services amounts to $508 million dollars annually (Vancouver Port Authority 2003). Most economic benefits are felt in Vancouver. Cruise ships also dock in Victoria and Prince Rupert. Though ships travel through the region, most cruise lines do not appear to have any central coast communities listed as ports of call; however, Royal Caribbean Cruise Lines has planned some test calls for Campbell River in 2003 (Gorecki and Wallace 2003). Some cruise ships also stop in Bella Bella, Ocean Falls and Alert Bay.

Figure 6-1. A common cruise ship route traveling through BC's central and north coasts. Data from Norwegian Cruise Lines: http://www.cruiseweb.com/NCL-ALASKA.HTM.

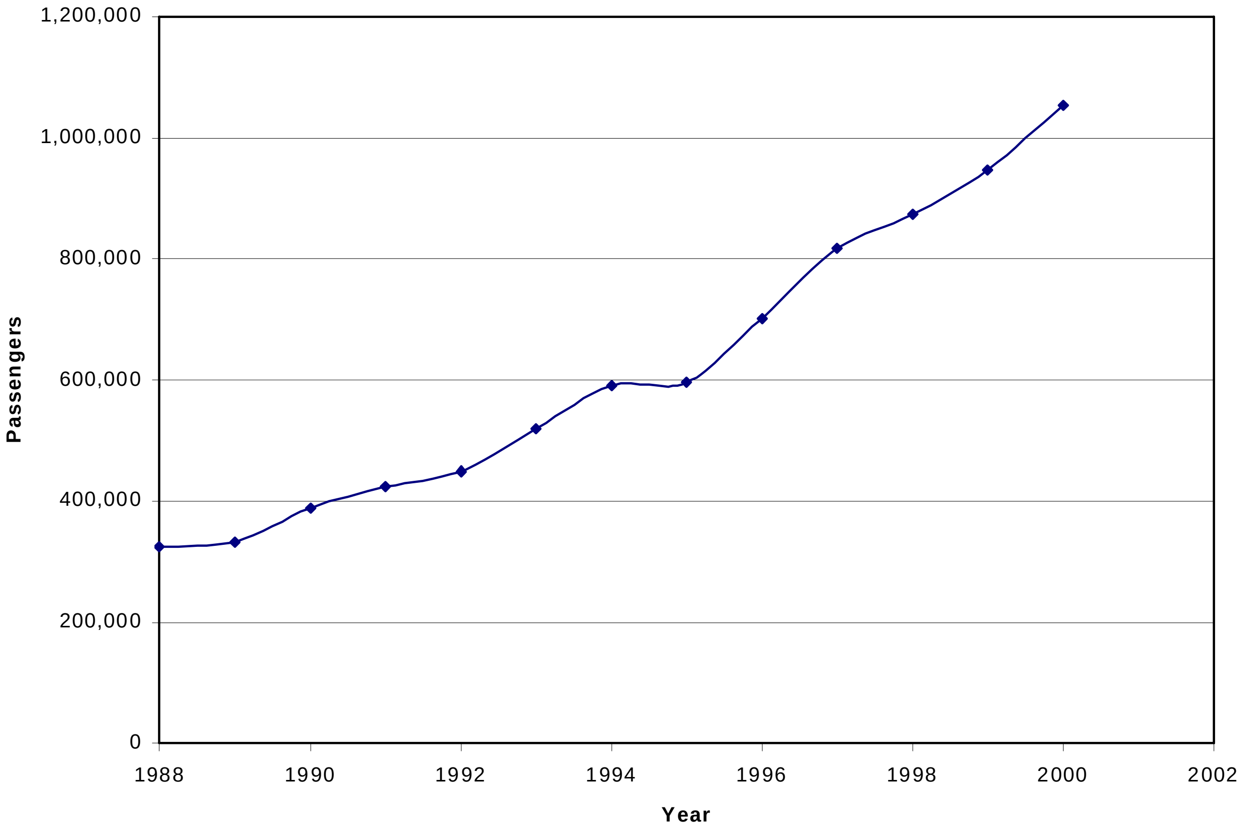

Figure 6-2. Numbers of cruise ship passengers leaving Vancouver between 1988-2000. Data from Transport Canada: http://www.tc.gc.ca/pol/en/ExcelSpreadsheets2.

Cruise lines have been recently criticized internationally and in British Columbia for their environmental record with respect to pollution (Ocean's Blue Foundation 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 US $30 million 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 illegally dumped harmful wastes into the environment (Nowell 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). 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).

Waste from cruise ships are categorized into eight types:

- Sewage: also termed blackwater, sewage from cruise ships is more concentrated than municipal sewage because less water is used to dilute wastes on ships than is on land.

- Grey water: includes wastewater from sinks, showers, galleys, and laundry.
- Oil pollution: as with other ships, bilge water often contains oil and fuel from on-board spills and wastes from engines and machinery.
- Hazardous wastes: includes dry cleaning sludge (containing perchlorethylene), waste from photo and x-ray processing laboratories (e.g. silver), paint waste and solvents, print shop wastes, deoderizers and disinfectants (e.g. chlorine) and batteries.
- Solid waste: includes plastic, paper, wood, cardboard, food waste, cans and glass. Much of the paper and food waste is incinerated on board.
- Air pollution from ship's combustion and incineration: air emissions (e.g. CO_2, PAHs) contributing to greenhouse gases and smog constituents.
- Ballast water: may contain oil, chemicals, and introduced species.
- Vessel coating: antifouling paints containing toxic chemicals or metals.

6.1. Wastewater: Black Water and Grey Water

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 litres of black water. During peak season, the combined releases of all cruise ships in BC waters are estimated to be 9.5 million litres of sewage per day, an amount equivalent to that produced by the city of Juneau, Alaska (approx. 25,000 people) (Nowell and Kwan 2001). Excluding Campbell River at the far southern end of the central coast, this represents more than double the sewage releases by the entire population of the central coast area.

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 system, (2) macerator/chemical, or (3) advanced treatment (Science Advisory Panel 2002). Wastewater treatment systems used by ships operating in Alaska are shown in Table 6-1. The Alaskan government requires passenger vessels to take 2 black and grey water samples per year. Analysis of these samples found that advanced treatment systems that have been recently installed on several large cruise ships (vessels marked with * on Table 6-1) are very effective at removing solids and fecal coliform bacteria; however these systems do produce a concentrated sludge that requires disposal (Science Advisory Panel 2002). Macerator-chlorinating systems reduce fecal coliform on vessels with less than 1000 passengers and crew; however, none of the ships using these systems or conventional biological treatment systems are within the limits to allow them to discharge black water within 3 nautical miles from shore (Table 6-1). 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 (Science Advisory Panel 2002). In some cases, macerator-chlorinating systems had high chlorine residuals and high chemical oxygen demand (Science Advisory Panel 2002). High residual chlorine is particularly problematic since it is toxic to marine life.

Wastewater sampling showed that black and grey water are quite similar in water quality. "Both have been shown to have (1) high levels of fecal coliform and suspended solids, (2) no measured hazardous substances, (3) somewhat elevated concentrations of trace metals (copper, zinc) and plasticizers" (Science Advisory Panel 2002). Grey water is usually not treated; however, it may be mixed with black water and treated. Some ships add chlorine to grey water to reduce bacteria (Table 6-1) (Science Advisory Panel 2002). Grey water adds an estimated 4 million litres of discharge per ship (based on a 7-day cruise). Grey water can contain organics, petroleum hydrocarbons, oils and greases, metals, suspended solids, nutrients, detergents, coliform bacteria and personal care products (Nowell and Kwan 2001).

Black water, like land-based sewage, contains many pharmaceuticals with poorly characterized environmental effects (see Section 5.1). Drugs such as anti-hypertensive drugs, which are taken by a significant portion of the middle aged and elderly in large quantities (1 to 2 grams per day) to reduce cholesterol levels in the blood, are found in sewage. For example, clofibric acid (2-(4)-chlorophenoxy-2-methyl propionic acid), has been found in high concentrations in sewage and is also widespread in German rivers, Swiss lakes and the North Sea (Buser *et al.* 1998). Such pharmaceuticals should be evaluated on the grounds of their ecotoxicological properties. Various other drugs and medications such as antibiotics, hormones and steroids can either be taken orally or applied topically to skin. They can enter the black water pathway as metabolites via excreta, or go to the grey water pathway via wash off from showers and sinks (Science Advisory Panel 2002). The scientific panel does not believe that the impacts of these chemicals in the case of cruise ships are significant. They base this argument on the very low level of these contaminants (often measured in parts per trillion), and the tremendous dilution factor which apply to the relatively low discharges of black and grey water (Science Advisory Panel 2002). Though this may be true, it should be noted that these are assumptions and the environmental effects of pharmaceuticals and other new persistent chemicals (see Section 10.3) are largely unknown.

A significant difference between effluents from cruise ships (black and grey water) and municipal outfalls is that cruise ships are not stationary. Consequently, localized impacts associated with cruise ship effluent may be more diffuse and less severe. In addition, impacts associated with releases of black/grey water, will be much more difficult to characterize than for municipal effluents. Though dilution is certainly not the solution to pollution, the Science Advisory Panel (2002) concluded that the mitigating effect of the vigorous mixing action of a moving ship and concentration limits for certain wastewater constituents effectively controls the pollution from black and grey water. Alaskan regulations require black and grey water to be discharged at least one nautical mile from shore at speeds of at least six knots (Nowell and Kwan 2001). The calculated dilution factor for a typical large cruise ship moving at 6 knots and discharging wastewater at $200m^3$/hr is 50,000 times (Science Advisory Panel 2002). For this reason, they consider most discharges of wastewater to be quite benign if discharges are made while the ship is underway. They do recommend that wastewater should not be discharged when the ship is stationary, within half a nautical mile of shellfish beds, within 1 nautical mile of shore, or within protected bays or inlets with low tidal exchange (Science Advisory Panel 2002).

Table 6-1. "Large" commercial passenger vessel operating in Alaska with registration and status and wastewater treatment (Alaska Department of Environmental Conservation 2003). Within Alaska waters is considered 3 miles from the coastline.

Large Vessel Operator	Large Vessel Name	Discharging Graywater within Alaska?	Graywater Treatment System	Discharging Blackwater within Alaska?	Blackwater Treatment System	Comments
Carnival Cruise Lines	*Carnival Spirit*	No	Ultrafiltration	No	Ultrafiltration	Is currently testing new system.
Celebrity Cruises	*Mercury**	Yes	Ultrafiltration	Yes	Ultrafiltration	Wastewater samples meet stringent requirements. System certified by USCG to discharge continuously.
Celebrity Cruises	*Infinity*	No	Unknown	No	Biological & chemical	
Celebrity Cruises	*Summit*	No	Unknown	No	Biological & chemical	Installing a chemical/ultrafiltration system.
Crystal Cruise Lines	*Crystal Harmony*	No	Unknown	No	Biological & chemical	Upgraded existing system. Researching new technology.
Holland America	*Amsterdam*	No	Unknown	No	Unknown	Currently installing bioreactor and UV disinfection system. System not certified for 2002.
Holland America	*Ryndam**	Yes	Bioreactor & UV disinfection	Yes	Bioreactor & UV disinfection	Wastewater samples meet stringent requirements. System certified by USCG to discharge continuously.
Holland America	*Statendam**	Yes	Bioreactor & UV disinfection	Yes	Bioreactor & UV disinfection	Wastewater samples meet stringent requirements. System certified by USCG to discharge continuously.
Holland America	*Veendam**	Yes	Bioreactor & UV disinfection	Yes	Bioreactor & UV disinfection	Wastewater samples meet stringent requirements. System certified by USCG to discharge continuously.
Holland America	*Volendam**	Yes	Bioreactor & UV disinfection	Yes	Bioreactor & UV disinfection	Wastewater samples meet stringent requirements. System certified by USCG to discharge continuously.
Holland America	*Zaandam**	Yes	Bioreactor & UV disinfection	Yes	Bioreactor & UV disinfection	Wastewater samples meet stringent requirements. System certified by USCG to discharge continuously.
Mitsui O.S.K.	*Nippon Maru*	No	Macerator/ Chlorinator	No	Macerator/ Chlorinator	This vessel is in Alaska for 8 days only

Norwegian Cruise Lines	*Norwegian Sky*	Yes (IPM)	None	No	Biological & chemical	Testing treatment system that uses micro filtration and UV filters to partially treat greywater.
Norwegian Cruise Lines	*Norwegian Wind*	Yes (IPM)	None	No	Biological & Macerator/ Chlorinator	Researching new technology.
Princess Cruise Line	*Dawn Princess*	Yes (IPM)	Chlorine	No	Biological & chemical	Installed Hamworthy Bioreactor. System has not been certified for continuous discharge for 2002.
Princess Cruise Line	*Ocean Princess*	Yes (IPM)	Chlorine	No	Biological & chemical	
Princess Cruise Line	*Regal Princess*	Yes (IPM)	Chlorine	No	Biological & chemical	
Princess Cruise Line	*Sea Princess*	Yes (IPM)	Chlorine	No	Biological & chemical	
Princess Cruise Line	*Star Princess*	Yes (IPM)	Chlorine	No	Biological & chemical	Installed Hamworthy Bioreactor. System has not been certified for continuous discharge for 2002.
Princess Cruise Line	*Sun Princess*	Yes (IPM)	Chlorine	No	Biological & chemical	Installed Hamworthy Bioreactor. System has not been certified for continuous discharge for 2002.
Radisson Seven Seas	*Seven Seas Navigator*	Yes	Membrane bioreactors and filtration	Yes	Membrane bioreactors and filtration	
Royal Caribbean Cruises Ltd.	*Legend of the Seas*	No	Unknown	No	Biological & chemical	
Royal Caribbean Cruises Ltd.	*Radiance of the Seas*	No	Unknown	No	Biological & chemical	
Royal Caribbean Cruises Ltd.	*Vision of the Seas*	No	Unknown	No	Electro/ Mechanical	Testing Hydroxyl system during 2002 season.
World Explorer Cruises	*Universe Explorer*	No	Unknown	No	Unknown	

* Vessels have installed advanced wastewater treatment systems that meet stringent wastewater discharge standards. These vessels are therefore certified by the US Coast Guard to discharge wastewater continuously.

IPM = Interm Protective Measures.

6.2. Oil

There are many sources of oil pollution from ships (see Section 4.1). The *Canada Shipping Act* requires a "zero discharge" of oily bilge water. Ships are required to have oily water separators and only processed bilge water with less than 15 parts of oil per million may be discharged into the ocean (Nowell and Kwan 2001).

6.3. Toxic Contaminants

Cruise ships produce many toxic chemicals. Disposal and handling of hazardous wastes are governed by a number of different regulations in various laws that detail prohibited chemicals, handling, storage and treatment of wastes, and how to report discharges. Standards adopted by the International Council of Cruise Lines require its members to treat photo processing wastes; dry-cleaning fluids, sludge, contaminated filters and other dry cleaning by-products; photocopying and printing cartridges and ink; unused pharmaceuticals; fluorescent and mercury vapour lamp bulbs; and batteries as hazardous materials that must be disposed of properly on 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). The wastewater sampling program did not find hazardous wastes in black or grey water so illegal discharge of these materials through this pathway is not suspected (Science Advisory Panel 2002). A report states that full disclosure from ships on the generation and disposal of hazardous wastes is not required in Canada and contends that illegal dumping of hazardous materials may still be an issue (Nowell and Kwan 2001).

6.4. Solid Waste

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

Solid waste, which may also contain hazardous materials such as batteries, is also 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).

6.5. Air Emissions

Ship exhaust as well as fumes from ship-board incinerators contributes 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, sulphur dioxide, and PAHs. Most cruise ships run on diesel bunker fuel that is 90% higher in sulphur than gasoline used to power cars. Toxic substances such as plastics that may be accidentally or intentionally incinerated on board can also release dioxins, furans and heavy metals (Gorecki and Wallace 2003).

6.6. Ballast Water

Ballast water is taken on for ship's stability and is a major pathway for introduced species (see Box 7.1). One method of dealing with introduced species in ballast water is to treat the water with chemicals. Many of the chemicals may lead to chlorine residuals.

6.7. Vessel Coating

Cruise ship hulls generally include a base anticorrosive coating covered by an antifouling coating. If the anticorrosive coating is not damaged or exposed, it should not leach into the seawater. The antifouling coating inhibits the growth of marine life on the hull (see section 7.3). Most cruise ship hulls are steel though smaller vessels and support boats may be aluminum. Steel hulls are typically coated with copper-based coatings. Copper and zinc are the most common releases. Alaska banned the use of TBT 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).

6.8. Regulations

Regulations, monitoring and enforcement of cruise ship pollution are generally stronger in the US than in Canada. Despite such regulations, numerous violations have occurred in US waters in the past, as is evident from the US General Accounting Office report (United States General Accounting Office 2000).

Until recently, when fourteen new no-discharge zones were designated, there were no specific regulations concerning ship-based sewage in Canadian waters. None of the no-discharge zones are in the central coast, though ten are in the Strait of Georgia. The northern-most zones, Carrington Bay and Cortez Bay, off of Cortez Island, are at the proposed southern boundary of the central coast LOMA. Sensitive areas in the central coast, such as protected areas and the vicinity of the sponge reefs, should be considered for no-discharge zones. The *Fisheries Act* could be invoked to prevent deposition of “deleterious substances” into fish habitat; however, no charges for pollution from cruise ships have been laid in British Columbia (Nowell and Kwan 2001).

6.9. Synthesis

Given the large volume of ships and numerous people transported through the central coast each year (over a million per year), wastes from cruise ships, including black water, grey water, oil, air emissions and hazardous materials, represent potentially significant pollution issues for the central coast LOMA. West Coast Environmental Law recommends harmonizing Canadian and US regulations to avoid pollution dumping in jurisdictions with less stringent requirements and pollution penalties (Nowell and Kwan 2001). The stricter US rules may, in fact, render Canadian waters more vulnerable to the intentional release of pollutants by cruise ships. Cruise ship pollution should be monitored. No-discharge zones should also be considered for sensitive areas in the central coast including marine protected areas, sponge reefs, clam beds and bird colonies.

Box 6.1. Additional Information on Pollution from Cruise Ships

- For more information on US and Canadian regulations and legislation pertaining to cruise ships, refer to:
    - (Sloan 1999; Nowell and Kwan 2001).

- General information impacts from cruise ships with many downloadable reports: Ocean's Blue Foundation website:
    - http://www.oceansblue.org/bluetourism/chartacourse/cruiseship/cruiselinks.html.

- For the Scientific Advisory Panel Report as well as other information on cruises in Alaska:
    - http://www.state.ak.us/local/akpages/ENV.CONSERV/press/cruise/cruise.htm.

- Environmental Protection Agency "White Paper" on impacts from cruise ships:
    - http://www.epa.gov/owow/oceans/cruise_ships/assess.htm.

- International Council of Cruise Lines waste management practices and procedures:
    - http://www.iccl.org/policies/environmentalstandards.pdf.

7. Shipping and Boating

In addition to oil tankers and cruise ships, many other types of vessels travel in or through the central coast, including container and cargo ships, barges, ferries, fishing and recreational vessels. Total vessel movement statistics maintained by the Canadian Coast Guard for the Comox zone provide an indication of temporal trends of shipping patterns in the central coast (Table 7–1). Total vessel movements describe the types of vessels frequenting the central coast (defined in Table 7–2) as well as their relative activity levels.

As is evident from Table 7–1, most vessel traffic in the central coast is associated with ferries. BC Ferries operates several routes in the central coast. Regular ferry trips are made through the Inside Passage year-round and to the Discovery Coast in the summer. There are also a regular, year–round smaller ferries between Port McNeill, Sointula and Alert Bay; and Campbell River, Quadra and Cortez Islands.

Tug boats towing oil barges, other barges and other tows also operate with high frequency. Traffic movement from fishing vessels appears to have increased in the years between 1999-2002 (Table 7-1).

Many of the same pollution issues described for oil tankers and cruise ships also apply to other forms of shipping and boating. This includes sewage, grey water, oily bilge water and ship board solid wastes. Ship-based pollution is often greatest in areas where boats are most concentrated, such as in harbours and marinas. A major source of chemical contamination is from antifouling paints applied to the hulls of boats. High levels of these compounds are often found in harbours. One such compound, TBT was banned on small vessels (<25 m) in 1989 following widespread observations of endocrine disruption in oysters and snails (see section 7.3). Harbours and marinas are also a source of wood preserved with chemicals such as creosote, as treated wood is used a primary building material.

Shipping leads to another major source of pollution: non-indigenous or exotic species that are transported in ballast water from place to place and introduced into new environments. This is considered biological pollution and is not covered in this report. See Box 7.1 for further information sources on introduced species. The treatment of ballast water may eventually involve chemical treatment. This may become a new source of chemical contamination, most likely in the form of chlorine residuals.

Table 7-1. Vessel Traffic Statistics (VTS) showing ship movements in the Comox Marine Zone 1990-2002 from marine communications and traffic services statistics. VTS represent movements of vessels in or out of a zone or movements within the zone but only one movement per day is counted (Personal communication, M. Dweyer, Canadian Coast Guard, 2003). Vessel movements in the Comox zone represent approximately 22 to 24% of the total vessel movements in BC.

MOVEMENTS BY VESSEL TYPE	COMOX 1999-00	COMOX 2000-01	COMOX 2001-02
Tanker <50000 DWT	44	42	46
Tanker >50000 DWT	0	2	1
Chemical Tanker	5	8	3
LPG/LNG Carrier	0	1	0
Cargo - General	2,811	3,453	3,938
Cargo - Bulk	333	360	297
Container	0	10	5
Tug	1,209	1,759	2,059
Tug with oil barge	1,135	1,277	1,591
Tug with chemical barge	308	432	1,133
Tug with Tow	13,984	15,867	20,538
Government	831	1,025	1,655
Fishing	2,597	3,720	5,241
Passenger Vessels	831	1,063	1,634
Other Vessels >20m	980	748	1,424
Other Vessels <20m	0	93	58
Sub-Total Movements	***25,068***	***29,860***	***39,623***
Ferry	67,257	67,434	60,249
Grand Total Movements	***92,325***	***97,294***	***99,872***

Table 7-2. Vessel definitions for VTS vessels in Table 7-1 (Personal communication, M. Dweyer, Canadian Coast Guard, 2003).

Vessel Types (vessels > 20m)	Definition
Cargo - General	A vessel utilized for the carriage of general cargo, which is not containerized; e.g., locomotives, farm machinery, market goods. Some specialized vessels may also be identified within this category; e.g., auto carriers.
Cargo - Bulk	A vessel utilized for the carriage of bulk cargoes; e.g., grain, iron ore, coal. Precaution is necessary as some vessels of this type may change their category when within a zone; e.g., an Oil-Bulk-Ore (OBO) ship may be carrying bulk inbound but convert to a tanker role and carry petroleum outbound.
Chemical Tanker	Is a tanker engaged in the carriage of liquid chemicals (excluding petro-chemicals).
Container	A vessel utilized primarily for the carriage of containerized cargo.
Ferry	A vessel specifically designed for the carriage of passengers and/or vehicles (including trains) which transits between two ports on a regular schedule.
Fishing	Any vessel used, outfitted, or designed for the purpose of catching, processing or transporting of fish. (*Fisheries Act*).
Government	Any vessel owned by the Government of any country and not engaged in commercial trade.
LPG/LNG Carrier	Is a vessel designed for and engaged in carriage of liquid petroleum gas or liquid natural gas.
Passenger Vessel	A ship utilized primarily for the carriage of human passengers. This does not include a ship identified as a "ferry".
Tanker	A ship in which the greater part of the cargo space is constructed or adapted for the carriage of liquid cargoes and is engaged in oil carriage of liquid cargoes (not to include tugs with oil barges).
Tug	A vessel specifically designed for towing purposes.
Tug with oil barges	A barge used for the transportation of oil and propelled by a towing vessel i.e. tugs
Other	All vessels, other than those defined above, which participate in the VTS System.

7.1. Wastewater

Sewage, grey water and oily wastewater are all produced to some extent, by most vessels; though small motor boats without a head or galley are only expected to produce oily bilge water. Next to cruise ships, BC Ferries transports the most number of people through the central coast. BC Ferries is in the process of upgrading the sewage systems of all of their vessels to state of the art systems (Hydroxyl CleanSea® Sewage system). The CleanSea® system uses bio-oxidation to handle sewage, grey water, and oily bilge water. No chlorine is used. Effluent reportedly surpasses all environmental regulations (Personal communication, Alicja Rudzki, Environmental Department, BC Ferries, 2003). Sewage from BC Ferries is not likely to be of major concern in the future.

Other boats operating in the central coast should also have treatment facilities or holding tanks. Most small recreational vessels, such as the numerous sports fishing boats frequenting the central coast, may not have sewage treatment systems or holding tanks. Raw sewage from holding tanks, as well as any treated effluent, is often released into the marine environment as there are only four pump-out stations in the central coast: Browns Bay Marina and Fisherman's Warf, both in Campbell River, Port McNeill Harbour Authority and Ocean Falls Public Dock (Georgia Strait Alliance 2003); www.marina.net). As previously noted (Section 6.8), there are no regulated "no–discharge zones" in the central coast. Most marinas and harbours have no dumping policies. Except in areas of very high boat traffic, including areas of high recreational use, impact from ship-based sewage and wastes is likely to be relatively diluted; although cumulative impacts of wastes from all boat use does lead to a significant amount of pollution. Each boater can take actions to prevent ship-board pollution (see Box 7.1).

7.2. Harbours and Marinas

Boats and ships are concentrated in harbours and marinas. 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. There are at least 28 marinas or harbours in the central coast, 18 of which also have fuel docks (Table 7–3). Oil and gas pollution is expected to be higher at marinas with fuel docks since many fuel spills occur when boaters are filling (Georgia Strait Alliance 2003). Kay (1989) notes that areas, particularly harbours, that are exposed to chronic discharges of petroleum hydrocarbons experience contamination from PAHs, as PAH concentrations in harbour sediments were found to be 260 times higher than in non-harbour sites. PAHs are of concern as they have been shown to be carcinogenic in animals and humans. Certain marine organisms, especially molluscs, are known to accumulate PAHs since they do not rapidly excrete or metabolize them. Harbours may also have increased levels of dioxins and furans from wood treatment facilities and combustion (Yunker and Cretney 1996).

Table 7-3. Harbours and marinas in the central coast (modified from http://www.marina.net/). Though many of these marinas serve recreational vessels over half of them (60%) offer fuel services. The nautical chart number the marinas appear on is given for relative location.

Marina	Locale	Chart#	Fuel Dock
ALERT BAY BOAT HARBOUR	ALERT BAY	3546	Y
SHEARWATER MARINE RESORT	BELLA BELLA	3720	Y
BLIND CHANNEL RESORT	BLIND CHANNEL	3543	Y
SULLIVAN BAY MARINE RESORT	BROUGHTON I. NORTH	3547	Y
BROWNS BAY MARINA	BROWNS BAY	3312, 3539	Y
FISHERMAN'S WHARF	CAMPBELL RIVER	3312, 3539	Y
DISCOVERY HARBOUR AUTHORITY	CAMPBELL RIVER	3312, 3539	Y
DISCOVERY HARBOUR MARINA	CAMPBELL RIVER	3312, 3539	Y
DISCOVERY MARINA	CAMPBELL RIVER	3312, 3539	N
FRESH WATER MARINA	CAMPBELL RIVER	3312, 3539	N
ROSMAR MARINA	CAMPBELL RIVER	3312, 3539	N
LAGOON COVE MARINA	CRACROFT I. EAST	3545, 3564	Y
FANNY BAY SMALL CRAFT HBR - D.F.O.	FANNY BAY	3513, 3527	N
ECHO BAY RESORT	GILFORD ISLAND	3515	Y
WINDSONG SEA VILLAGE RESORT	GILFORD ISLAND	3515	N
GREENWAY SOUND MARINE RESORT	GREENWAY SOUND	3547, 3570	N
GOD'S POCKET	HURST ISLAND	3546, 3548	N
MINSTREL ISLAND RESORT	MINSTREL ISLAND	3564	Y
PORT HARDY HARBOUR AUTHORITY	PORT HARDY	3548	Y
QUARTERDECK MARINA & R.V. PARK	PORT HARDY	3548	Y
TOWN OF PORT MCNEILL HARBOUR	PORT MCNEILL	3546	Y
APRIL POINT LODGE & MARINA	QUADRA ISLAND	3312	N
HERIOT BAY INN & MARINA	QUADRA ISLAND	3312	Y
HERIOT BAY SMALL CRAFT HBR	QUADRA ISLAND	3312	N
QUATHIASKI COVE GOV'T WHARF	QUADRA ISLAND	3312	Y
SEASCAPE WATERFRONT RESORT	QUADRA ISLAND	3312	N
KELSEY BAY SMALL CRAFT HBR	SAYWARD	3539	Y
TELEGRAPH COVE MARINA	TELEGRAPH COVE	3546	Y

7.3. Antifouling Paints

Harbours and marinas have also been the sites with greatest contamination from antifouling paints containing organotin compounds. The most common antifouling compound, TBT, has been used as a biocide on the hulls of boats since the 1970s in Canada and around the world. TBT has been described as "the most toxic substance ever deliberately introduced into natural waters" (Stewart and Thompson 1994). Shellfish such as mussels and oysters, whelks and flatfish have all shown TBT contamination in BC (Stewart and Thompson 1994). TBT contamination has been shown to disrupt reproduction in molluscs, most notably in neogastropod snails such as whelks. Female whelks contaminated with TBT displayed masculine traits such as the development of a penis and vas deference (termed imposex). This can lead to an inhibition of reproduction. The condition is irreversible and manifested itself in rapid population declines or even complete extirpation of the affected species from heavily contaminated areas such as Vancouver Harbour (Pierce *et al.* 1998; Tester *et al.* 1996). In recognition 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) in 1989.

Several studies have evaluated the effectiveness of this law 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. Industrial harbours with traffic from ships greater than 25m such as Vancouver Harbour show no reduction in TBT levels (Pierce *et al.* 1998). 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 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 but not in industrial harbours; populations of whelks are still absent from Vancouver Harbour.

Most harbours in the central coast have generally low large ship traffic and are frequented by boats under 25m that must comply with the anti-TBT regulations. Large ships frequenting the central coast including cruise ships (Section 6.7) and ferries use copper-based antifouling paints rather than TBT (Science Advisory Panel 2002); Personal communication, Alicja Rudzki, BC Ferries, 2003). The Canadian Navy is also in the process of phasing out TBT in favour of copper-based antifoulants (Personal communication, Duane Freeman, CFB Esquimalt, 2003). The TBT ban should therefore be largely effective in protecting biota in the central coast. Indeed, 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 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, *N. lamellosa*, while no other species previously sampled at that site could be found in the 2000 survey (Reitsema *et al.* 2002). Authors note that the sampling location is directly adjacent to a slipway that may be the source of TBT. This finding is indicative that although TBT contamination in most of BC has been reduced since 1989, it has not been eliminated.

TBT accumulates and persists in marine sediment, as well new inputs of TBT exist (Stewart and Thompson 1994; Stewart and Thompson 1997). New sources include the use of TBT paints on boats over 25 m (even though new, anti-leaching formulations are required, pollution has not abated), leaching from old paint chips, and illegal use of remaining stocks of TBT paints on smaller boats. Stewart and Thompson (1994) found TBT in sediments from sites with intensive shipping activity to remote coastlines to a deep, sedimentary basin. They concluded that TBT contamination is still extremely widespread despite improvements that have been made over the past decade.

7.4. Wood Preservatives

Wood preservatives are used to prolong the life of wood products used in construction materials such as pilings, piers, docks, fence posts and railway ties. They are considered pesticides. The greatest concern about wood preservative contamination used to be from plants producing these products; however, best practices have resulted in an estimated 90% decrease in the discharge of contaminated effluent (Johannessen and Ross 2002). No wood preservation plants are found in the central coast. The main source of wood preservatives in the environment is non-point source run off 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 central coast are likely to be the main users of preserved wood products; however, other marine operations such as aquaculture facilities, log booms, private docks, and shore stabilization efforts will also contribute to this type of pollution.

Creosote is, by far, the most prevalent wood preservative used in BC (Figure 7-1). Other preservatives include Chromated Copper Arsenate (CCA); Pentachlorophenol (PCP); and two similar chemicals, Ammoniacal Copper Arsenate (ACA) and Ammonical Copper Zinc Arsenate (ACZA) (Figure 7-1).

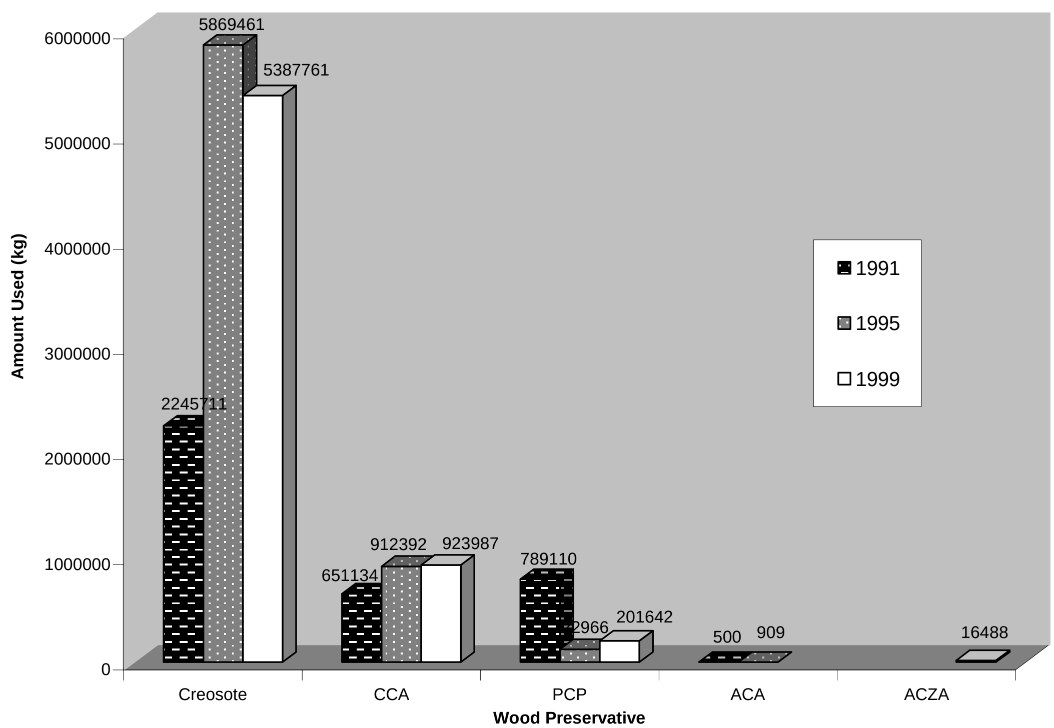

Figure 7-1. Wood preservative used in BC in 1991, 1995 and 1999. Data from (Johannessen and Ross 2002; ENKON Environmental Limited 1999).

Creosote is a complex mixture containing over 90% cyclic aromatic compounds, including PAHs (85%), phenolics (10%) and oxygen, sulphur and nitrogen heterocyclics (5%) (Johannessen and Ross 2002). Only a small fraction of creosote is mobilized by contact with water; however, creosote exposed to solar radiation is more mobile and can drip into the aquatic environment (Hutton and Samis 2000). The toxicity of the water soluble fraction of creosote is higher than would be expected from the PAH content. 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 also likely add to the toxicity of creosote (Padma *et al.* 1998).

There is also 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 7-1). PCP is a complex group of chlorinated hydrocarbons of various carbon chain length, that is used in over 2,000 commercial products. Its complexity and widespread usage makes sources of PCP in the environment difficult to pinpoint. 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). As noted previously (in Section 3.2.4), PCP concentrations in the livers of copper rockfish living near a salmon farm in BC were elevated but did not differ from a non-aquaculture site that also had sources of PCP contamination (Levings 1994). Sources of PCP contamination were impossible to pinpoint due to its widespread use. Yunker *et al*. (2002) found evidence of PCP in many harbours sampled, including Campbell River. They also found evidence of PCP from remote locations in Clayquot sound and the Queen Charlotte Islands, indicating widespread contamination from wood preservatives in BC (Yunker *et al.* 2002).

CCA is the next most common wood preservative used (Figure 7-1). Copper, chromium and arsenic are all toxic heavy metals (Johannessen and Ross 2002). CCA is used in the construction of marine docks, pilings and bulkheads; however, current data are insufficient to quantify leaching rates of CCA into the environment (Hingston *et al.* 2000). Synergistic toxicity of copper and chromium is believed to make CCA more toxic than its component parts (Cox 1991).

No information on the effects of ACA or ACZA is available though component metals are known to be toxic. Relative use of these preservatives is very low (Figure 7-1).

7.5. Synthesis

The central coast is composed of coastal communities in which boating represents a major form of transportation. Many commercial and recreational activities in the central coast require boat transportation. Ships also transit through the central coast. Ship-board pollution is associated with all forms of boating and cumulative impacts may be significant. For instance, small oil leaks from all vessels frequenting the central coast are likely to represent a greater source of oil pollution than is associated with infrequent major oil spills. Cumulative impacts from small vessels, such as recreational fishing boats and pleasure craft, may be more difficult to control than pollution from large boats. Programs to educate individual boaters on how to take responsible action could prevent oil and other forms of pollution. Impacts of contamination from boats are expected to be greatest where boats are found in the highest concentration, namely harbours and marinas. Consequently, harbours and marinas should be seen as small scale hotspots for some contaminants. Of particular concern are persistent chemicals such as PCP and TBT, though regulations limiting the use of both are already in place. More information about the distribution of chemicals as well as creosote-impregnated logs in the central coast would be of use to evaluate contamination levels. This could be achieved through stricter regulations or reporting requirements by governing agencies.

Box 7.1 Additional Information on Shipping, Boating and Related Issues

- Introduced species: Shipping activities can introduce non-native species through ballast water and hull fouling. The number of reported marine invertebrate introductions to the Strait of Georgia per decade closely correlates to the number of foreign ships arriving in the Port of Vancouver. Ballast water in ships using the Port of Vancouver and other ports in the Strait of Georgia contained up to 13,000 invertebrates/m^3. Mandatory ballast water exchange protocols have been put in place to reduce the number of alien species introduced through ballast water but it is not completely effective since some ships are exempt from the requirement (Levings *et al.* 2002b).
    - For a review of marine and estuarine alien species in the Strait of Georgia, refer to (Levings *et al.* 2002b).
    - A similar review has not been completed for the central coast.
    - http://www.psat.wa.gov/shared/backgrnd.html
    - http://answest.fws.gov/
    - http://ballast-outreach-ucsgep.ucdavis.edu/Newsletters/Newsletter%20Main.html.

- Individual boaters need to do their share to prevent pollution. For an excellent guide to green boating, refer to: http://www.georgiastrait.org/greenboating.php.

8. Forestry and Forest Products

Forestry is an important industry in the central coast. The central coast is located in the Coast Forest Region (formerly the Vancouver Forest Region). Forest districts located in the Coast Forest Region that fall within the central coast include Campbell River, Port McNeill and Midcoast; however, the Coast Forest Region also includes areas in the north coast and Queen Charlotte Islands, as well as parts of the Lower Mainland, Sunshine Coast and Southern Vancouver Island. Total revenue from the entire Coast Forest Region was approximately 348 million dollars in 2001, representing 27.7% of total forest revenue in BC (Ministry of Forests 2001). Many forestry companies hold tree farm licenses in the central coast LOMA (Figure 8-1).

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, such as damage to fish habitat and sedimentation, are not covered in this report. See Box 8.1 for some information sources on other topics.

8.1. Pulp and Paper Mills

There are two pulp mills in the central coast: Western Pulp Limited Partnership in Port Alice, and the Norske Skog Canada Mill in Elk Falls, near Campbell River. Both discharge effluent into the marine environment (Table 8–1). A pulp mill operated in Ocean Falls during the period 1917-1980 but is now closed (Kay 1989). There are also two mills in the North Coast: Skeena Cellulose near Prince Rupert, and Eurocan in Kitimat.

Table 8-1. Pulp mills in the central coast (Grant and Ross 2002).

Mill Name	Location	Type	Discharge ($m^3 \bullet d^{-1}$)	Bleach Used
Norske Skog Canada	Elk Falls	Kraft, CTMP	167,837	100% Chlorine Dioxide (ClO_2)
Western Pulp Limited Partnership	Port Alice	Sulphite	136,882	Chlorine

CTMP=Chemical Thermal Mechanical Pulp

Effluent from pulp and paper mills has represented a significant source of environmental contamination. Pulp bleaching (using liquid chlorine) and the condensation of polychlorinated phenoxyphenols were important sources of dioxins and furans in pulp mill effluent. 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).

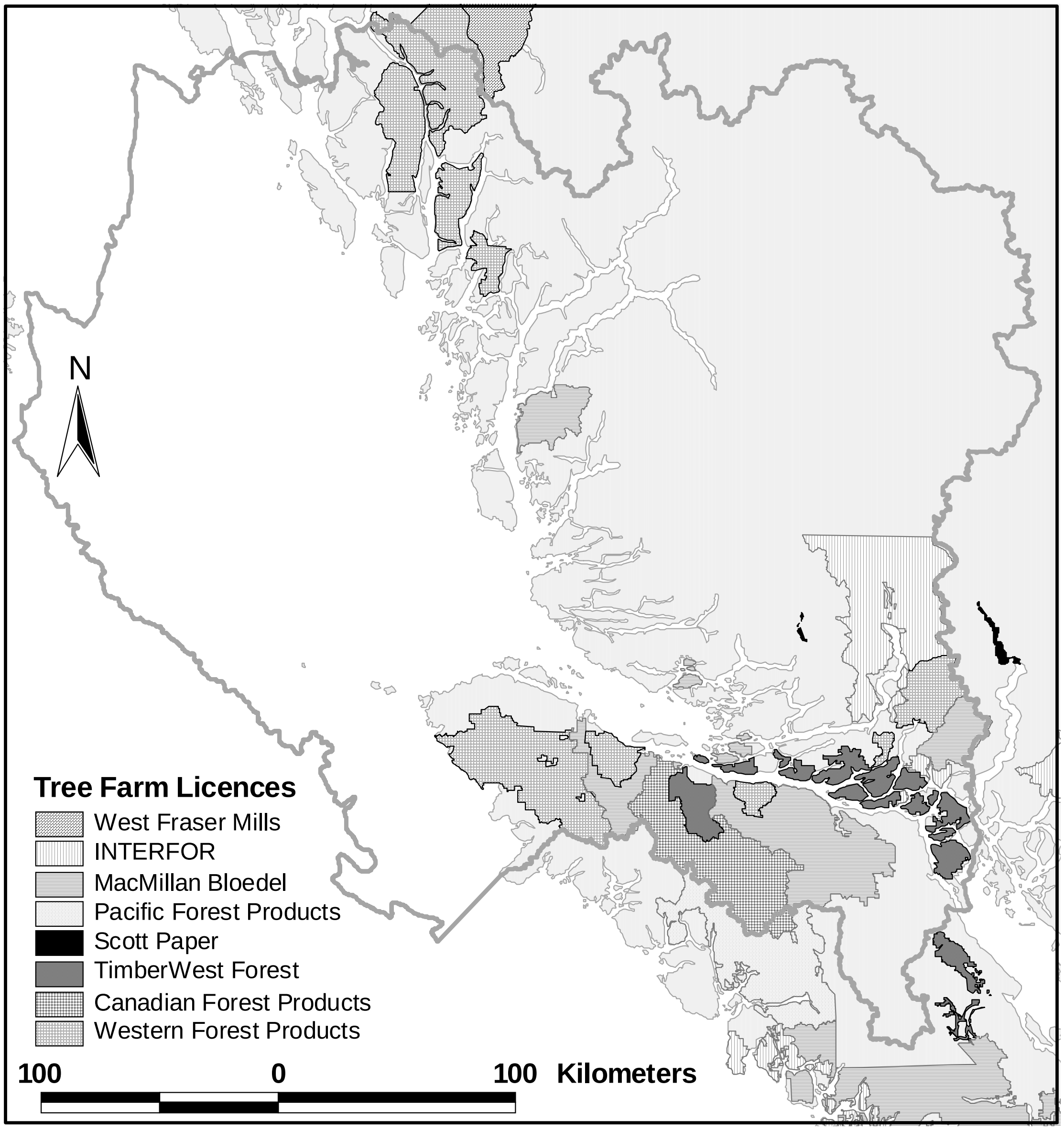

Figure 8-1. Tree Farm Licenses (TFLs) in the central coast of BC. TFLs are concentrated in the southern portion of the proposed central coast LOMA. Data from the BC Ministry of Forests as of 1997.

Both pulp mills in the central coast, like most mills in BC, have had secondary treatment of effluent since before 1993. In addition to secondary treatment, the Elk Falls mill also switched from elemental chlorine (liquid) to chlorine dioxide (gas) in the bleaching process to reduce toxicity of the effluent (Pierce *et al.* 1998). The Western Pulp mill in Port Alice still uses chlorine in the bleaching process (Table 8-1); however, sulphite pulp processing requires much lower bleaching levels than the kraft process does. Dioxin and furan levels in Port Alice mill effluent have always been well below mills using the kraft process (Yunker *et al.* 2002).

A 98.6% compliance with requirements of the Chlorinated Dioxins and Furans Regulation of the Canadian Environmental Protect Act (CEPA) have resulted in a decline of over 99% in the discharge of dioxins and furans from pulp mills. Currently, 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. 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, historically introduced contaminants 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. 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 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). Yunker *et al.* (2002) recommend continued monitoring of dioxins and furans in crabs and sediments in this area. They also call for surveys and monitoring projects that focus on quiescent zones where fine sediments with greatest proportions of contaminants are likely to settle.

The pulping process used at the Port Alice mill has never produced the high concentrations of dioxin and furans that other mills did. Sediment samples from 1987/88 showed much lower concentrations of these contaminants 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).

In addition to pulp and paper mills, other sources of dioxins and furans exist in the central coast area. Some of these other sources have also been eliminated or curtailed such as the discontinuation of leaded gasoline, reductions of PCP-based wood preservatives and PCP-contaminated wood chips. However, other sources such as municipal wastewater discharge, waste incineration, combustion, and storm water runoff persist (Bright *et al.* 1999). See Section 10.2.2 for more information.

Emerging contamination concerns from pulp and paper mill operations include sublethal effects of chronic exposure to some of the natural plant ingredients found in pulp. Possible endocrine disrupting compounds in pulp mill effluent include natural plant hormones, heavy metals, chlorinated compounds, and surfactants such as alkylphenol ethoxylates (Johannessen and Ross 2002). 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. Though 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). More research into these matters is required in order to fully understand the scope of the problem.

8.2. Pesticides

Pesticides used in forestry are of concern if they are applied directly or if they are allowed to drift onto the surface of aquatic ecosystems, particularly anadromous fish habitats. Pesticides are defined as agents used to prevent, repel or mitigate pests. They can be grouped according to the type of pest they control such as herbicides, insecticides and fungicides (Norris *et al.* 1983). Only two herbicides are used in forestry in the central coast: glyphosate (Vision®) and triclopyr (Release®). No insecticides are used (Personal communication, Conrad Berube, Senior Pest Management Officer, BC WLAP). Information on amounts of herbicides used in the central coast is not easily accessed.

Glyphosate is a broad-spectrum, nonselective systemic herbicide sold under the trade names including 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, especially isopropylamine salt but also trimethylsulfonium salt. Glyphosate is generally distributed as water-soluble concentrates and powders (EXTOXNET 2003a), and is applied at a rate of application of up to 4.48 kg/Ha (Norris *et al.* 1983).

Glyphosate is highly soluble in water (Norris *et al.* 1983), and is moderately persistent in soil, having an estimated average half-life of 47 days. 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, 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, and volatilization or photodegradation losses will be negligible. 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 2003a).

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 slightly toxic to aquatic invertebrates (Table 8-2). It is considered to have a very low potential to accumulate in aquatic animals (EXTOXNET 2003a).

Table 8-2. 96-hour LC_{50} toxicity measurements of pesticides used in forestry in the central coast (EXTOXNET 2003c; EXTOXNET 2003a; EXTOXNET 2003b).

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 LC_{50}

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 2003c).

In natural soil and in aquatic environments, the ester and amine salt formulations 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 mobile. 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 2003c).

The parent triclopyr compound and its amine salt are considered nontoxic to fish and to the aquatic invertebrate Daphnia, a waterflea (Table 8-2). 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 2003c).

Glyphosate is applied either by ground or aerial broadcast application while triclopyr is only licensed for ground application in BC. 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 streams are fish-bearing and on theapplication method. No buffer zone is required for individual application of herbicides (Samis *et al.* 1992). These regulations are considered sufficient for preventing glyphosate and triclopyr from entering water bodies if they 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. There is no information about the behaviour of these herbicides in the marine environment.

Historically, attitudes about pesticide use in forestry were less conservative. In 1957, 156,000 acres of forest were sprayed with the pesticide DDT to control an outbreak of black-headed budworm that was defoliating forests on Vancouver Island. Spraying took place, from an airplane, between June 10-20, 1957, in the Englewood—Port Hardy—Port Alice region. One pound of DDT was mixed in a solution containing an emulsified solvent and diesel oil and applied at a rate of one American gallon per acre. Streams that were sampled had toxic concentrations of DDT several days following spraying. Coho fry, and trout, to a lesser extent, suffered high mortalities, as did fish-food organisms. Ironically, the budworm infestation also declined in areas that had not been sprayed, suggesting that the use of DDT had been unnecessary (Hourston 1958). No recent investigations of this event have been made.

8.3. Fire Control Chemicals

In addition to forestry, forest fires can also impact aquatic environments and fish habitat through the loss of forest cover, increased siltation, soot and ash smothering, introduction of PAHs and perhaps fire suppression or retardant chemical. 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). In 2000-01, only 110 Ha of forest burned in the entire Vancouver Forest Region, though the 10-year average is 1,556 Ha per year. This represents only 6.7% of the total area burnt in BC in 2000-01. Fires in this region are also small in size (Ministry of Forests 2001).

The forest districts in the central coast area (Campbell River, Port McNeill and Midcoast) have had relatively low fire activity over the past ten years (Table 8-3). In addition, fire-retardant dispersed from airtankers have been used on a small proportion of fires in the region (~4%). Despite the low usage rates, fire retardants are a concern because their acute toxicity, particularly to fish when it is applied to water, is very great. There is little information about the mobility or persistence of fire-retardant chemicals, or on the behaviour of the 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.

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 include mixtures of salts, such as diammonium phosphate, ammonium sulphate, ammonium phosphate, or ammonium polyphosphate, as the active fire retardant (Johannessen and Ross 2002). The toxicity of the 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). Toxicity is however, greatly increased in the long-term fire retardants with the addition of corrosion inhibitors necessary to prevent corrosion of storage containers and fire fighting equipment. Sodium ferrocyanid is often used as a corrosion inhibitor in products like Fire-Trol® (Johannessen and Ross 2002). When sodium ferrocyanid is exposed to sunlight it produces cyanide. Therefore, even very dilute solutions of sodium ferrocyanid is highly toxic to fish (Norris *et al.* 1983; Little and Calfee 2000). The addition of sodium ferrocyanid to the fire retardant increases its toxicity by 100-fold in rainbow trout (Little and Calfee 2000).

Table 8-3. Number of fires and fire retardant (FR) used in the past ten years (1993-2002) in the Vancouver Forest Region and Districts V8-V10 (Personal communication, G. Bell and P. Taudin-Chabot, BC Ministry of Sustainable Resource Management, 2003).

	Campbell River District (V8)	Port McNeill District (V9)	Midcoast District (V10)
Total # Fires	363	163	99
Area burned (Ha)	255	250	1040
Total # Fires using airtankers	5	5	14
Total FR (Litres) used over 10 years	475,331	79,729	270,318

8.4. Anti-Sapstain Compounds

Anti-sapstain chemicals are used by lumber mills to prevent fungal growth on lumber. Anti-sapstain chemicals used in BC during the 1990s include 2-(thiocyanomethylthio)benzothiazole (TCMTB), didecyl dimethyl ammonium chloride (DDAC), 3-iodo-2-propynyl butyl carbamate (IPBC), sodium carbonate, two forms of borate (disodium octaborate tetrahydrate and disodium tetraborate decahydrate) and Azaconazole. TCMTB, IPBC, and DDAC have been shown to be highly toxic to salmon. 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 have been reduced to very low levels or have been 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). No data were found on the extent of anti-sapstain chemical use specific to the central coast.

8.5. Log Booming and Log Storage

Coastal waters are often used as a low cost means of transporting and storing logs. Many nearshore log sorting and storage facilities exist in the central coast, both in intertidal and deeper water. Log storage facilities cause physical, chemical and biological disturbances (Williamson *et al.* 2000). Impacts include changes to the infaunal community by physical compaction of the sediment that brings the anoxic zone closer to the surface, elimination of aerobic benthic infauna in areas where there is a continual deposition of bark, and damage to eelgrass beds due to shading and physical alteration (Williamson *et al.* 2000; Waldichuk 1979). Ocean dumping of bark and wood debris under sawmills also leads to the build up of wood debris on benthic habitats.

Chemical leachates are also a concern. 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 high carbon content, strong colour, and high concentrations of tannins, lignins, resin acids and phenolics. This leachate can be toxic to aquatic life; however, very little information about its impacts are known (Frankowski and Hall 1999). 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 (Waldichuk 1979). More information and field studies to test the effects of log booms on the marine environment in general are necessary.

8.6. 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. PCBs are a persistent environment contaminant (Section 10.2.1).

There are also potentially numerous contaminated sites associated with logging camps in the central coast. Sources of contaminants in logging camps include PAHs from gasoline at fuel refilling sites, batteries, pesticides, and other chemicals.

8.7. Synthesis

The forestry sector generates chemical wastes and has historically been considered a major polluter of coastal environments in BC. Increased regulations on pulp mill effluent and the release of dioxins and furans has greatly improved this situation; however the legacy of past contaminants remains, since many are highly persistent. Areas with high currents and/or low sedimentation rates, such as around Campbell River, are of particular concern since such contaminants may still be bioavailable. Herbicides used in forestry are regulated and represent a poorly understood, yet probably low risk in BC. Though large-scale risks may prove to be minimal, greater research into contamination from flame retardants, leachates from log storage, and endocrine disrupting chemicals and derivatives from pulp mills should be investigated.

Box 8.1 Additional Information on Pollution Impacts Related to Forestry

- Extensive literature exists on impacts of forestry; however few information sources specific to the central coast exist. For more information about impacts of logging on salmon and habitat in the central coast, refer to: (Harvey and MacDuffee 2002).
- Sedimentation in fish habitat is a major pollution concern associated with forestry activities. There is much literature on this subject. One source is: (Birtwell 1999).

9. Mining

There is a long history of mining in the central coast, concentrated on the north end of Vancouver Island (Figure 9-1). The first real mine was a coal mine near Fort Rupert, 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. Copper mining came next, first with the Yreka Copper Mine, located west of Neroutsos Inlet. The Yreka Mine operated periodically between 1902 and 1967 and disposed of mine tailings into Neroutsos inlet, immediately south of Rupert Inlet. Following this, the Utah Construction and Mining Company established the Island Copper Mine on the north shore of Rupert Inlet in 1971. There are also active mines in the central coast, including the Quinsam Coal Mine and the Myra Falls Metal Mine (Figure 9–2).

9.1. Island Copper Mine (Rupert Inlet)

Earlier exploration of the North Island area had found more than 254 million tonnes of ore containing an average of 0.52% copper plus 0.017% molybdenum metals. The Island Copper Mine, an open pit mine, opened on the shores of Rupert Inlet (Figure 9–3) and 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) and 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. It producing some 358 million tonnes of tailings that were discharged into Rupert Inlet through an underwater tailings placement system (Poling *et al.* 2002).

Though this type of mining 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 (Table 9-1), extensive monitoring of Rupert Inlet was required. Long-term data sets from a year before the mining began in 1971 until four years after its closure in 1995 exist. The story of the Island Copper Mine is covered in detail elsewhere (Poling *et al.* 2002).

Table 9-1. Potential environmental impacts of marine disposal of mine tailings (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

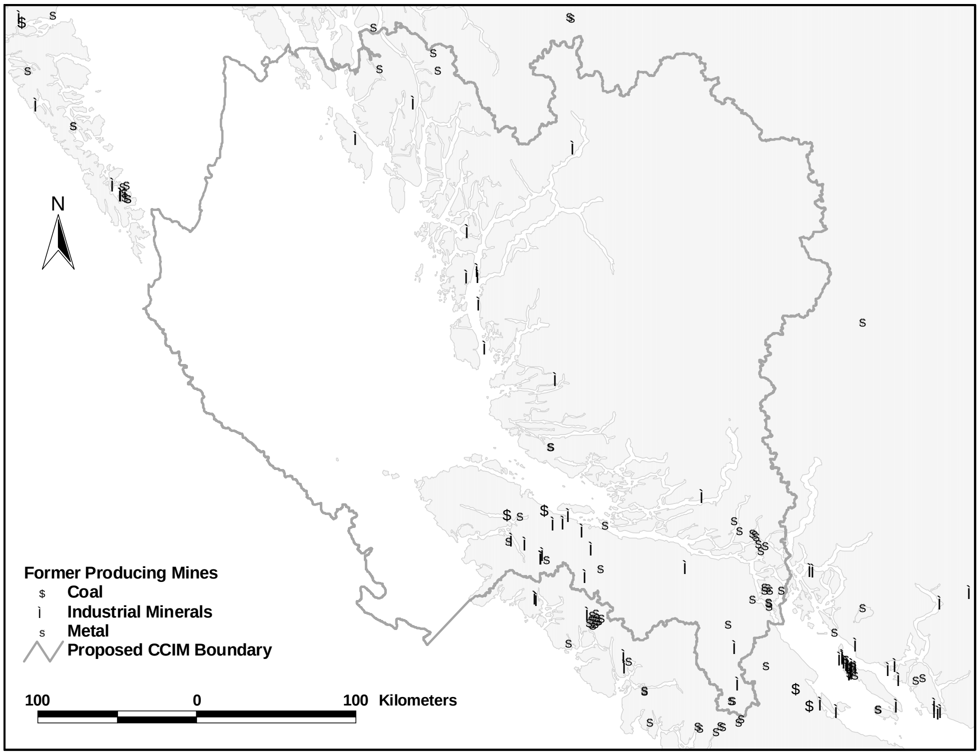

Figure 9-1. Historic mine sites of the central coast. The Island Copper Mine, near Quatsino Sound, is the most recent mine that was closed (in 1995). Data from the BC Ministry of Energy and Mines.

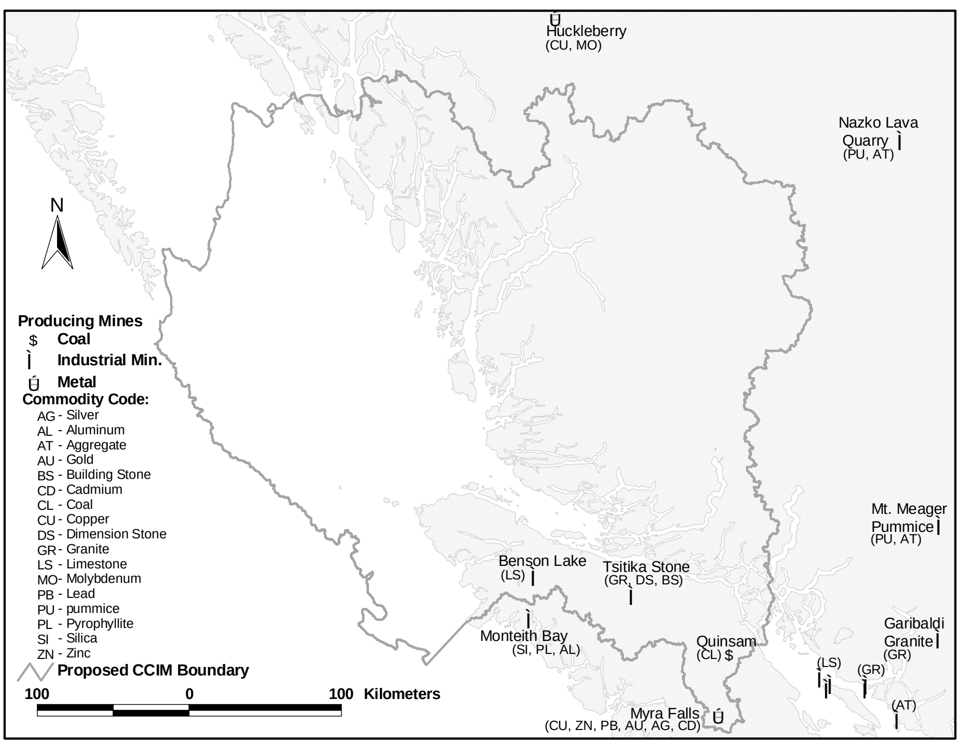

Figure 9-2. Current mines in the central coast. Two mines of concern within the proposed central coast LOMA are Quinsam Coal Mine and the Myra Falls Metal Mine. Data from the BC Ministry of Energy and Mines.

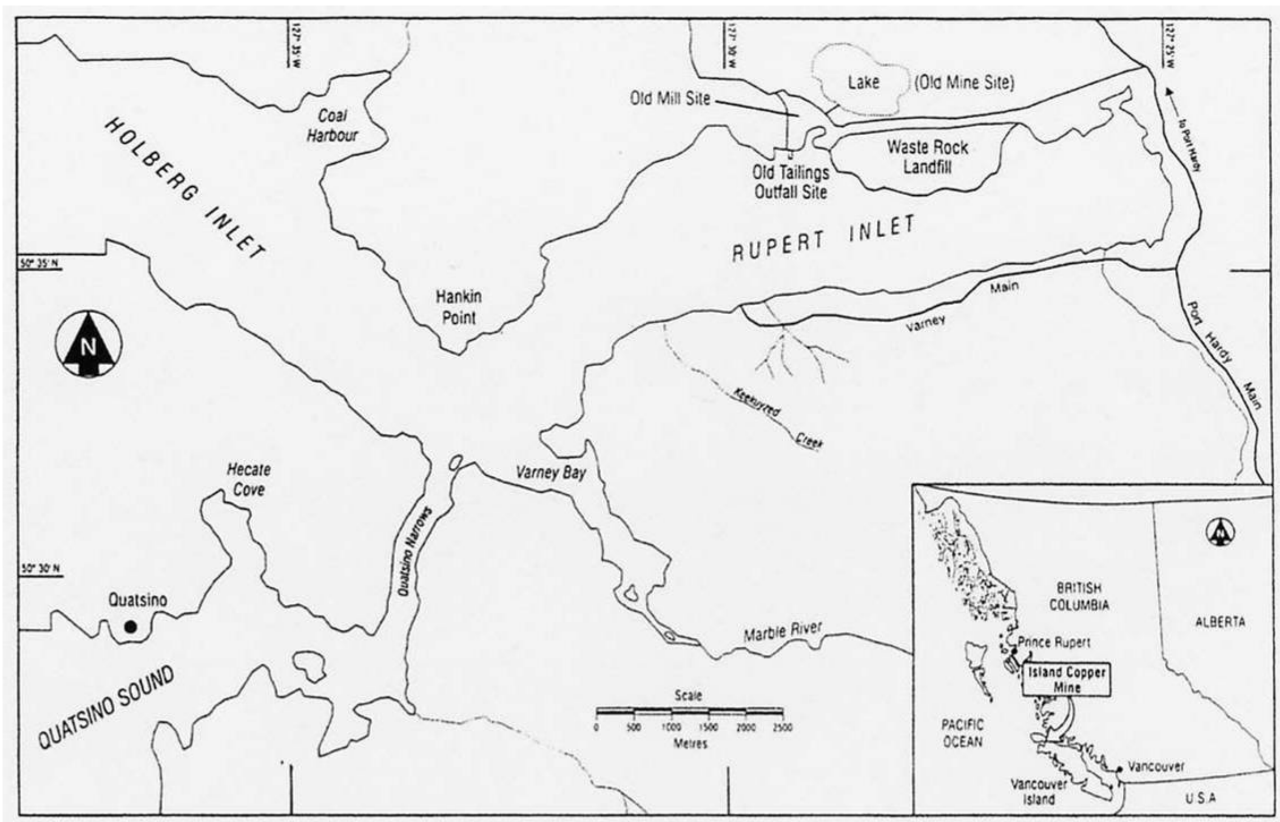

Figure 9-3. Location of Island Copper Mine (Poling *et al.* 2002).

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

- 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 behaviour 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 (greater than 20 cm/yr) caused immediate and slow losses of species in buried sediments; 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, consistent with "sustained ecological succession." The rapid recovery of the sediments in Rupert Inlet is encouraging given that ecological communities from tailings and reference sites were still distinguishable 12 years after mine closure at another mining site in Howe Sound (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.

Most pertinent to this report is the information on toxicity of effluent and bioaccumulation of metals. 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, with 100% survival almost always observed.

In the early 1970s, there was concern that the tailings might release biologically active toxic trace elements such as copper and arsenic. Many organisms were tested for bioaccumulation of metals such as copper, cadmium and zinc, throughout the operation of the mine. Data on trace metals spanning 20 years for the following species are available: rockweed (*Fucus*), eelgrass (*Zostera*), mussels (*Mytillus edulis*), butter clam (*Saxidomus giganteus*), littleneck clam (*Protothaca staminea*) and Dungeness crab (*Cancer magister*). There were few instances where trace metals exceeded reference levels. 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. There are indications that metal concentrations, particularly copper, had returned to background values in 1997 (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, 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. Dungeness crab in test and reference areas fluctuated synchronously. Another 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 mine was flooded with seawater and capped with freshwater, creating a meromictic lake. This is considered to represent a passive treatment system for ARD. ARD problems, as have been found in the Britannia Beach Mine site in Howe Sound, are not expected, though the possibility remains a concern (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).

9.2. Quinsam Coal Mine (Campbell River)

Quinsam Coal Mine opened as an open pit mine in 1987, went underground in 1990 and has been fully underground since 1994. The mine produces approximately 360,000 tonnes of coal per year and employs 45 people. A coal preparation plant is associated with the mine. Coal is loaded onto barges and delivered directly to Vancouver or Seattle, or it is barged to a ship loading facility on Texada Island (Quinsam Coal Corporation 2003).

The Quinsam Coal Mine is on the Quinsam River which drains 280 km^2 of land on the east coast of Vancouver Island. It 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, with these changes being attributed to the mine. Despite the 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 (Ministry of Environment and Environment Canada 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).

9.3. Myra Falls Mine (Strathcona Park)

The Myra Falls Metal Mines are located in the south-west corner of the central coast 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 January 2002, proven reserves were 6.47 metric tonnes, grading 7.5% zinc, 1.4% copper, 0.5% lead, 1.4 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 (Mining Technology 2003).

ARD is described as the single largest environmental problem facing the mining industry today (O'Kane *et al.* 1997). ARD is caused when sulphide minerals in rocks and mine tailings are weathered and exposed to water and air. Sulphide weathering produces acidic compounds that become dissolved in water. Since many metals become highly soluble under acidic conditions, metal leaching often occurs as a result of ARD. ARD and metal leaching are concerns at most metal mines and some coal mines, where high concentrations of sulphide minerals and trace metals are exposed with an increase in the amount of rock surface exposure. 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. Dissolved metals such as copper, zinc, and cadmium can be toxic to fish and animals, and can adversely affect environmental health, as can the low pH levels caused by the ARD itself (Ministry of Water, Land and Air Protection2003a).

Studies have been undertaken to monitor ARD and to develop a mitigation plan for the Myra Falls Mines (Desbarats 2002; O'Kane *et al.* 1997; O'Kane *et al.* 2001). Desbarats (2002) studied flow from the mine and found that though pH was near neutral for most of the year, it would drop sharply to 2.2 with the first autumn rains. The mine discharge is directed to treatment and settling ponds. From there, once it has reached regulatory standards, the mine water is discharged to Myra Creek and flows into Buttle Lake. Buttle Lake eventually drains via Campbell River to Discovery Passage (Personal communication, Alexandre Desbarats, 2003). O’Kane *et al.* (1997; 2001) have been investigating ways to mitigate ARD from Myra Falls using a soil cover system that will function as an oxygen ingress barrier, a water infiltration barrier, and a medium for establishing vegetation cover. ARD and metal leaching issues relating to the Myra Falls Mines, as well as from the Quinsam Coal and Island Copper Mines, should be followed closely to ensure that environmental effects do not occur in downstream environments in the central coast.

9.4. Synthesis

Mining can have serious and lasting environmental effects; therefore, federal and provincial regulations require careful monitoring and extensive mitigation and reclamation programs. The three mines of primary concern in the central coast are the Island Copper Mine at the north end of Vancouver Island, and the Quinsam Coal Mine and Myra Falls Metal Mines at the southern boundary of the central coast. Abundant data exists about Rupert Inlet, Quatsino Sound, and the environmental effects of the Island Copper Mine. Although copper levels are still elevated in the sediment, the copper is not bioavailable. Biological communities also appear to have been either not affected by mine operations or are recovering now that operations have ceased. Continued monitoring should be carried out to ensure that mine tailings do not shift or slump to cause new burial and defaunation as was the case at an old mine site in Alice Arm, on the North Coast (Burd *et al.* 2000). ARD issues should be followed closely from Island Copper, Quinsam and Myra Falls to ensure that environmental effects related to acidic conditions or toxic metal leachates do not occur.

Box 9.1. Additional Information on Impacts of Mining and Related Issues

- For the complete story of the Island Copper Mine environmental monitoring, refer to: (Poling *et al.* 2002).

- For additional information on submarine tailings and disposal for mines, refer to: (Ellis *et al.* 1995).

- More information on Acid Rock Drainage (ARD) in BC can be found at:
  - http://wlapwww.gov.bc.ca/soerpt/9mitigation/minesites.html

- For information on environmental effects of ARD from Britannia Mines on components of the marine environment in Howe Sound:
  - (Barry *et al.* 2000; Grout and Levings 2001; Marsden *et al.* 2003)

10. Other Environmental Contaminants

Many different sources of chemical contaminants to the central coast area exist including local, regional and global sources. Contaminants can be transported great distances in the atmosphere from their source of origin. Chemical properties such as persistence and volatility or adsorption onto air-bourne chemicals enable chemicals such as PCBs, dioxins, furans, PAHs, heavy metals (particulate cadmium and gaseous mercury, copper, and lead) and organic compounds such as pesticides (i.e. hexachlorocyclohexane, toxaphene, DDT, lindane) to be transported globally. Some of these harmful chemicals are no longer used in North America and Europe. These are often termed “legacy” compounds. Others continue to be in use worldwide, so that local sources add to global sources, making the origins of contaminants difficult to pinpoint. In addition to these “old” contaminants, there are many new persistent chemicals including brominated flame-retardants, polychlorinated napthalenes and chlorinated paraffins, that are becoming more relevant (Moore *et al.* 2002). Knowledge about the effects of these new compounds is often very scarce and they tend to be poorly regulated to date (Grant and Ross 2002). Metals can also be transported great distances, though most metal pollution tends to remain close to the pollution source (Macdonald *et al.* 2003). This section provides additional information on some of the more problematic classes of chemicals.

10.1. Long-Range Transport of Contaminants in the Pacific

Worldwide transport of chemicals began to receive attention when persistent chemicals began to be found in arctic environments that are much removed from the sources of the contaminants. The Arctic, as well as alpine lakes and glaciers, have 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 their condensation in colder climates. Atmospheric transportation is very complex and varies with each chemical congener. The chemical’s properties, such as it’s tendency to partition onto water, particles, air, snow or lipid, as well as several processes such as solvent switching and solvent depletion, will determine how chemicals are transported in the environment (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 across the Pacific and shown to take a week to be transported across the Pacific (Macdonald *et al.* 2003). As a result of this general air pattern, pollutants from Asia have been detected in Washington State (Jaffe *et al.* 1999). Following bans or restrictions of PCBs and DDT, their concentration in the North Pacific decreased rapidly. However, this trend no longer seems to hold in many 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 contaminants (Macdonald *et al.* 2003). Currents from the south are thought to transport contaminants to BC (Pierce *et al.* 1998). Chemicals that partition strongly into water, such as β-HCH, will load into water through rainfall, fog or air-sea exchange, rather than remain in the atmosphere. Transport via ocean currents will take much longer to transport contaminants from place to place than transportation in air. While air may take a period of days to weeks (metres per second), movements in the ocean will be measured in years (cm per second) (Macdonald *et al.* 2003). Volumes moved by ocean currents as opposed to the atmosphere can be quite great (Personal communication, Robie W. Macdonald, Fisheries and Oceans Canada, 2003).

One reason for the great concern over these chemicals is due to their ability to biomagnify up the food chain to apex feeders and the negative effect this has on the health of those animals. 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. For instance, a study in Alaska showed that salmon transported POPs from the open ocean into rivers and lakes where they spawned. Local, non-anadromous fish showed elevated concentrations of POPs relative to fish in a nearby lake with no anadromous fishes (Ewald *et al.* 1998). Contaminants accumulated in salmon will therefore be deposited in aquatic environments. They may also be transferred to terrestrial ecosystems through consumption by beers, wolves and other predators and scavengers of salmon.

10.2. 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 contaminants are declining or are stable; however, contaminants still in use in other parts of the world can be transported long distances and deposited in the environment in areas much removed from the source. Another issue of concern is contaminated sites that will take many years to remediate.

POPs are of concern because of their toxicity, persistence, and potential for bioaccumulation within organisms. POPs are usually halogenated, lipophilic and hydrophobic; therefore, they tend to accumulate in lipid tissues of organisms. They are also known to biomagnify up the food chain into apex predators. POPs are also semi-volatile allowing atmospheric transportation before deposition.

10.2.1. PCBs

Polychlorinated biphenyls (PCBs) are a class of synthetic chlorinated hydrocarbons that have been extensively used in plastics, inks, paints, pesticides, and as dielectric, hydraulic, high-temperature lubricating and heat transfer fluids. PCBs have not been manufactured in North America since 1970; however, they are still in use, particularly in electrical equipment. 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. The forestry sector is the largest user of PCB-containing electrical equipment in BC; BC Hydro is second (Kay 1989).

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 extremely stable, with extensive half-lives in the environment. PCBs are lipophilic, hydrophobic, and are not readily metabolized; therefore, they have high bioaccumulation potential. They have 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.* 2002).

10.2.2. Dioxins and Furans

Dioxins (polychlorinated dibenzo-p-dioxins, PCDD) and furans (polychlorinated dibenzofurans, PCDF) have no intentional uses but are rather the byproducts of combustion processes including municipal and industrial incineration, fires, automobiles; production of chemicals such as pesticides pharmaceuticals and domestic products; industrial bi-products, i.e. from chlorine bleaching in pulp mills and combustion of wood chips with wood preservatives; and natural sources such as forest fires and volcanic activity. Limits to dioxin emissions from pulp mills greatly reduced dioxins contamination in BC (see Section 8.1); however, numerous sources in BC, as well as abroad, still exist.

Dioxins and furans are extremely long lived (half life from 10-12 years to centuries), very toxic, and bioacculumulate in animals and humans (Grant and Ross 2002). Dungeness crabs have been used as indicator species to biomonitor dioxins and furans in BC. They are ideal biomonitors because they have a limited ability to metabolize chlorinated contaminants so levels often mirror those in surface sediments (Yunker *et al.* 2002).

10.2.3. PAHs

PAHs, or Polycyclic Aromatic Hydrocarbons, are a family of organic molecules comprising two or more fused aromatic, or benzene, rings. They were discussed in section 4.4 since one source of PAHs is oil spills and chronic oil pollution. Other sources of PAHs include fuel combustion, aluminum smelting, creosote-treated products, pulp and paper mills, sawmills, and metallurgical and coking plants.

The chemical properties depend on the structure and molecular weight of the particular PAH. They are generally relatively persistent, particularly after burial in sediments, have low vapour pressure, and low water solubility. Once released into the environment, PAHs associate with particles and are transported in the air until they are deposited onto water or soil surfaces. In the marine environment, sediments are a final sink for PAHs unless the sediments are disturbed and PAHs are remobilized. Not all PAHs bioaccumulate in all organisms as many organisms have some ability to metabolize them. They are, however, known to be carcinogenic and cause liver tumours in fish (Grant and Ross 2002).

10.2.4. 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). Several forms of pesticides have already been discussed in this report including antifouling paints such as TBT and copper compounds on boat hulls and aquaculture nets, anti-sea lice pesticides used in salmon farming, and pesticides and fungicides used in forestry. Most pesticides used in the world are applied to terrestrial environments and applied in urban, forestry 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 in water or atmospherically from great distances. Although pesticides in use today are less detrimental than OC pesticides, many are still moderately persistent, bioaccumulative and toxic (Grant and Ross 2002).

OC pesticides including aldrin, dieldrin, chlordane, DDT, alpha-hexachlorocyclohexane (α–HCH) and toxaphene are now largely banned. They are still of concern because they are highly persistent, bioaccumulative and toxic. Many OC pesticides are endocrine disruptors, carcinogenic, and cause immunosuppression (Grant and Ross 2002).

Despite their discontinuation in North American, new sources remain and are transported to BC. For instance, after DDT was banned in the 1970s, its concentrations in bird eggs near DDT sources in the

Strait of Georgia declined (Whitehead 1989). In contrast, concentrations in populations in remote locations have not declined due to long-range atmospheric transport from countries that continue to use these chemicals (Elliott *et al.* 1989; Addison 1998).

10.3. Poorly Regulated and New POPs

200-1,000 new chemicals are released into the environment globally each year. The only requirement for a company manufacturing or importing a new chemical into Canada is that it must notify Environment Canada to specify if the company has any information on the chemical's toxicity or environmental impacts. Full toxic effects of new chemicals, including synergistic effects among chemicals, are rarely known. Once again, chemicals that are toxic, highly persistent, and bioaccumulate are of greatest concern. Many of them have been found to be carcinogenic and endocrine disruptors (Grant and Ross 2002).

Compounds with these properties can be found in a multitude of products that people use each day without any thought to environmental effects. Uses include surfactants in detergents and soaps; flame retardants used in products ranging from electronic components in TVs and computers to textiles; paints and inks; sealants; oil and gas additives; chemicals in plastics; refrigerants; pesticides; stain repellants (such as Scotchguard^{TM}); fire fighting foams; personal care products such as shampoos and perfumes; cleaning products; and pesticides. For more information on several categories of these poorly regulated chemicals see Table 10-2. Also see (Grant and Ross 2002; Johannessen and Ross 2002).

10.4. Trace Metal Contamination

Although metals are natural elements in the environment, many anthropogenic sources increase metal concentrations (Table 10-1). Common anthropogenic sources to the marine environment include mines and metal refineries, landfill leachate, sewage treatment plants, urban runoff and atmospheric deposition. It can sometimes be difficult to determine if metal concentrations are from natural or anthropogenic sources if background levels of metal are not available. Some metals such as copper (Cu), zinc (Zn) and iron (Fe) are essential elements necessary for nutrition of animals and growth of plants. Other metals, such as mercury (Hg) and lead (Pb), are not. While all metals can be toxic at high concentrations, some such as cadmium (Cd), mercury, copper and lead are particularly toxic even at low concentrations. Metals are not subject to bacterial degradation and so are essentially permanent additions to the sea, though deposition and uptake of metals does occur (Clark 2001). If an organism can not excrete a metal, it will accumulate in tissues and may biomagnify in predators. Toxicity, bioaccumulation and biomagnification vary greatly with the metal, the chemical form of each metal (not all forms are bioavailable), and the characteristics of organisms in contact with them.

Table 10-1. Worldwide emissions of trace metals to the atmosphere (in thousands tonnes per year) (Clark 2001).

Metal	Natural Sources	Anthropogenic Sources
Arsenic	12.0	18.0
Cadmium	1.3	7.6
Copper	28.0	35.0
Lead	12.0	332.0
Nickel	30.0	56.0
Zinc	45.0	132.0

10.4.1. Mercury (Hg)

Mercury is used in gold mining activities, antifouling paints, laboratory instruments, and electrical equipment. Major sources of anthropogenic mercury to the oceans include atmospheric emissions of elemental or oxidized mercury from coal-fired power plants; municipal medical and hazardous waste incinerators; and direct discharges from municipal and industrial wastewater. Municipal outfalls that contain mercury from dental and medical offices, and the light industry, are probably the most important local conduit of mercury into coastal environments (Macdonald *et al.* 2002). Elementary mercury is volatile and can have long residence times in the atmosphere, thus it can be transported great distances. It is insoluble in water, adsorbs to particles and settles out. Marine sediments are therefore a mercury sink. Methylmercury is the most bioavailable and toxic form that 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.

10.4.2. Copper (Cu)

Copper is used in electrical equipment, in alloys, as a chemical catalyst, in antifouling paints, as a wood preservative and in pesticides. Copper sources in the central coast that have already been discussed include the Island Copper Mine, antifouling paints for nets in salmon farms, and wood preservatives. Though copper is an essential mineral (i.e. it is necessary for the blood pigment in crustaceans), it is the most toxic metal after mercury and silver. It does not generally accumulate in food chains. Copper in seawater is usually in the form of $CuCO^3$ or $CuOH^-$, however it also forms complexes with organic molecules. Most copper is adsorbed onto particles and becomes incorporated into the sediments and may not be bioavailable (Clark 2001).

10.4.3. Cadmium (Cd)

Cadmium is widely distributed in the earth’s crust. It is usually associated with zinc and is often produced as a byproduct in zinc smelting. It has been used since the 1950s as a stabilizer in pigments in plastics, in electroplating, in solders and alloys, and in Ni-Cd batteries. Various sources include atmospheric deposition from impurities in zinc, coal, and iron, steel and phosphate, sewage sludge, and rinsing water of electroplating. Most cadmium is deposited into sediments on the continental shelf; however its fate is not altogether known (Clark 2001). Some marine organisms accumulate large concentrations of cadmium, though no environmental effects have been reported. Various toxic effects such as reductions in growth, immune impairment, renal dysfunction, and cancer have been noted in mammals (Grant and Ross 2002). It does not appear to accumulate in food chains (Clark 2001). Though cadmium is not volatile, it is associated with particles (Grant and Ross 2002). The long-range transport of cadmium has been observed in the North Pacific (Macdonald *et al.* 2002).

Canadian Food Inspection Agency, shellfish growers and Fisheries and Oceans have been concerned about elevated levels of cadmium in oysters cultured in BC that have exceeded some international acceptability limits. 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 (Kruzynski *et al.* 2002; Kruzynski 2000). An increasing trend of cadmium northward along the BC coast has been observed, so elevated cadmium levels may be of concern in the central coast, particularly around shellfish growing areas in fjords, upwelling areas, and areas with other local sources of cadmium. 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^{-1} dry weight kidneys) (Elliott and Scheuhammer 1997).

10.4.4. Lead (Pb)

Lead is used in metallic form and much of it is recycled and recovered; however, a greater amount is in compound form and is lost to the environment. Lead is widely used in leaded gasoline and 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 (Grant and Ross 2002). Anthropogenic sources of lead dwarf natural inputs (Clark 2001). Though many toxicological effects of lead exist, it is not thought to be particularly toxic to marine organisms (Clark 2001). Lead is generally detected in sediments near point sources including smelter, acid mine drainage areas, and urban and industrial sites (Grant and Ross 2002). Another source of lead, gun shot, has caused increased levels of lead in some estuaries. Consequently, some waterfowl have shown increased levels of lead and some bald eagles have contracted lead poisoning from scavenging contaminated waterfowl (Elliott and Harris 2001).

10.4.5. 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, levels are usually far below toxic concentrations (Clark 2001).

10.5. Endocrine Disrupting Chemicals

Many chemicals have been found to have the ability to modify, mimic or generally disrupt natural hormonal processes. These are termed endocrine disrupting chemicals. An endocrine disruptor is defined as: an external agent that interferes in some way with the role of natural hormones in the body. An agent might disrupt the endocrine system by affecting any of the various stages of hormone production and activity, such as by preventing the synthesis of hormones, by directly binding to hormone receptors, or by interfering with the natural breakdown of hormones (United States Environmental Protection Agency 1997). The endocrine system produces chemical signals in the form of hormones which control and regulate virtually every process in the body from development, growth, reproduction to immune response. Chemicals that disrupt the endocrine system can therefore show a wide range of effects such as developmental deformities, reproductive disorders, feminization of males or masculinization of females, immune suppression and behavioural changes. Endocrine disruption chemicals may be associated with sewage, pulp and paper mills, and mining and metals in the central coast. In addition, many of the persistent organic chemicals (both legacy and new) reviewed in this section are believed to have endocrine disrupting properties. Table 10-3 lists some major chemical classes associated with endocrine disruption. Section 7.3 discusses a well-known endocrine disrupter, TBT. Much more work on endocrine disruptors needs to be done.

Table 10-2. Characteristics, sources, and global releases of new, poorly regulated persistent contaminants (Grant and Ross 2002).

Minimally-Regulated Chemicals	Global Releases	Uses/Sources	Environmental Persistence	Bioaccumulation Potential	Toxicity
Polychlorinated Paraffins Short Chain (10-13 Carbons) Medium Chain (14-19 Carbons) Long Chain (20-30 Carbons)	300 kt/yr	• flame retardants • paints and sealants • additives in oil • placticizers	**High**	**High**	**High** short chain (C10-C13) • kidney and liver damage
Brominated Flame Retardants Polybrominated biphenyls (PBBs) Polybrominated diphenyl ethers (PBDEs)	 2 kt/yr 40 kt/yr	• electronic equipment (televisions & computers) • textiles • sewage sludge	**High**	**High**	**High** PBB: tetra/hepta PBDE: tetra/penta • effects liver and thyroid
Fluorinated Organic Surfactants Perfluoro-octane sulfonate	na	• stain repellents (Scotchgard) on textiles, carpeting • fire-fighting foams	**High**	**High**	**Moderate** • can promote tumors
Polychlorinated Naphthalenes 75 Compounds (1-8 Chlorine Atoms)	150 kt/yr	• insulation (ships and wires) • additives in engine oils • capacitor dielectrics • contaminants in PCB mixtures	**High**	**High**	**High** hexa, hepta, penta PCNs • Ah-receptor mechanisms
Alkyl-Phenolic Polyethoxylates degradation products: nonylphenol octylphenol	300 kt/yr	• surfactants in detergents • surfactants in paint • pulp and paper production • sewage treatment plants • pesticide emulsifiers	**Moderate**	**Moderate**	**Moderate** • endocrine disrupting • reproductive impairment
Polychlorinated Terphenyls	2.4 kt/yr 1955-1980	• fire retardants • placticizers • inks, sealants	**High**	**High**	**High (similar to PCBs)** • endocrine disrupting • reproductive impairment

Table 10-3. Major chemical classes associated with endocrine disruption and their inputs to Canadian aquatic environment (Hewitt and Servos 2001).

Class	Examples of specific chemicals	Inputs to Canadian aquatic environments
Industrial chemicals	PCBs + metabolites	• Industrialized harbours • Atmospheric deposition
	Non-ionic surfactants (APEOs)	• Municipal sewage effluents • Textile effluents • Industrial sites
	Brominated diphenyl ether	• Industrialized harbours • Flame retardant leachates
	Phthalates	• Plastic leachates
	Bisphenol A	• Municipal sewage • Industrialized harbours
Pesticides	Organochlorines (e.g. DDT)	• Atmospheric deposition • Agricultural runoff
Halogenated organic contaminants	TBT	• Marine harbours • Application sites
	PCDD/PCDFs	• Industrialized harbours • Wood preservatives • Contaminated sediments
Other pollutants	Heavy metals	• Acid rain • Chlor-alkali plants • Mine tailings
	PAHs	• Industrialized harbours • Atmospheric deposition • Oil sands deposits and processing
Natural products	17β-estradiol	• Municipal sewage • Animal waste runoff
	Plant sterols Stillbenes Flavenoids	• Pulp mill effluents • Agricultural runoff

10.6. Contaminants in Biota in the Central Coast

Information on contaminant levels in wildlife in the central coast is extremely 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. Our understanding of contaminants in the central coast, and indeed the Pacific, would be greatly enhanced by the development of a broad scale monitoring program that incorporates numerous trophic levels (Macdonald *et al.* 2002). Choice of sentinel species or biomonitors should be cosmopolitan species with various life histories. Species found in BC that were recommended as biomonitors by (Rainbow 1995) include the seaweeds *Ulva* and *Fucus*; bivalves mussels (*Mytilus*) and oysters (*Crassotea gigas*); polychaete *Nereis*; barnacles of the genus *Balanus*; and amphipods. Other authors recommend the use of high trophic level species such as sea birds, birds of prey and marine mammals (Elliott and Harris 2001; Elliott and Scheuhammer 1997; Ross *et al.* 2000).

10.6.1. Algae

No information on contaminants in algae is available for the central coast. Macdonald *et al. (2002)* remark that edible seaweed in BC and Japan has shown elevated arsenic levels, but the bioavailability of the contaminant is not known. *Fucus* and eelgrass (*Zostera marina*) were regularly sampled for metals in Rupert Inlet and Quatsino Sound and were found to have slightly higher levels of copper and zinc while the Island Copper Mine was in operation (Poling *et al.* 2002).

10.6.2. Invertebrates and Zooplankton

Zooplankton are a critical component of marine food webs. As such, they presumably play an important role in the biomagnification of contaminants. There is, however, no information on contaminants in zooplankton, although amphipods, sea urchins, bioluminescent microbes and squid are known to accumulate organochlorine compounds in other parts of the Pacific (Macdonald *et al.* 2003).

There are some data on contaminants in certain sentinel species, usually focused around areas of concern such as pulp mills and mines. Dungeness crabs, used as sentinel species to monitor dioxin and furan levels, have been sampled around the harbour of the pulp mill in Campbell River and the pulp mill in Port Alice (Section 8.1) (Yunker *et al.* 2002).

An extensive monitoring program was undertaken in Rupert Harbour and Quatsino Sound to monitor effects of the Island Copper Mine (Section 9.1) They sampled numerous species for metals including mussels, butter clams, littleneck clams, Dungeness crab, as well as many other species that were not encountered frequently enough over the years to show temporal trends (Poling *et al.* 2002).

Shellfish and crabs intended for human consumption are regularly tested for contaminants by the Canadian Food Inspection Agency. They are only tested for paralytic shellfish poisoning (PSP) toxins (Canadian Food Inspection Agency 1997).

Snails, oysters and some other species have also been monitored for organotin compounds in various locations in BC, particularly harbours. Often biological effects such as rates of imposex in snails or shell hardening in oysters are used as a marker rather than testing for the contaminants (See Section 7.3 for a discussion). Thompson and Stewart (1994) review organotin levels in biota in BC and provide ranges of measurements of tributyltin, dibutyltin and monobutyltin for Dungeness crab, clams, oysters and mussels as well as chinook, coho, and flatfish. Some samples originate from Jervis Inlet and Alice Arm; however, none were collected from the central coast itself.

One study did sample shrimp, prawn and fish tissue in various locations in the Central and North Coasts (Quatsino Sound, Laredo Sound, Surf Inlet and Hecate Strait) to determine a baseline level of metals (Harding and Englar 1989). Data for central coast locations from this study are shown in Table 10–4.

10.6.3. Fishes

Most contaminant research in fishes has been carried out on salmonids. Though some POPs may be accumulated in contaminated nearshore juvenile habitats, salmon are thought to mainly accumulate contaminants in the open ocean (Arkoosh *et al.* 1991). 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. Sockeye, chinook, and coho salmon have been shown to accumulate POPs during their open ocean phase. Adult chinook salmon returning to Puget Sound have been shown to be relatively contaminated with PCBs (mean of 2.2 mg kg^{-1} lw), 99% of which was estimated to be from the marine residence phase (Arkoosh *et al.* 1991). Returning adult chinook in BC also had appreciably higher (>90%) POP loads than out-migrating smolts (Ross, unpublished data). Sockeye salmon were shown to transport OC compounds from the open ocean to lakes in Alaska (Ewald *et al.* 1998; O'Neill *et al.* 1998). Atmospheric deposition of contaminants into the Pacific Ocean may represent an important route for food chain contamination in this region (Ross *et al.* 2000). Accumulation of these contaminants by salmonids can then be transferred to their predators (such as killer whales, Section 10.6.5) as well as transported back into coastal areas such as spawning streams and lakes (Ewald *et al.* 1998).

Contamination in other fishes including rockfish and flatfish has been investigated in certain areas. Unlike salmon, which are thought to accumulate contaminants from widespread sources, fishes that remain resident in coastal waters are likely to accumulate contaminants from more localized sources. For instance, 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). There have been no investigations of contamination in resident fishes in the central coast. Though levels of contamination similar to those in highly polluted areas such as Puget Sound are not expected, some contamination issues in fishes resident in the central coast area may be found near local sources of contaminants such as harbours, aquaculture sites, pulp mills and outfalls.

10.6.4. Birds

The effects of OC contaminants on fish-eating birds were instrumental in the banning of DDT in North America and Europe. One well publicized effect of DDT is DDE-induced egg-shell thinning leading to reproductive failures in birds. OC levels in seabird eggs from industrialized areas of BC, such as the Strait of Georgia and Fraser River Estuary, showed significant declines during the decade following the ban. Changes in remote areas such as the Queen Charlotte Islands were not as apparent (Elliott and Scheuhammer 1997). Elliott *et al.* (1997a) reported OC and PCB contamination levels in eggs from seabirds from the Queen Charlotte Islands as well as three central coast locations: Thomas Island (northern Vancouver Island), and Moore and Whitmore Islands (Hecate Strait). They did not find differences in contamination levels among sites, though they did observe interspecies differences. The most prevalent contaminants were DDE (a DDT metabolite) 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. The authors related contamination levels to foraging mode and trophic level. Seabirds foraging in inshore or continental shelf areas (e.g. auklets) were exposed to lower levels of contaminants after DDT and PCB restrictions 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, likely reflecting continued inputs from long-range atmospheric transport from Asian sources.

Bald eagles may also be at risk as a result of long-range transport and deposition of chemicals used in other parts of the world. OC pesticides and PCBs have been found in bald eagles in the Aleutian Islands, Alaska (Estes *et al.* 1997).

Cadmium represents an issue of concern in the central coast. Heavy metals in nesting seabirds have been measured in five seabird species in the Queen Charlotte Islands. Leach's storm-petrels nesting on Hippa Island had the highest cadmium levels and one of the highest levels reported in any wild animal. Neither the source of cadmium nor the significance of the finding was known (Harfenist *et al.* 2002). Cadmium is, however, being considered as a possible cause of population declines in white-winged scoters and long-tailed ducks after elevated cadmium concentrations were found during major die-offs (Harfenist *et al.* 2002). No information on cadmium or any other heavy metals from sea birds in the central coast is available. Mercury levels in seabirds from the Queen Charlotte Islands were not high enough to be of concern (Harfenist *et al.* 2002).

10.6.5. Marine Mammals

Marine mammals that consume fish or other mammals (seals, dolphins and whales) can serve as good sentinel species to assess contamination risks since they are high trophic level organisms that are often exposed to very high levels of fat-soluble environmental contaminants (Ross 2000). Contamination in harbour seals and killer whales from the central coast have been studied (Ross *et al.* 2004; Ross *et al.* 2000).

Ross *et al.* (2004) studied contaminants (PCB, dioxins and furans) in populations of harbour seals (*Phoca vitulina*) along a gradient of pollution: Puget Sound (heavily industrialized), Strait of Georgia (moderately industrialized) and Queen Charlotte Strait (remote). Harbour seals are relatively abundant, non-migratory seals with adult home ranges of approximately 20 km^2 such that contaminant signals provide an integrated measure of food chain contamination in these different areas. Results showed that seals from Puget Sound were heavily contaminated with PCBs while those from the Strait of Georgia had high levels of dioxins and furans (PCDD/Fs). Sources of these contaminants are believed to be local industry and pulp mills in these regions. Contaminants were lowest in seals from the Queen Charlotte Strait, concurrent with increasing distance from urban and industrial areas. Contaminants in the Queen Charlotte Strait seals were, however, dominated by less chlorinated PCBs and PCDD/Fs. These "light" contaminants are more volatile than heavily chlorinated PCBs, PCDD/Fs congeners and therefore travel greater distances. The "light" contaminant signature in the seals from the Queen Charlotte Strait are indicative of long-range atmospheric transport of contaminants (Ross *et al.* 2004).

Contamination of killer whales (*Orcinus orca*) in the central coast has also been investigated. Ross *et al.* (2000) studied PCBs and PCDD/Fs in three populations of killer whales: transients, northern residents and southern residents. Both transients and northern resident home ranges include the central coast. All three populations had high levels of PCBs; transients and southern residents are considered among the most polluted marine mammal in the world. The level of PCBs in most of the whales sampled surpassed adverse effects levels established for harbour seals; therefore, they are considered to be at risk for toxic effects such as immunotoxicity, neurotoxicity, reproductive impairment and endocrine disruption. Levels of dioxin and furans, on the other hand were low in all three groups likely reflecting the ability of killer whales to metabolize and excrete these planar compounds. Transients were more contaminated than residents reflecting their elevated trophic level as transients consume marine mammals while residents mainly consume salmon. Contaminants in salmon, particularly their primary prey item, chinook, may explain some of the contamination of the residents. Long-range atmospheric transport of contaminants also plays a significant role in the contamination of northern resident killer whales. Proximity of southern residents to additional sources of contaminants likely explains the differences in contamination between southern and northern residents (Grant and Ross 2002).

There are no studies of contaminants from sea otters in the central coast; however, some information exists for sea otters from the Aleutian Islands and California. High levels of organometallic and OC 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 given the remote location (Estes *et al.* 1997). However, local sources of PCBs associated with military installations may represent a regional source to sea otters.

10.7. Synthesis

Regulatory controls placed on many POPs in the 1970s have greatly reduced local sources of these harmful pollutants. Atmospheric transport and deposition from distant sources now appears to be the primary source of these contaminants to high trophic level species inhabiting the central coast. Consequently, areas of BC that are removed from local sources of pollution may be at risk for adverse effects. The global transport of semi-volatile “legacy” POPs and “new” POPs present health risks for high-trophic level biota such as salmon, birds, seals and whales. Subsistence-oriented humans in the central coast may also be at risk. A greater understanding of the transport and fate of POPs through food chains and the abiotic environment is necessary to provide a critical foundation for risk assessments on a regional and global scale. Understanding the long-range transport of POPs should be a priority in order to determine relative risks to various areas of the coast. Local sources of POPs such as pulp mills, aquaculture feed and historical contamination in harbours and other sites are still of concern in the central coast. The development of a monitoring program encompassing a broad spatial scale and major trophic levels, including sentinel species such as harbour seals, would play a significant role in identifying the relative importance of local, regional and international sources of persistent, bioaccumulative and toxic compounds. Biomonitoring is also crucial to the assessment and monitoring of marine environmental quality in the central coast.

Box 10.1 Additional Information on Chemical Contaminants

- Toxic metals in the environment: (Clark 2001)
- Endocrine disruptors in marine environments:
  - See a special theme issue of Water Quality Research Journal of Canada, Volume 36, no. 2, 2001. Abstracts available at: http://www.cciw.ca/wqrjc/36-2.htm;
  - EPA fact sheet: http://www.epa.gov/ORD/WebPubs/endocrine/factsheet.pdf;
  - EPA Report: http://www.epa.gov/ORD/WebPubs/endocrine/endocrine.pdf.
- Long-range transport of chemical contaminants: (Macdonald *et al.* 2003).
- Chemical contaminants in the North Pacific: (Macdonald *et al.* 2002; Rice *et al.* 1996; Kay 1989).
- Contaminants in Wildlife:
  - Whales: (Ross 2001; Ross *et al.* 2000);
  - Salmon: (Johannessen and Ross 2002);
  - Seals: (Ross and Troisi 2001);
  - Birds: (Elliott *et al.* 1997b; Elliott *et al.* 1997a).

Table 10-4. Trace metal concentrations (mean ± s.d.) in µg g^{-1} dry weight in sediment or muscle of harvested species (Harding and Goyette 1989).

Location/Station	n	Aluminum	Cadmium	Chromium	Copper	Mercury	Lead	Zinc
Sediment								
Surf Inlet (S)	3	187±2875	1.09±0.23	26.6±4.1	30.5±4.1	0.13±0.03	7.7±4.0	74.6±10.9
Laredo Sound (L)	2	22750±212	1.05±0.07	35.1±0.4	36.3±.49	0.20±0.046	11.5±0.7	99.9±3.0
Quatsino Sound (Q)	4	28650±3113	1.1±0.24	50.6±8.2	100.6±45.3	0.080±0.008	9.5±2.6	98.6±3.4
Sidestripe Shrimp, *Pandalopsis dispar*								
S1	24		0.15±0.08	0.5±0.1	16.1±3.4	0.11±0.05	1.19±0.15	52.3±3.4
S3	24		0.15±0.03	0.5±0.1	14.2±3.4	0.14±0.06	1.22±0.15	50.1±2.1
L2	12		0.23±0.12	0.6±0.1	13.3±5.5	0.15±0.06	1.01±0.22	52.8±4.4
Q2	32		0.12±0.04	0.5±0.1	12.3±3.0	0.17±0.08	0.69±0.55	48.8±4.7
Pink Shrimp, *Pandalus borealis*								
S2	18		0.13±0.02	0.6±0.3	11.0±2.0	0.13±0.03	1.27±0.30	48.1±3.3
S3	12		0.53±1.02	0.6±0.1	12.0±1.7	0.17±0.04	1.47±0.54	47.4±5.7
Q2	6		0.43±0.44	3.7±7.5*	22.2±8.9	0.15±0.11	0.70±0.47	39.8±24.1
Q3	20		0.12±0.05	0.5±0.2	10.2±2.3	0.21±0.14	0.70±0.54	42.8±8.8
Prawn, *Pandalus platyceros*								
S2	4		0.14±0.02	0.6±0.2	19.5±3.3	0.13±0.08	1.25±0.24	52.9±6.3
S3	4		0.12±0.02	0.5±0.1	15.4±5.4	0.12±0.06	1.09±0.15	49.3±7.2
Rex Sole, *Glyptocephalus zachirus*								
Q2	3		0.13±0.01	0.7±0.1	1.1±0.1	0.01±0.01	1.57±0.40	17.2±3.0
Dover Sole, *Microstomus pacificus*								
Q2	7		0.15±0.03	0.6±0.1	1.6±1.4	0.22±0.08	2.85±2.72	17.9±4.1
Pacific Hake, *Merluccius productus*								
S2	3		0.27±0.03	0.5±0.1	2.8±1.2	0.43±0.30	4.06±2.55	25.2±7.0

* mean and s.d. high due to an unusual value of 19.0 µg g^{-1} in the data set.

11. Additional Contaminant Issues

The primary issues associated with present levels of chemical contamination in the central coast have been dealt with in Sections 3 to 10. Information on other issues, which may be more significant in other parts of British Columbia, follows.

11.1. Runoff from Agriculture and Urban Areas

Contaminants, particularly pesticides applied to crops, lawns and gardens, are found in runoff from agricultural and urban areas. These are significant sources of pesticides in many areas, such as the Strait of Georgia and Puget Sound (Grant and Ross 2002). Very little agriculture takes place in the central coast and is mainly in the extreme south of the region (See Section 2.7 and Figure 2-9). Urban application of pesticides is also presumed to be greatest in the south of the region, around Campbell River. Other population centres in the central coast are small, suggesting that pesticide runoff will take place on a small scale. None-the-less, education programs, such as the "Whale Friendly Lawn" program that promotes using ecologically sensitive gardening techniques over the use of pesticides and herbicides, could be developed for the central coast.

11.2. Ocean Dumping

Many ocean dumpsites have been established in BC, including eight in the central coast: Cape Mudge, Johnstone Strait (Hanson Island, Hickey Point), Kingcome Inlet, Malcolm Island, Queen Charlotte Strait, Neroustos Inlet and Port Alice (Figure 11-1) (Environment Canada and Pacific and Yukon Region 2003). The following materials are considered for ocean dumping (Environment Canada and Pacific and Yukon Region 2003):

- 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.

Mine tailings, such as those discussed in Section 9 are also dumped, as they were in Rupert Inlet. Many of the same issues with ocean disposal of mine tailings exist with the dumping of dredge spoils (see Table 9-1).

Permits must be obtained from Environment Canada and 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 can not exceed 0.75 mg/kg dry weight for 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. Ocean dumpsites can have elevated levels of mercury, cadmium, lead, zinc and copper. Fish and invertebrate were sampled 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).

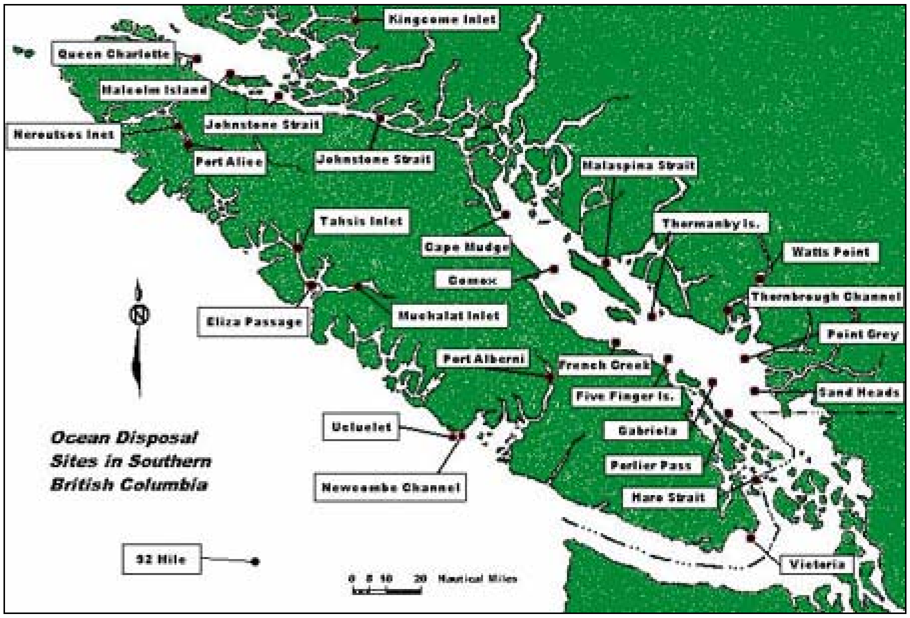

Figure 11-1. Locations of ocean disposal sites in parts of the Central and South Coast Areas (Environment Canada and Pacific and Yukon Region 2003).

Table 11-1. Volume, in cubic metres, of material disposed at some dump sites in the central coast, 1995-1999 (Environment Canada and Pacific and Yukon Region 2003).

Disposal Site	1995	1996	1997	1998	1999
Cape Mudge	7,200	0	0	8,000	1,920
Johnstone Strait-Hanson Island	6,000	6,000	15,600	4,000	6,500
Johnstone Strait-Hickey Point	8,400	3,600	6,000	0	3,250
Kingcome Inlet	0	0	0	0	0

11.3. Sediment Contamination

Contaminants often end up being deposited in the sediments (sedimentation). We have described several instances of sediment contamination in this report including areas adjacent to:

- fish farms: copper, zinc, pharmaceuticals and others (Section 3.1-3.2);
- wastewater outfalls (Section 5.1);
- harbours and marinas: metals, especially TBT, and others (Section 7.2);

- pulp mills: dioxins and furans (Section 8.1), and PCBs (Section 10.2.1).
- mine tailings: metals (Section 9.1);
- ocean dump sites (Section 11.2).

Sediment contamination represents a significant concern since sediment often becomes the repository for contaminants in the ocean. Contaminated sediments may also represent a contamination source to marine food webs as they can be disrupted by the action of burrowing infauna (bioturbation), or uptaken by benthic fauna. Disruption of the sediments by tidal currents, wave action or dredging may also re-suspend contaminants.

Sediments accumulate contaminants over time. Measuring contaminants in sediment cores can be used to determine contaminant trends over time. Sediment cores are a key resource to understanding current loadings in the context of pre-industrial loadings (Macdonald *et al.* 2002). They can also be used to integrate contaminant inputs from point and non-point sources (Grant and Ross 2002).

The cumulative effects of various activities that introduce contaminants to sediments represents a complex issue but merits consideration. For instance, sediments in Quatsino Sound may have received contaminants from mine tailings in Rupert Inlet and Neroustos Inlet, as well as contaminants from the pulp mill in Port Alice. Sediments from industrial sites no longer in use, such as the pulp mill in Ocean Falls, should also be considered.

11.4. Tourism

Tourism represents a growing industry in the central coast that is mostly focused around ecotourism, and sportsfishing. A healthy marine environment in the central coast area will represent an important foundation for growth in these sectors. Tourism also brings wastes and contaminants associated with the presence of additional people. Impacts from cruise ships have already been addressed in Section 6.0. Other effects related to tourism are increased boat use, and associated oil, and sewage pollution, particularly around marinas (Section 7.2). Remote lodges may be a source of pollution from leaking septic systems as discussed in Section 5.2. To date, any impacts associated with tourism are likely to be localized and probably quite minor. Hazardous and polluting materials that often accompany humans such as batteries, electrical equipment, oil and gas should be disposed of carefully to ensure the high standards of environmental quality are maintained in remote regions of the central coast.

11.5. Military Activity

Military activities also take place in coastal waters. Navy and military bases in coastal BC are found in Esquimalt and Comox (South Coast). Ship-based contaminants discussed in Section 7.0 such as oil, PAHs, sewage and grey water also apply to naval ships; however, most military exercises go on in waters around Nanoose Bay, in the Strait of Georgia, and near Victoria (Personal communication, Duane Freeman, Department of National Defense, 2003). Naval exercises have also been implicated with noise pollution.

It does not appear that there are any munitions dump sites in the central coast (Personal communication, Duane Freeman, Department of National Defense, 2003); however, an Ottawa task force is conducting a review of all military dump sites used during World War II. Information from this report by the Department of National Defense is forthcoming.

Worldwide testing of atomic weapons introduces radionuclides into the atmosphere. Though there is evidence of long-range transport of radionuclides originating from radioactive waste disposed of in the Northwest Pacific ocean by the former Soviet Union, radionuclides are not considered to pose a risk to the marine environments in the Northeast Pacific (Macdonald *et al.* 2002).

11.6. Canadian Coast Guard

The Canadian Coast Guard (CCG), a branch of Fisheries and Oceans Canada, provides search and rescue, boating safety, environmental response, icebreaking, marine navigation service, marine communications and traffic services, and navigable waters protection services in Canadian waters. Coast Guard services in the central coast include lighthouses, navigational aides, and search and rescue. CCG ships are likely contributing ship-based pollutants as discussed in Section 7. Historical sources of contaminants to the marine environment in the central coast may also include mercury that was used at and transported to lighthouse stations, and cadmium and mercury in batteries from lighthouses and navigational aids that were discarded overboard. The Coast Guard is currently in the process of assessing contamination and recovering discarded batteries (Kruzynski 2000).

11.7. Other Sources of Contaminants near the Central Coast

Additional heavy industry is found adjacent to the central coast study area at the head of the Kitimat Arm, near the town of Kitimat. The region is the site of several industries, including an aluminum smelter, a pulp mill and a methanol manufacturing plant (Pierce *et al.* 1998). Particles bound to contaminants are likely to be sedimented out in the basins of the upper reaches of the Kitimat Fjord system. PAHs attributable to the aluminum smelter and PCDDs and PCDFs released from the pulp mill, sawmill and wood treatment facility have been found in sediment cores in the Kitimat Arm. Concentrations of these contaminants reached a maximum in the early 1970s and have since declined (Pierce *et al.* 1998). The town of Kitimat, with a population of over 40,000 (2001 Canadian census for the Kitimat-Stikine Regional District) developed around these industries.

12. Future Risks and Emerging Issues

12.1. Population Growth

Projected risks of chemical contamination in the oceans are often assumed to be a function of increased population growth in the coastal zone. “During the past decade, expanded industry and increasing coastal populations have escalated pressures on productive marginal seas.” (Macdonald *et al.* 2002) There is good reason for this statement. Human pressures on coastal zones are on the increase worldwide. In 1998, an estimated two-thirds of the world’s population (3.6 billion) lived within 60 km of the coast. Since the human population is increasing by approximately 77 million per year, impacts of human population on the coastal zone and marine environment are likely to increase (Macdonald *et al.* 2002).

In British Columbia, population growth in the coastal zone has also been implicated with increased levels of pollution. The Georgia Basin is one of the most rapidly developing regions in North America. The population in the region exceeded 2 million in 1993 and is projected to increase steadily by 24-32% for the Puget Sound region and Greater Vancouver area by 2010.

Growth is also expected in the communities on the east coast of Vancouver Island (West *et al.* 1994).

The central coast is one coastal region that has, for the time being, departed from this international trend. Most regions in the central coast are experiencing population declines due to aging populations and migration to larger urban centres in the south. The population of the Mount Waddington Regional District declined by 11% between 1981 and 2001; most of this occurred since 1996. This drop is attributed to the closing of the Island Copper Mine, timber harvesting reductions, and a down-turn in salmon fisheries with the associated vessel buybacks (Ministry of Sustainable Resources Management Coast and Marine Planning Branch 2002). The population of the Comox-Strathcona Regional District seems to be relatively stable and some growth may be expected in Campbell River. The population of the northern part of the central coast (in the Central Coast Regional District) is considered to be stable, but no growth is forecast for the next 25 years.

Though the resident population is not expected to grow significantly in the near future, increased impacts on the marine environment may be caused by industrial activities and transient activities. Not included in resident population statistics are transient workers such as people working in forest camps. Another potential source of transient workers (as well as resident employment) to the region is the potential development of oil and gas. Workers involved in exploration, development and production of this industry would be required. Lastly, increasing rates of tourism, particularly on cruise ships (Section 6.0) also bring additional humans to the central coast.

12.2. Oil and Gas Development

Federal and provincial moratoria on offshore exploration of oil and gas on Canada's Pacific Coast have been in affect for nearly three decades. Lifting of the moratoria was briefly considered in the early 1980s and though it was not lifted, it did lead to the production of West Coast Offshore Environmental Assessment Panel Report on offshore oil and gas issues. In recent years the government of British Columbia has expressed a renewed interest in the establishment of an offshore oil and gas industry. The primary area of interest for offshore oil and gas is the Queen Charlotte Basin (Figure 12-1). Oil and gas exploration, development, and production have the potential to be significant marine environmental quality issues in the central coast.

Several reports have examined the issues surrounding offshore oil and gas development in the Queen Charlotte Basin. Recent reviews covering physical, oceanographical, geological, biological, social, and economic issues, as well as assessments of ecological and economic risk, are available (Crawford *et al.* 2002; Cretney *et al.* 2002d; Cretney *et al.* 2002b; Cretney *et al.* 2002c; Cretney *et al.* 2002a; Jacques Whitford Environment Ltd. 2001; Crawford *et al.* 2002; Strong *et al.* 2002).

The Queen Charlotte Basin is expected to have substantial petroleum reserves. 18 exploratory oil probes have been completed (Figure 12-1). Speculative estimates are 1.5 billion m^3 oil and 730 billion m^3 (or 26 Tcf) natural gas. Recoverable reserves, however, are more along the lines of 400 million m^3 oil and 550 billion m^3 (or 20 Tcf) gas. For comparison, these recoverable oil estimates amount to approximately 10% of Canada's current oil and gas production but 3 times the amount of oil produced in BC and an equivalent amount of BC conventional gas reserves. The most prospective geographic areas, in order of importance are southern Hecate Strait, Queen Charlotte Sound, eastern Graham Island, northern Hecate Strait and Dixon Entrance (Strong *et al.* 2002). Activity is not expected on western Graham Island, southern Queen Charlotte Islands (or between the islands) or on the adjacent Pacific Continental Shelf west of the Queen Charlotte Islands (Strong *et al.* 2002). Shell, D.F. Smith (Chevron), Petro Canada, and Mobile Oil all hold tenures in the central coast. Oil leases have been relinquished by oil companies in some areas of Queen Charlotte Strait and the Queen Charlotte Islands (Figure 12-2).

12.2.1. Environmental Risks

There are three main oil and gas development phases: exploration, drilling and production (Strong *et al.* 2002). A fourth stage, which will not be discussed here, is decommission (Jacques Whitford Environment Ltd. 2001). Transportation is yet another issue as discussed in Section 4. Exploration for oil and gas reserves depends primarily upon seismic surveys using air guns. Drilling would take place using some type of ocean drill rig. Production either involves a pipeline on the ocean bottom from the well to a storage site or long-term production from a drilling platform. Environmental impacts are associated with each of these phases. Impacts can be expected on various biota from seismic testing, drilling mud, platform, noise (from drilling and operations), pipeline (construction and operations) and oil spills (Table 12-1). Many unknowns exist, particularly with respect to drilling muds and in the juvenile and larval stages of fishes.

Oil pollution, both from chronic exposures and catastrophic spills, represents the greatest long-term impact related to oil and gas exploration. Effects of chronic and catastrophic oil spills on biota are reviewed in Sections 4.5-4.7 and are relevant to this discussion. Risk of oil spills relate to possible oil blowouts, tanker spills, and pipeline leaks.

Physical impacts from seismic activity and noise pollution from drilling and operations (both subtidal noise and aerial noise i.e. from helicopters) are also of great environmental concern, but will not be discussed in this review of chemical contamination. (See Box 12.1 for sources of information.)

With oil and gas development comes increased shipping. Sources of pollution, as with other forms of shipping, include chronic oil pollution, ballast water issues (oil pollution and introduced species), and sanitary and domestic wastes. These are reviewed in Sections 6 and 7. Oil platforms also have sanitary and domestic wastes, in a manner similar to ship-board sewage. Drainage from the decks of rigs and platforms may be an additional source of chronic oil pollution.

Drill cuttings must be disposed of somewhere; many of the same issues exist as with the disposal of mine tailings and ocean dumping (Section 9.1). Other chemical contamination sources associated with drilling will be discussed here.

12.2.2. Drilling Mud

Drilling mud is a liquid product. There are many types available, with a large variety of properties depending on what is required at the particular site. The base of the drilling mud can be water, diesel or mineral oil. Very fine, dry clay microparticles (bentonite) are added to this base to form a stable colloidal suspension that has a slightly greater density than water. Various components are added to the mud to achieve or accentuate certain properties.

Components include: barite (for extra density); tannins and lignosulfonates (for thinning); caustic soda (pH control); biocides (corrosion control); and carboxymethyl cellulose or starch (for gelling and filter cake properties) (West Coast Offshore Exploration Environmental Assessment Panel 1986).

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

- To provide oil well control by creating and maintaining a hydrostatic column of fluid to counter-balance pressure.
- To provide a viscous mud flush to pick up the small cut rock particles (cuttings) under the bit and convey them to the surface.
- To provide a cake or skin against penetrated permeable formations to prevent leakage as well as loss of hydrostatic column thereby generating pressure.
- To provide a gel under static conditions 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. The fate of water-based muds has been modeled for the east coast and is described in detail in Crawford *et al.* (2002). The primary chemical constituents of drilling mud are bentonite, which consists of the clay mineral montmorillonite, an aluminum silicate that flocculates in water, and barite, or barium sulphate.

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

- physical, chemical and biological properties of the drill mud and its components;
- pathways by which drill mud components move in the environment;
- partitioning of the drill mud between the different pathways;
- dose-response of the organisms of interest to the drill mud components;
- physical and biological environment receiving the discharges.

Modeling work has focused on questions such as how quickly and how much of the discharge plume will reach the bottom (settling velocity); how flocculation, or particle aggregation, will effect settling rate, vertical distributions and plume dispersion; how the bottom stress environment affects the fate and impact of the drill mud; and the biological effects of drill muds (e.g. bentonite and barite in particular) on a species of interest (e.g. the sea scallop, *Placopecten magellanicus*).

Biological effects have focused on the scallop due to its commercial value on the Atlantic Coast (Georges Bank), and its susceptibility due to its benthic habitat, limited juvenile mobility, and its filter-feeding in the benthic boundary layer where drill waste concentrations are the largest. Crawford *et al.* (2002) explain that the analysis focused on sub-lethal effects, such as impaired growth, because neither barite nor bentonite is thought to be highly toxic to scallops. The observed sublethal effects from barite and bentonite arise from the negative influence of fine inorganic particles on the scallop's feeding process. 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.

The modeling exercises have assumed that most of the drill mud fines will be held in suspension in the water. They have not, to date, modeled the deposition, erosion, critical shear stress, bedload transport, or partitioning of barite between the water column and sediment. Other issues that have not been adequately addressed are the presence of trace chemicals and metals in mud. The overall discharge of drilling muds is thought to be too small a concentration spread over a large space so that decay of contaminants in space and time will make the risk negligible. However, Crawford *et al*. (2002) acknowledge that toxic or sublethal effects in biota could arise if extreme toxicity or a concentrating mechanism exists. Concentrating mechanisms could be: the bottom boundary, the surface boundary, a local low energy environment, sequestering in the sediment, and bioaccumulation.

12.2.3. Produced Water

Produced water represents the largest volume waste stream from offshore oil and gas production activities. Produced water is that which is extracted from the well along with the oil and gas during the extraction process. It consists of formation water (naturally occurring water in the geological formation); injection water (injected into the well during the process); condensed water or seawater, in the case of gas production and oil production respectively (injected to maintain reservoir pressure); and other technological waters (treatment chemicals such as emulsion breakers, corrosion inhibitors, biocides, etc). The formation water component of production water is, in effect, a brine which derives its salinity from the major ions found in seawater. However, depending on the nature of the formation, it also contains a number of metal and organic constituents of environmental interest including:

- hydrolysis metals,
- heavy metals,
- organic chemicals including petroleum hydrocarbons,
- nutrients,
- radionuclides, and
- treating chemicals.

Modeling of produced water on the east coast has generally used a plume dispersion model (also called a convective decent model) to model near-field concentrations and an advection-diffusion model to look at concentrations further from the platform. Results generally show 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, described in Crawford *et al.* (2002), examined sublethal effects of alkylphenols, a natural constituent of produced water, on cod (*Gadus morhua*). A simulation indicated that fish could accumulate body burdens of 1-10 mg/g in the vicinity of the platforms. Dosing levels based on these theoretical body burdens provided evidence in controlled laboratory experiments of reproductive impairment in males and females. At the lowest levels studied, slowed development of eggs in females was estimated to result in smaller egg size and a 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. Authors of the study noted that in addition to the reduced fitness of the smaller eggs, the delay in spawning would cause an environmental mismatch of the plankton bloom and further reduce the fitness of the larval cod. Experiments such as these, as well as modeling of produced water plumes, 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 stimulate or inhibit microbial production. Increases in primary production and an increased vertical flux of detritus to the benthos may be expected (Crawford *et al.* 2002).

12.2.4. Characteristics of the Physical Environment to be Included in Risk Assessments

The physical environment of the central coast consists of elements that must be considered in the context of oil and gas production. Cretney *et al.* (2002c) provide a detailed discussion of related issues. The Queen Charlotte Basin consists of a complex physical environment. Surface currents and tides in the region are reasonably well understood and have been modeled; however bottom currents and currents and tides in the winter are less understood. Bathymetry is highly variable and geochemistry of the bottom also requires more study to identify hazards such as areas of potential slope failure. The region, particularly around Cape St. James, is well known for its strong winds and wicked winter storms. Conjunction of wind and waves can lead to extreme waves. For example, during an intense North Pacific storm in October 1968, an oil-drilling rig anchored in the vicinity of Cape St. James was hit by a 29-m wave, propagating against a strong local ebb current (Cretney *et al.* 2002c). Better tracking and prediction of these storm events and giant waves will be required. The Queen Charlotte Basin also represents an area of high seismic activity (major tectonic features are shown in Figure 12-1). High risk areas should be avoided and design standards for oilrigs in the Queen Charlotte Basin should take into consideration threats of earthquakes and site-specific characteristics such as sea-bottom stability. Tsunamis caused by earthquakes and landslides are also a real risk in the region that must be considered (Cretney *et al.* 2002c). Unlike the east coast of Canada and Alaska, there is not much of a threat from icebergs in the central coast. Such considerations must enter into ecological risk assessments. Cretney *et al.* (2002c) recommends the following:

- Physical oceanography programs should continue to provide details of the current regime in all seasons, with special emphasis on bottom currents and freshwater runoff.
- Physical oceanography projects should continue to elucidate the interaction of strong currents and waves, and the creation of giant waves in the Basin area. They recommend the fitting of new sensors to the existing buoy array to accurately measure giant waves and the two-dimensional wave spectra.
- Natural Resources Canada should be encouraged in its continuing studies of earthquakes in the Queen Charlotte Basin.
- Tsunami modeling studies should be encouraged to assess the effect of megathrust event on the Queen Charlotte Fault. Simulations of tsunamis originating from regions within the Queen Charlotte Basin could be encouraged.

- Efforts should be intensified to get the model SEAMAP going for the Queen Charlotte Assessment Area.
- Studies of the geochemistry of the seabed in the Queen Charlotte Assessment Area should begin, perhaps in concert with SEAMAP and other studies of the geomorphology of the area.

12.2.5. Other Considerations

Other special considerations with respect to oil and gas exploration and development in the central coast exist. Of particular relevance are the unique sponge reefs in Hecate Strait and Queen Charlotte Sound (Section 2.4.1). Potential impacts include physical damage by drilling, drill cuttings, anchoring, construction of platforms and pipelines, and sedimentation and contamination from drilling mud. Sponge reefs should be protected with adequate buffer zones to avoid these hazards (Strong *et al.* 2002). Crawford *et al.* (2002) discuss the potential impacts of drill mud discharges on sponge reefs and admonish that smothering is a distinct possibility if the drilling takes place adjacent to a sponge reef. They list questions that need to be answered in order to assess the possible impacts of drill mud to the sponge reefs:

- Is the discharge plume likely to reach the bottom?
- How often does the bottom stress exceed 0.1 Pa at the drill site and at the sponge beds?
- Will clay (bentonite) concentrations of 0.1 – 10 mg/l affect the sponges?
- Does barite affect the sponges?
- Are scallops a reasonable proxy for sponges?
- Are the sponges sensitive to any of the trace chemicals in the proposed drill mud? If so, at what levels?

There are regions and times that will be particularly sensitive to oil and noise pollution, including bird nesting colonies, breeding grounds, nursery areas, marine mammal haul-outs, sea otter habitat and important larval and plankton accumulation areas. Much of this information does not exist for the central coast (Strong *et al.* 2002). Knowledge of some sensitive areas, such as important seabird colonies and productive groundfish banks and breeding areas has been documented. Risk of damage to these areas and species should be minimized.

12.2.6. Synthesis

The development of offshore oil and gas in the Queen Charlotte Basin has the potential to greatly impact marine environmental quality in the central coast. Effects of catastrophic oil spills and chronic oil pollution, particularly on sensitive habitats and species, are of great concern. Other chemical contamination sources exist, particularly chemicals in drilling mud and produced water; however, many of the risks are uncertain. Uncertainties of the effects of these contaminants on the environment of the central coast must be included in risk assessments.

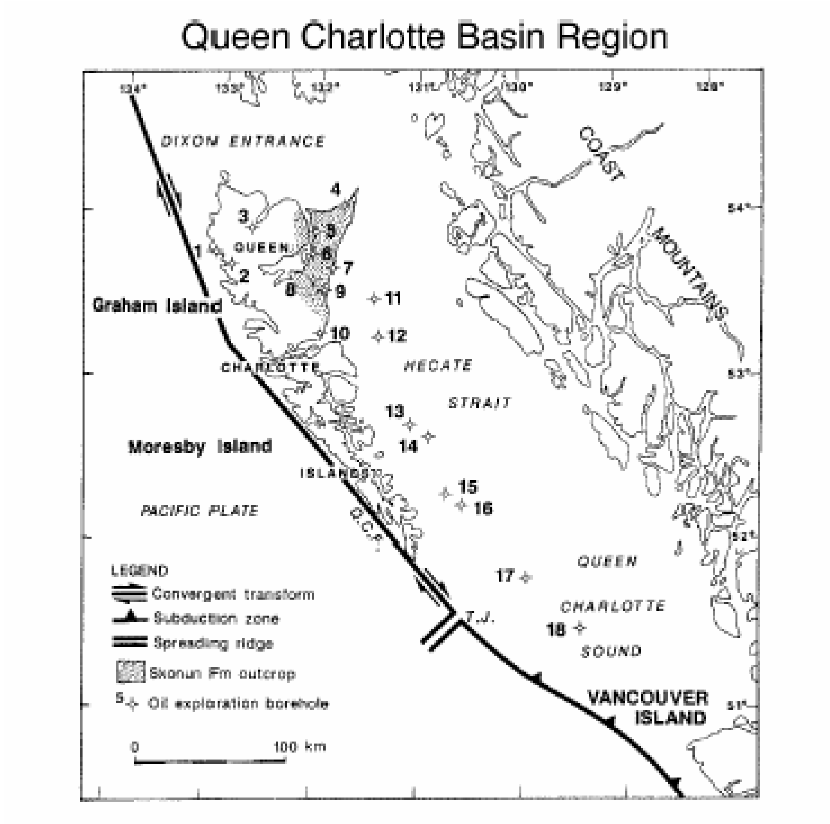

Figure 12-1. Major tectonic features and locations of previous drilling holes in the Queen Charlotte Basin (Strong *et al.* 2002).

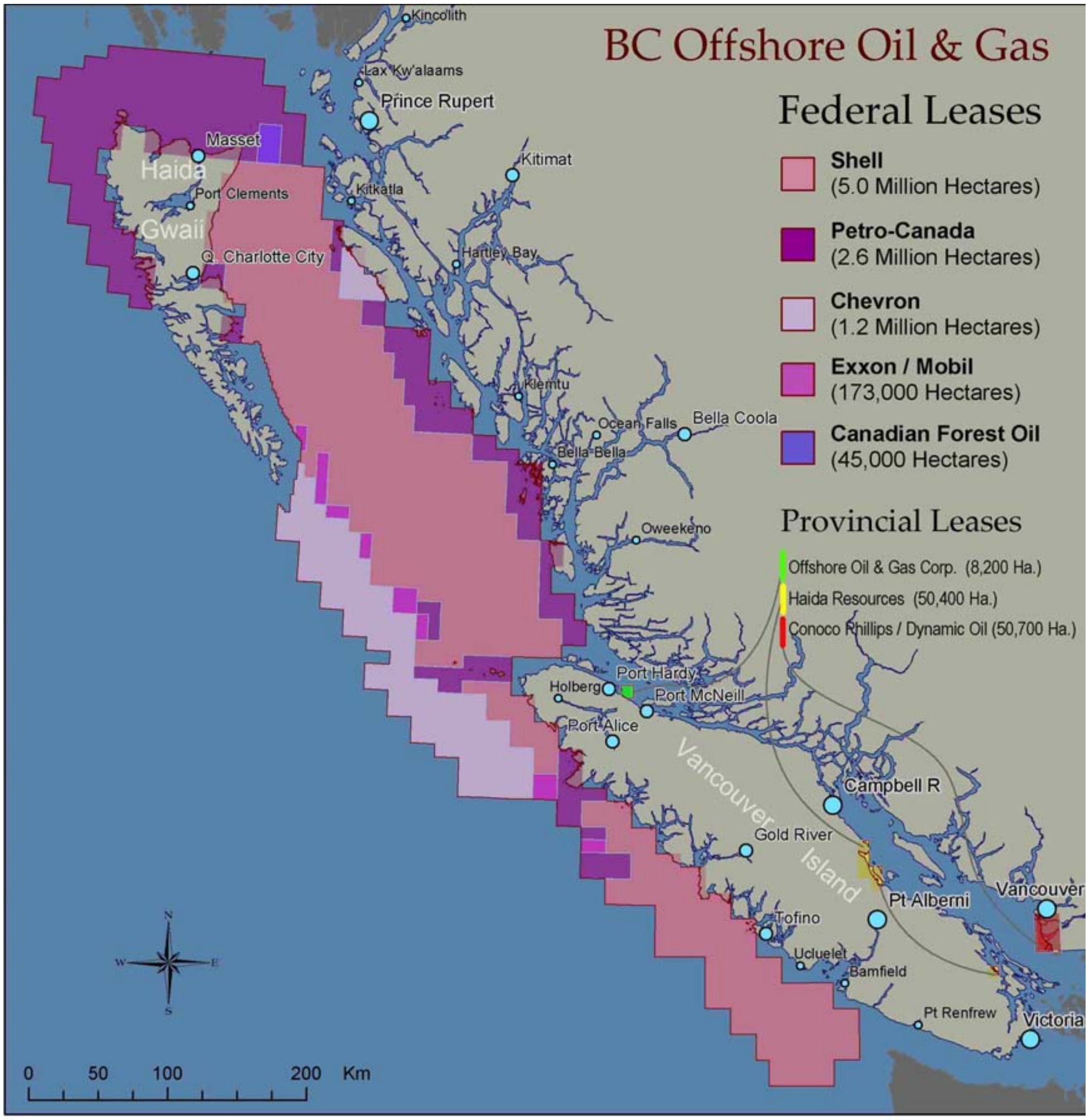

Figure 12-2. Offshore oil and gas leases in the central coast (Map used with permission by J. Ardron, Living Oceans Society, Sept. 2003).

Table 12-1. Potential oil and gas exploration and development concerns on various biota (modified from Strong *et al.* 2002).

Species/Group Lifestage	Seismic	Drilling Mud	Platform	Noise	Pipeline	Oil Spills
Salmon						
Egg				X		X?
Larval				X		X
Juvenile-E				X		X
Juvenile-C	X?			X?		
Adult						
Fishery	X?			?		X
Product				?		X?
Herring						
Egg						X
Larval	?					X?
Juvenile-C						X?
Adult	?					
Fishery						X
Product						X
Groundfish						
Egg				X?		
Larval				X?		
Juvenile	X?	?		?	X?	
Adult	X?	?	?	?		
Fishery	X?	?	+?	?	X?	?
Product		?				
Shellfish						
Egg	?			X?		
Larval	?			X?		X?
Juvenile	?	?		X?		
Adult	X?	?	?	?	X?	X?
Fishery	?	?	?	?	?	X?
Product		?		X?		
Seabirds						
Nesting	X	?	?	X		X
Adults	X	?	X	X		X
Marine Mammals						
Sea otters		?				X
River otters/mink						X
Seals		?				X
Sea lions		?				
Dolphins/Whales	X	?		X		X?

? = Unknown; X = known negative impacts; X? = uncertain but likely impacts; +? = possible positive impacts; Juvenile-E = juveniles in estuaries; Juvenile-C = juveniles in coastal areas.

Box 12.1. Additional Information on Oil and Gas Exploration and Development and Related Issues

- Additional information from scientific review and consultant reports:
  - Jacques Whitford Environmental LTD report: http://www.em.gov.bc.ca/Oil&gas/Offshore/JWLReport/intro.pdf;
  - Scientific Review Panel Report: http://www.em.gov.bc.ca/Oil&gas/offshore/OffshoreOilGasReport/Default.htm#REPORT%20OF;
  - PSARC Papers: http://sci.info.pac.dfo.ca/PSARC/resdocs/02-habitat.htm;
  - Physical Oceanography and Geology: (Cretney *et al.* 2002b);
  - Fate of oil: (Crawford *et al.* 2002);
  - Chemical properties of petroleum: (Cretney *et al.* 2002d);
  - Determining ecological risk of oil and gas: (Cretney *et al.* 2002c);
  - Bottom topography and potential hazards to industrial installations: (Strong *et al.* 2002).

- Opposition to lifting the offshore oil and gas moratorium: http://www.oilfreecoast.org/.

- Seismic testing: causes physical damage resulting in fish kills as well as possible lethal or sublethal effects to larvae, displacement and stress to birds and mammals. For more information of effects, as well as mitigating actions such as exclusion zones and timing, refer to: (Strong *et al.* 2002).

- Noise pollution: from seismic testing as well as from drilling and production operations may cause stress and disruption in wildlife, particularly whales and birds. For more information, refer to: (Ross *et al.* 2004; Strong *et al.* 2002; Jacques Whitford Environment Ltd. 2001; United States Geological Survey 2000).

- Conflict with fisheries: exclusion zones and buffers are required around platforms, anchors and pipelines to avoid collisions and damage that can lead to oil spills. Drilling mud may also cover fishing grounds. Fishing area may therefore be affected. Refer to: (Strong *et al.* 2002; Jacques Whitford Environment Ltd. 2001).

12.3. Other Emerging Issues

The Provincial Government assured the province that growth of the salmon aquaculture industry would occur with the lifting of the moratorium of new salmon aquaculture leases. Therefore, growth of this industry, particularly in the central coast is practically a certainty. New farms should be carefully sited to mitigate impacts. Ways to assess cumulative impacts of salmon farms should be studied and total contaminant loadings should be monitored. The lifting of the moratorium on new leases does present the opportunity to relocate poorly sited farms and ones that are too close to sensitive areas. In addition, the offshore culture of salmon should be considered. Potential impacts are unknown.

The central coast has a complicated geological history and contains many compounds that may be of future interest to the mining industry. Future environmental impacts will have to be assessed as they arise.

Alternative energy production, including wave, tidal and wind generation, is under consideration for marine waters in British Columbia. Impacts associated with infrastructure, including generators, transformers, and cabling, may be a source of future contaminants to the central coast if any of these industries develop.

Increased effects of globally or regionally produced contaminants will have to be monitored carefully and risks continually re-assessed. Contaminant transportation pathways may change with global climate change (Macdonald *et al.* 2003).

12.4. Cumulative Effects

Cumulative effects occur when two or more stressors interact to impact the environment. Impacts from various stresses may be additive (i.e. linear) or they may be synergistic (i.e. exponential). Synergism arises when environmental stressors interact in such a way so that the outcome is not additive, but multiplicative (Myers 1995). The *Canadian Environmental Assessment Act* requires that cumulative effects must be considered in all environmental reviews, as does the provincial environmental assessment legislation, the *BC Environmental Assessment Act* (Jamieson and Chew 2000). Though cumulative effects are acknowledged to be important; evaluating and quantifying them is not at all straight-forward and few scientists have adequately addressed these issues (Myers 1995).

Models have been used in attempt to understand cumulative impacts. Many are based on retrospective analyses of changes in land-use and its effects on terrestrial systems. One type of model, Instream Flow Incremental Model (IFIM), attempts to look at the effects of various parameters of flow regimes of streams. Some watershed-level studies have also made attempts to model cumulative impacts of logging (Jamieson and Chew 2000). By and far, such models are limited by the fact that they over-simplify extremely complex issues as the data needs for complicated models are often not met. Determining the pertinent parameters to model and how each will interact (linearly or synergistically) are other major challenges. Moreover, models attempting to evaluate cumulative impacts are difficult to test in order to evaluate how well they predict reality.

Another way to evaluate cumulative impacts is scope for growth experiments on indicator species (Jamieson and Chew 2000). However, an appropriate indicator species must be available and results may only be applicable to the population level and not the community or ecosystem level.

Environmental Impact Assessments often employ an interaction matrix to evaluate cumulative effects (Jamieson and Chew 2000). Though useful for identifying possible cumulative effects, they do not test for actual cumulative effects. As with other models, best guesses must be used to determine the cumulative effects function (additive or multiplicative).

Despite the importance of cumulative effects and the serious lack of theory to explain them, very little research is being done on cumulative effects (Jamieson and Chew 2000; Myers 1995). It must, therefore, be viewed as an important information gap.

Considering cumulative effects in the central coast pertains to several areas such as:

- Impacts of salmon farms in a local region: Is there a “carrying capacity” for number of pens in a certain region? What is it? What happens if it is exceeded?
- Numerous sources of chemical contaminants. For instance, increased PCP levels have been identified in copper rockfish near salmon farms (Levings 1994), although no direct link of the contamination to a particular source could be made since PCP is so widely used in BC waters.
- Synergistic effects of various chemicals. Wildlife may be exposed to and uptake many contaminants. Effects of contaminants are often synergistic, not additive.
- Effects of other threats, such as global climate change, on chemical contamination.

13. Conclusions

In comparison to other locations in BC, and indeed the world, the central coast is a relatively pristine environment with respect to chemical contamination. Its remote nature and low resident population have helped to preserve environmental quality in the region. Nonetheless, marine environmental quality in the central coast must be evaluated on its own terms rather than in comparison with other regions. A challenge exists to maintain marine environmental quality to the highest degree in this unique region.

Pollution and contamination issues do exist. Sources of contamination represent local, regional and global scales. Timescales of impact also vary from short to long-term.

- Local scale issues (small spatial component, short term effects) probably include:
  - sewage outfalls
  - some aquaculture impacts.

- Regional scale issues (broad scale, widespread or diffuse in nature, or local impact but for long time scales) include:
  - chronic oil pollution
  - cruise ship pollution
  - wood preservatives
  - sediment contamination in harbours (i.e. TBT, PAH, PCP, metals).

- Global scale issues (broad spatial scale and long temporal scale) include:
  - Bioaccumulation of persistent chemicals globally transported by various pathways such as atmospheric and ocean transport, in biota (i.e. salmon, whales), and in contaminated fish feed.

Although chemical contamination and pollution does occur, there are many positive examples of improvements that have taken place over the past few decades relating to regulatory control. These include banning PCBs and some OC pesticides, and the virtual elimination of dioxin and furan releases from pulp mills. Industry-driven improvements such as better aquaculture feed formulations and feeding techniques to reduce the amount of organic and chemical loading, as well as the development of vaccines to reduce the use of antibiotics in salmon farms, have also reduced contamination. Similarly, solutions are needed for other issues that may be affecting the central coast such as contamination from antifouling chemicals used on boats and aquaculture nets, contamination from wood preservatives, pollution from cruise ships, and POPs in salmon feed.

Public education programs such as the “Guide to Green Boating” and “Toxic Smart” (Georgia Strait Alliance), and the “Whale Friendly Lawn” (Various organizations around Puget Sound) will help to raise awareness of issues and to educate and inspire individuals to personally reduce sources of contamination and pollution.

More comprehensive solutions must be sought for global-scale contamination issues including world-wide control of persistent chemicals. The Stockholm Convention (2001) provides an international framework to eliminate the twelve most problematic POPs on a global scale. The long-range transport of persistent organic pollutants is probably the most critical chemical contamination issue threatening the central coast. Because controlling the source of contamination is so difficult, effort should instead be placed on developing monitoring programs to identify and monitor risks, as well as sampling and modeling exercises to track pollutants and identify pathways.

There are also many information gaps, uncertainties and unknowns that require more research on emerging issues such as:

- endocrine disrupting chemicals in pulp mill effluent;
- unregulated flame retardants;
- effects of relatively new and/or recently identified chemicals in the marine environment including pesticides used in salmon farming, new POPs, and degradation products of contaminants;
- contamination risks associated with oil and gas development including the fate and effects of contaminants in drilling muds and production water;
- effects of chronic oil pollution; and
- means of assessing marine ecosystem health.

The possibility of oil and gas exploration and subsequent development in the central coast represents a potential risk to biota. The development of this industry could, however, spur studies of the physical, chemical and biological environment of the central coast. The major challenge in identifying risks and evaluating and monitoring marine environmental quality in the central coast is the over-arching lack of data and information about this region.

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References

Addison, R. F. 1996. The use of biological effects monitoring in studies of marine pollution. Environmental Reviews **4**: 225-237.

Addison, R. F. 1998. Pacific marine and freshwater ecosystems. *In* Pierce, R. C., Whittle, D. M., and Bramwell, J. B. (*eds.*). Chemical contaminants in Canadian aquatic ecosystems. Canadian Government Publishing, Ottawa, Canada. 8-18, 229-263, 267-280, 292-303-303.

Alaska Department of Environmental Conservation. 2003. Cruise ship waste disposal and management. http://www.state.ak.us/local/akpages/ENV.CONSERV/press/cruise/cruise.htm.

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

Arkoosh, M. R., Casillas, E., Clemens, E., McCain, B. B., and Varanasi, U. 1991. Suppression of immunological memory in juvenile chinook salmon (*Oncorhynchus tshawytscha*) from an urban estuary. Fish & Shellfish Immunology **1**: 261-277.

Balfry, S. K., Albright, L. J., and Evelyn, T. P. T. 1996. Horizontal transfer of *Renibacterium salmoninarum* among farmed salmonids via the fecal-oral route. Diseases of Aquatic Organisms **25**: 63-69.

Barnes, K. K., Kolpin, D. W., Meyer, M. T., Thurman, E. M., Furlong, E. T., Zaugg, S. D., and Barber, L. B. 2002. Water-quality data for pharmaceuticals, hormones, and other organic wastewater contaminants in U.S. streams, 1999-2000. open-file report 02-94. USGS. Iowa city, Iowa.

Barry, K. L., Grout, J. A., Levings, C. D., Nidle, B. H., and Piercey, G. E. 2000. Impacts of acid mine drainage on juvenile salmonids in an estuary near Britannia Beach in Howe Sound, British Columbia. Canadian Journal of Fisheries and Aquatic Science **57**: 2032-2043.

Baussant, T., Sanni, S., Jonsson, G., Skadsheim, A., and Borseth, J. F. 2001a. Bioaccumulation of polycyclic aromatic compounds: 1. Bioconcentration in two marine species and in semipermeable membrane devices during chronic exposure to crude oil. Environmental Toxicology and Chemistry **20**: 1175-1184.

Baussant, T., Sanni, S., Skadsheim, A., Jonsson, G., Borseth, J. F., and Gaudebert, B. 2001b. Bioaccululation of polycyclic aromatic compounds: 2. Modeling bioaccumulation in marine organisms chronically exposed to disperal oil. Environmental Toxicology and Chemistry **20**: 1185-1195.

Birtwell, I. K. 1999. The effects of sediment on fish and their habitat. Canadian Stock Assessment Secretariat Research Document. 99/139. Fisheries and Oceans Canada. Pacific Science Advice and Review Committee Habitat Subcommittee.

Birtwell, I. K., Fink, R., Brand, D., Alexander, R., and McAllister, C. D. 1999. Survival of pink salmon (*Oncorhynchus gorbuscha*) fry to adulthood following a 10-day exposure to the aromatic hydrocarbon water-soluble fraction of crude oil and release to the Pacific Ocean. Canadian Journal of Fisheries and Aquatic Science **56**: 2087-2098.

Booth, J. 1998. Study to identify preliminary representative marine areas in the Queen Charlotte Sound Marine Region. Coastal and Ocean Resources Inc.

Brannon, E. L., Collins, K. C. M., Moulton, L. L., and Parker, K. R. 2001. Resolving allegations of oil damage to incubating pink salmon eggs in Price William Sound. Canadian Journal of Fisheries and Aquatic Science **58**: 1070-1076.

Bright, D. A., Cretney, W. J., Macdonald, R. W., Ikonomou, M. G., and Grundy, S. L. 1999. Differentiation of polychlorinated dibenzo-p-dioxin and dibenzofuran sources in coastal British Columbia, Canada. Environmental Toxicology and Chemistry **18**: 1097-1108.

Brooks, K. M. 2001. An evaluation of the relationship between salmon farm biomass, organic inputs to sediment, physiochemical changes associated with those inputs and the infaunal response-with emphasis on total sediment sulfides, total volatile sulfides, and oxidation-reduction potential as surrogate endpoints for biological monitoring. Aquatic Environmental Sciences. Port Townsend, Washington. http://www.salmonfarmers.org/.

Brooks, K. M., Stierns, A. R., Mahnken, C. V. W., and Blackburn, D. B. 2003. Chemical and biological remediation of the benthos near Atlantic salmon farms. Aquaculture **219**: 355-377.

Brown, E. D., Baker, T. T., Hose, J. E., Kocan, R. M., Marty, G. D., McGurk, M. D., Norcross, B. L., and Short, J. 1996. Injury to the early life history stages of Pacific herring in Prince WIllliam Sound after the *Exxon Valdez* oil spill. *In* Rice, S. D., Spies, R. B., Wolfe, D. A., and Wright, B. A. (*eds.*). Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland. 448-462.

Bue, B. G., Sharr, S., Moffitt, S. D., and Craig, A. K. 1996. Effects of the *Exxon Valdez* oil spill on pink salmon embryos and preemergent fry. *In* Rice, S. D., Spies, R. B., Wolfe, D. A., and Wright, B. A. (*eds.*). Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland. 619-629.

Burd, B., Macdonald, R., and Boyd, J. 2000. Punctuated recovery of sediments and benthic infauna: A 19-year study of tailings depostion in a British Columbia fjord. Marine Environmental Research **49**: 145-175.

Buser, H.-R., Muller, M. D., and Theobald, N. 1998. Occurrence of the pharmaceutical drug clofibric acid and the herbicide mecoprop in various Swiss lakes and in the North sea. Environmental Science & Technology **32**: 188-192.

Canadian Food Inspection Agency. 1997. Summary of marine toxin records in the Pacific region 1997. Burnaby, BC.

Clark, R. B. 2001. Marine pollution. Fifth Edition Clarendon Press, Oxford.

Collier, T. K., Krone, C. A., Krahn, M. M., Stein, J. E., Chan, S-L., and Varanasi, U. 1996. Petroleum exposure and associated biochemical effects in subtidal fish after the *Exxon Valdez* oil spill. *In* Rice, S. D., Spies, R. B., Wolfe, D. A., and Wright, B. A. (*eds.*). Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland. 671-683.

Conway, K. W. 1999. Hexactinellid sponge reefs on the British Columbia continental shelf: Geological and biological structure with a perspective on their role in the shelf ecosystem. Canadian Stock Assessment Secretariat Research Document. (99/192). http://www.dfo-mpo.gc.ca/csas/CSAS/English/Publications/Research_Doc_e.htm.

Cox, C. 1991. Chromated copper arsenate. Journal of Pesticide Reform **11**: 2-6.

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

Crawford, W. R. 2002. Physical characteristics of Haida eddies. Journal of Oceanography **58**: 703-713.

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

Cretney, W., Crawford, W., Masson, D., and Hamilton, T. 2002b. Physical oceanographic and geological setting of a possible offshore oil and gas industry in the Queen Charlotte Basin. Canadian Science Advisory Secretariat. 2002/004. Fisheries and Oceans Canada.

Cretney, W., Sinclair, A., Wright, C., and Burd, B. 2002c. Role of modelling in ecological risk assessment and management with emphasis on the offshore oil and gas industry. Canadian Science Advisory Secretariat. 2002/125. Fisheries and Oceans Canada.

Cretney, W., Yunker, M., and Yeats, P. 2002d. Biogeochemical benchmarks for source identification of contaminants from an offshore oil and gas industry. Canadian Science Advisory Secretariat. 2002/129. Fisheries and Oceans Canada.

Cretney, W. J. and Yunker, M. B. 2000. Concentration dependency of biota-sediment accumulation factors for chlorinated dibenzo-*p*-dioxins and dibenzofurans in dungeness crab (*Cancer magister*) at marine pulp mill sites in British Columbia, Canada. Environmental Toxicology and Chemistry **19(12)**: 3012-3023.

Daughton, C. G. and Ternes, T. A. 1999. Pharmaceuticals and personal care products in the environment: Agents of subtle change? Environmental Health Perspectives **107**: 907-944.

Davies, I. M., Rodger, G. K., Redshaw, J., and Stagg, R. M. 2001. Targeted environmental monitoring for the effects of medicines used to treat sea-lice infestation on farmed fish. ICERS Journal of Marine Science **58**: 477-485.

Desbarats, A. J. 2002. Temporal analysis of the flow rate and chemistry of discharge waters from 8-level, Lynx Mine, Myra Falls Operations, Vancouver Island, Canada. 2002 Denver Annual Meeting. Geological Society of America,

Dewailly, E., Nantel, A., Weber, J. P., and Meyer, F. 1989. High levels of PCBs in breast milk of Inuit women from Arctic Québec. Bulletin of Environmental Contamination and Toxicology **43**: 641-646.

Doerffer, J. W. 1992. Oil spill response in the marine environment. Pergamon Press, Oxford, New York, Seoul, Tokyo.

Downs, C. A., Shigenaka, G., Fauth, J. E., Robinson, C. E., and Huang, A. 2002. Cellular physiological assessment of bivalves after chronic exposure to silled *Exxon Valdex* crude oil using a novel molecular diagnostic biotechnology. Environmental Science & Technology **36**: 2987-2993.

Duncan, P. B. and Hooten, A. J. 1996. Influence of residual and applied oil on intertidal algal recruitment. *In* Rice, S. D., Spies, R. B., Wolfe, D. A., and Wright, B. A. (*eds.*). Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland. 238-248.

Easton, M. D. L., Luszniak, D., and Von der Geest, E. 2002. Preliminary examination of contaminated loadings in farmed salmon, wild salmon and commercial salmon feed. Chemosphere **46**: 1053-1074.

Elliott, J. E. and Harris, M. L. 2001. An ecotoxicological assessment of chlorinated hydrocarbon effects on bald eagle populations. Reviews in Toxicology **4**: 1-60.

Elliott, J. E., Martin, P. A., and Whitehead, P. E. 1997a. Organochlorine contaminants in seabird eggs from the Queen Charlotte Islands. *In* Vermeer, K. and Morgan, K. H. (*eds.*). The ecology, status, and conservation of marine and shoreline birds of the Queen Charlotte Islands. Environment Canada, Delta. 137-146.

Elliott, J. E., Noble, D. G., Norstrom, R. J., and Whitehead, P. E. 1989. Organochlorine contaminants in seabird eggs from the Pacific coast of Canada, 1971-1986. Environmental Monitoring and Assessment **12**: 67-82.

Elliott, J. E. and Scheuhammer, A. M. 1997. Heavy metal and metallothionein concentrations in seabirds from the Pacific coast of Canada. Marine Pollution Bulletin **34**: 794-801.

Elliott, J. E., Wilson, L. K., Langelier, K. M., Mineau, P., and Sinclair, P. H 1997b. Secondary poisoning of birds of prey by the organophosphorus insecticide, phorate. Ecotoxicology **6**: 219-231.

Ellis, D. V. and Hoover, P. M. 1990. Benthos tailings beds from an abandoned coastal mine. Marine Pollution Bulletin **21**: 477-480.

Ellis, D. V., Poling, G. W., and Baer, R. L. 1995. Submarine tailings disposal (STD) for mines: an introduction. Marine Georesources and Geotechnology **13**: 3-18.

ENKON Environmental Limited. 1999. Sources and releases of toxic substances in wastewaters within the Georgia Basin. 1004-003. Prepared for Environment Canada. Surrey, British Columbia.

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

Environmental Research Foundation. 1998. Drug's in the water. http://www.rachel.org/bulletin/index.cfm?issue_ID=501. (Rachel`s Environmental Health News #614)

Estes, J. A., Bacon, C. E., Jarman, W. M., Norstrom, R. J., Anthony, R. G., and Miles, A. K. 1997. Organochlorines in sea otters and bald eagles from the Aleutian Archipelago. Marine Pollution Bulletin **34**: 486-490.

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

EXTOXNET. 2003a. Glyphosate. http://ace.ace.orst.edu/info/extoxnet/pips/glyphosa.htm.

EXTOXNET. 2003b. The extension toxicology network. http://ace.orst.edu/info/extoxnet/.

EXTOXNET. 2003c. Triclopyr. http://ace.ace.orst.edu/info/extoxnet/pips/triclopy.htm.

Fisheries and Oceans Canada. 2000. The effects of salmon farming in British Columbia on the management of wild salmon stocks. Report of the Auditor General of Canada.

Fisheries and Oceans Canada. 2003. Fishing communities in transition: The Gislason review. http://www-comm.pac.dfo-mpo.gc.ca/publications/Gislason/.

Frankowski, K. and Hall, K. J. 1999. Using constructed wetlands for the treatment of woodwaste leachate. Means, J. L. and Hinchee, R. E. Wetlands & Remediation: An International Conference. 325-332 Battelle Press, Ohio.

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

Gardner, J. and Peterson, D. L. 2003. Making sense of the salmon aquaculture debate: Analysis of issues related to netcage salmon farming and wild salmon in British Columbia. Pacific Fisheries Resource Conservation Council. http://www.fish.bc.ca. 2003.

Georgia Strait Alliance. 2003. Green boating program. http://www.georgiastrait.org/CleanBoating/disposalsites.php.

Gorecki, K. and Wallace, B. 2003. Ripple effects: The need to assess the impacts of cruise ships in Victoria, BC. Vancouver Island Public Interest Research Group.

Grant, S. C. H. and Ross, P. S. 2002. Southern resident killer whales at risk: Toxic chemicals in the British Columbia and Washington environment. Canadian Technical Report Of Fisheries and Aquatic Sciences **2412**.

Grout, J. A. and Levings, C. D. 2001. Effects of acid mine drainage from an abandoned copper mine, Britannia Mines, Howe Sound, British Columbia, Canada, on transplanted blue mussels (*Mytilus edulis*). Marine Environmental Research **51**: 265-288.

Harding, L. and Goyette, D. 1989. Metals in northeast Pacific coastal sediments and fish, shrimp, and prawn tissues. Marine Pollution Bulletin **20**: 187-189.

Harding, L. E. and Englar, J. R. 1989. The *Nestucca* oil spill: Fate and effects to May 31, 1989. Reg. Prog. Rep. 89-11. Environment Canada, Conservation and Protection, Environmental Protection, Pacific Region.

Harfenist, A., Sloan, N. A., and Bartier, P. M. 2002. Living marine legacy of Gwaii Haanas. III: Marine bird baseline to 2000 and marine bird-related management issues throughout the Haida Gwaii region. Parks Canada technical reports in ecosystem science No. 36. 036. Parks Canada.

Harvey, B and MacDuffee, M. 2002. Ghost runs: The future of wild salmon on the north and central coasts of British Columbia. Raincoast Conservation Society. www.raincoast.org.

Haya, K., Burridge, L. E., and Chang, B. D. 2001. Environmental impacts of chemical wastes produced by the salmon aquaculture industry. ICERS Journal of Marine Science **58**: 492-496.

Heilskov, A. C. and Holmer, M. 2001. Effects of benthic fauna on organic matter mineralization in fish-farm sediments: Importance of size and abundance. ICERS Journal of Marine Science **58**: 427-434.

Herwig, R. P., Gray, J. P., and Weston, D. P. 1997. Antibacterial resistant bacteria in surficial sediments near salmon net-cage farms in Puget Sound, Washington. Aquaculture **149**: 263-283.

Hewitt, M. and Servos, M. 2001. An overview of substances present in Canadian aquatic environments associated with endocrine disruption. Water Quality Research Journal of Canada **36**: 191-213.

Hilborn, R. 1996. Detecting population impacts from oil spills: A comparison of methodolofies. *In* Rice, S. D., Spies, R. B., Wolfe, D. A., and Wright, B. A. (*eds.*). Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland. 639-644.

Hingston, J. A., Collins, C. D., Murphy, R. J., and Lester, J. N. 2000. Leaching of chromated copper arsenate wood preservatives: A review. Environmental Pollution **111**: 53-66.

Holmer, M., Lassus, P., Stewart, J. E., and Wildish, D. J. 2001. ICES symposium on environmental effects of mariculture - Introduction. ICERS Journal of Marine Science **58**: 363-368.

Hourston, W. R. 1958. Effects of black-headed budwom control on salmon and trout in British Columbia. Conference on forest insect defoliators, insecticide spraying, and resultant mortality of fish and fish-food organisms. Department of Agriculture; Department of Fisheries Fisheries Research Board, Ottawa. 1958.

Howes, D., Harper, J. R., and Owens, E. H. 1993. Physical shore-zone mapping system for British Columbia. Sidney, B.C. : Coastal & Ocean Resources Inc.

Hutton, K. E. and Samis, S. C. 2000. Guidelines to protect fish and fish habitat from treated wood used in aquatic environments in the Pacific region. Canadian Technical Report of Fisheries and Aquatic Sciences **2314**: vi + 34 p.

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

Irons, D. B., Kendall, S. J., Erickson, W. P., McDonald, L. L., and Lance, B. K. 2000. Nine years after the *Exxon Valdez* oil spill: Effects on marine bird populations in Prince WIlliam Sound, Alaska. The Condor **102**: 723-737.

Jacques Whitford Environment Ltd. 2001. British Columbia offshore oil and gas technology update. JWEL Project No. BCV50229. Jacques Whitford Environmental Ltd. Burnaby, BC. www.jacqueswhitford.com.

Jaffe, D., Anderson, T., Covert, D., Kotchenruther, R., Trost, B., Danielson, J., Simpson, W., Berntsen, T., Karlsdottir, S., Blake, D., Harris, J., Carmichael, G., and Uno, I. 1999. Transport of Asian air pollution to North America. Geophys.Res.Letts. **26**: 711-714.

Jamieson, G. S. and Chew, L. 2000. Cumulative effects assessments: An evaluation of DFO science research options. Canadian Stock Assessment Secretariat. 2000/105. Fisheries and Oceans Canada; Pacific Biological Station. Nanaimo, BC.

Jamieson, G. S., Chew, L., Gillespei, G., Robinson, A., Bendell-Young, L., Heath, W., Bravender, B., Tompkins, A., Nishimura, D., and Doucette, P. 2001. Phase 0 review of the environmental impacts of intertidal shellfish aquaculture in Baynes Sound. Canadian Science Advisory Secretariat Research Document. 2001/125.

Jamieson, G. S. and Olesiuk, P. F. 2001. Salmon farm - Pinniped interactions in British Columbia: An analysis of predator control, its justification and alternative approaches. Canadian Science Advisory Secretariat Research Document. 2001/142.

Janz, D. M., McMaster, M. E., Weber, L. P., Munkittrick, K. R., and Van der Kraak, G. J. 2001. Recovery of ovary size, follicle cell apoptosis, and HSP70 expression in fish exposed to bleached pulp mill effluents. Canadian Journal of Fisheries and Aquatic Science **58**: 620-625.

Jewett, S. C., Dean, T. A., Woodin, B. R., Hoberg, M. K., and Stegeman, J. J. 2002. Exposure to hydrocarbons 10 years after the *Exxon Valdez* oil spill: Evidence from cytochrome P4501A expression and biliary FACs in nearshore demersal fishes. Marine Environmental Research **54**: 21-48.

Johannessen, D., Verrin, S., Birch, R., Borg, K., and Pringle, J. 2003a. An ecological overview of British Columbia's central coast integrated managment area. (DRAFT).

Johannessen, D. I., Haggarty, D., and Pringle, J. 2003b. A science-based boundary for the central coast integrated management area (draft). (DRAFT). Prepared for the DFO Pacific Science Advisory Review Committee.

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

Kannan, K., Guruge, S., Thomas, N. J., Tanabe, S., and Giesy, J. P. 1998. Butyltin residues in southern sea otters (*Enhydra lutris nereis*) found dead along California coastal waters. Environmental Science and Technology **32**: 1169-1175.

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

Kruzynski, G. M. 2000. Cadmium in BC farmed oysters: A review of available data, potential sources, research needs and possible mitigation strategies. Canadian Stock Assessment Secretariat. 2000/104.

Kruzynski, G. M., Addison, R. F., and Macdonald, R. W. 2002. Proceedings of a workshop on possible pathways of cadmium into the Pacific oyster *Crassostrea gigas* as cultured on the coast of British Columbia, Institute of Ocean Sciences, March 6-7, 2001. Canadian Technical Report of Fisheries and Aquatic Sciences. 2405. Fisheries and Oceans Canada.

Kuhnlein, H. V. 1995. Benefits and risks of traditional food for indigenous peoples: Focus on dietary intakes of Arctic men. Canadian Journal of Physiology and Pharmacology **73**: 765-771.

Kurz, W. A., Apps, M. J., Commeau, P. G., and Trofymow, J. A. 1996. The carbon budget of British Columbia's forests, 1920-1989: Preliminary analysis and recommendations for refinements. FRDA 261.

Leaney, A. D. and Morris, S. 1981. The Bella Coola River estuary status of environmental knowledge to 1981. Special Estuary Series. 10. Fisheries and Oceans Canada and Environment Canada.

Levings, C. D. 1994. Some ecological concens for the net-pen culture of salmon of the Northest Pacific and Atlantic Oceans, with special reference to British Columbia. Aquaculture **4**: 65-141.

Levings, C. D., Ervik, A., Johannessen, P., and Aure, J. 1995. Ecological criteria used to help site fish farms in fjords. Estuaries **18**: 81-90.

Levings, C. D., Helfield, J. M, Stucchi, D. J, and Sutherland, T. F. 2002a. A perspective on the use of performance based standards to assist in fish habitat management on the seafloor near salmon net pen Operations in British Columbia. Canadian Science Advisory Secretariat Research Document. (2002/075). http://www.dfo-mpo.gc.ca/csas/.

Levings, C. D., Kieser D., Jamieson, G. S, and Dudas, S. 2002b. Marine and estuarine alien species in the Strait of Georgia, British Columbia. *In* Claudi, R., Nantel, P., and Muckle-Jeffs, E. (*eds.*). Alien invaders in Canada's waters, wetlands, and forests. Natural Resources Canada, Canadian Forest Service, Ottawa.

Lewis, M. A. and Metaxas, A. 1991. Copper tolerance of *Skeletonema costatum* and *Nitzschia thermalis*. Aquatic Toxicology **19**: 265-280.

Little, E. E. and Calfee, R. D. 2000. The effects of UVB radiation on the toxicity of fire-fighting chemicals. Missoula, MT.

Loughlin, T. R., Ballachey, B. E., and Wright, B. A. 1996. Overview of studies to determine injury caused by the *Exxon Valdez* oil spill to marine mammals. *In* Rice, S. D., Spies, R. B., Wolfe, D. A., and Wright, B. A. (*eds.*). Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland. 798-808.

Macdonald, R. W. and Crecelius, E. A. 1994. Marine sediments in the Strait of Georgia, Juan de Fuca Strait and Puget Sound: What can they tell us about contamination? *In* Wilson, R. C. H., Beamish, R. J., Aitkens, F., and Bell, J. (*eds.*). Review of the marine environment and biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proceedings to the BC/Washington symposium on the marine environment, January 13 & 14, 1994. Can. J. Fish. Aquat. Sci. 1948: 101-134.

Macdonald, R. W., Mackay, D., Li, Y.-F., and Hickey, B. M. How will global climate change affect risks from long-range transport of persistent organic pollutants? 2003.

Macdonald, R. W., Morton, B, Addison, R. F., and Johannessen, S. C. 2002. Marine environmental contaminant issues in the North Pacific: What are the dangers and how do we identify them? *In* Perry, R. I, Livingston, P, and Bychkov, A. S (*eds.*). PICES Science: The First Ten Years and a Look Into the Future. 61-86.

Mackas, D. L. and Galbraith, M. D. 2002. Zooplankton distribution and dynamics in a north Pacific eddy of coastal origin: 1. Transport and loss of continental marine species. Journal of Oceanography **58**: 725-738.

Marsden, A. D., DeWreede, R. E., and Levings, C. 2003. Survivorship and growth of *Fucus gardneri* after transplant to an acid mine drainage-polluted area. Marine Pollution Bulletin **46**: 65-73.

Marty, G. D., Okihiro, M. S., Brown, E. D., Hanes, D., and Hinton, D. E. 1999. Histopathology of adult Pacific herring in Prince William Sound, Alaska, after the *Exxon Valdez* oil spill. Canadian Journal of Fisheries and Aquatic Science **56**: 419-426.

McLeay, D. 2002. Ecologically significant concentrations of endocrine-disruptive chemicals (EDCs) in wastewaters. McLeay Environmental Ltd. Victoria, BC.

Mining Technology. 2003. Myra Falls, zinc, copper, gold and silver mine. http://www.mining-technology.com/projects/myra/.

Ministry of Agriculture, Food and Fisheries. 2001. Tenures included in the salmon aquaculture policy framework cap.

Ministry of Employment & Investment (Economics Branch), Terry, E., Booth, J, and Komori, V. 2000. Central coast land & coastal resource management plan: Socio-economic & environmental/marine base case: Final report. Province of British Columbia.

Ministry of Environment. 1991. Summary of municipal treatment facilities.

Ministry of Environment, Lands and Parks and Environment Canada. 2000. Water quality trends in selected British Columbia waterbodies. http://wlapwww.gov.bc.ca/wat/wq/trendsWQS/WatTrendFeb29.pdf.

Ministry of Forests. 2001. Annual performance report. http://www.for.gov.bc.ca/hfd/pubs/docs/mr/annual/ar_2000-01/.

Ministry of Sustainable Resources Management Coast and Marine Planning Branch. 2002. North Island Straits coastal plan.

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

Ministry of Water, Land and Air Protection. 2003b. West coast offshore traffic risk management project. http://wlapwww.gov.bc.ca/eeeb/taskforc/vesselrpt3.htm.

Miranda, C. D. and Zemelman, R. 2002. Bacterial resistance to oxytetracycline in Chilean salmon farming. Aquaculture **212**: 31-47.

Moore, M. R., Vetter, W., Gaus, C., Shaw, G. R., and Muller, J. F. 2002. Trace organic compounds in the marine environment. Marine Pollution Bulletin **45**: 62-68.

Morton, A. B. and Symonds, H. K 2002. Displacement of *Orcinus orca* (L.) by High Amplitude Sound in British Columbia, Canada. International Council for the Exploration of the Seas (ICES) Journal of Marine Sciences **59**: 71-80.

Mos, L., Jack, J., Cullon, D., Montour, L., Alleyne, C., and Ross, P. S. 2003. The importance of marine foods to a near-urban First Nation community in coastal British Columbia, Canada: Towards a risk-benefit assessment. Journal of Toxicology and Environmental Health **in press**.

Myers, N. 1995. Environmental unknowns. Science **269**: 358-360.

Nash, C. E. 2000. The net-pen salmon farming industry in the Pacific Northwest. NOAA Tech. Memo. NMFS-NWFSC-49. US Department of Commerce.

Nash, C. E., Iwamoto, R. N., and Mahnken, C. V. W. 2000. Aquaculture risk management and marine mammal interactions in the Pacific Northwest. Aquaculture **183**: 307-323.

Noakes, D. J., Beamish, R. J., and Kent, M. 2000. On the decline of Pacific salmon and speculative links to salmon farming in British Columbia`. Aquaculture **183**: 363-386.

Norcross, B. L., Brown, E. D., Foy, R. J., Frandsen, M., Gay, S. M., Kline, T. C. Jr., Mason, D. M., Patrick, E. V., Paul, A. J., and Stockesbury, K. D. E. 2001. A synthesis of the life history and ecology of juvenile Pacific herring in Prince William Sound, Alaska. Fisheries Oceanography **10**: 42-57.

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

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

O'Kane, M., Januszewski, S., and Dirom, G. 2001. Waste rock cover system field trials at the Myra Falls operation - A summary of three years of performance monitoring. http://www.okane-consultants.com/.

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

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

Ocean's Blue Foundation. 2003. Cruise related links. http://www.oceansblue.org/bluetourism/chartacourse/cruiseship/cruiselinks.html.

Office of the Auditor General of British Columbia. 2003. Managing contaminated sites on provincial lands. 5. National Library of Canada Cataloguing in Publication data. Victoria, BC.

Olesiuk, P. F. and Bigg, M. A. 1988. Seals and sea lions on the British Columbia coast. Department of Fisheries and Oceans, Nanaimo.

Padma, T. V., Hale, R. C., and Roberts, M. H., Jr. 1998. Toxicity of water-soluble fractions derived from whole creosote and creosote-contaminated sediments. Environmental Toxicology and Chemistry **17**: 1606-1610.

Paone, S. 2000. Farmed and dangerous: Human health risks associated with salmon farming. Friends of Clayquot Sound. Tofino, BC. http://www.farmedanddangerous.org/.

Paone, S. 2001. Industrial disease: The risk of disease transfer from farmed to wild salmon. A Friends of Clayquot Sound Report. http://www.farmedanddangerous.org/.

Pearson, W. H., Elston, R. A., Bienert, R. W., Drum, A. S., and Antrim, L. D. 1999. Why did the Prince William Sound, Alaska, Pacific herring (*Clupea pallasi*) fisheries collapse in 1993 and 1994? Review of hypotheses. Canadian Journal of Fisheries and Aquatic Science **56**: 711-737.

Pellettieri, M. B., Hallenbeck, W. H., Brenniman, G. R., Cailas, M., and Clark, M. 1996. PCB intake from sport fishing along the northern Illinois shore of Lake Michigan. Bulletin of Environmental Contamination and Toxicology **57**: 766-770.

People for Puget Sound and Georgia Strait Alliance. 1995. Puget Sound-Georgia Basin sewage report. http://www.pugetsound.org/sewage/report/default.htm.

Peterson, C. H., McDonald, L. L., Green, R. H., and Erickson, W. P. 2001. Sampling design begets conclusions: The statistical basis for detection of injury to and recovery of shoreline communities after the 'Exxon Valdez' oil spill. Marine Ecology Progress Series **210**: 255-283.

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

Pohle, G., Frost, B., and Findlay, R. 2001. Assessment of regional benthic impact of salmon mariculture within the Letang Inlet, Bay of Fundy. ICERS Journal of Marine Science **58**: 417-426.

Poling, G. W., Ellis, D. V., Murray, J. W., Parsons, T. R., and Pelletier, C. A. 2002. Underwater tailing placement at Island Copper Mine: A success story. Society for Mining, Metallurgy and Exploration, Littleton, Colorado.

Quinsam Coal Corporation. 2003. Home page. http://www.quinsam.com/index.html.

Rainbow, P. S. 1995. Biomonitoring of heavy metal availability in the marine environment. Marine Pollution Bulletin **31**: 183-192.

Reitsema, T. J., Thompson, J. A. J., Scholtens, P., and Spickett, J. T. 2002. Further recovery of northeast Pacific neogastropods from imposex related to tributyltin contamination. Marine Pollution Bulletin **44**: 257-261.

Rice, S. D., Spies, R. B., Wolfe, D. A., and Wright, B. A. 1996. Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium. (18). 1-16.

Ross, P. S. 2000. Marine mammals as sentinels in ecological risk assessment. Human and Ecological Risk Assessment **6**: 29-46.

Ross, P. S. and Birnbaum, L. S. 2003. Integrated human and ecological risk assessment: A case study of persistent organic pollutants (POPs) in humans and wildlife. Human and Ecological Risk Assessment **9:1**: 303-324.

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

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

Ross, P. S. and Troisi, G. M. 2001. Pinnipeds. *In* Shore, R. F. and Rattner, B. A. (*eds.*). Ecotoxicology of wild mammals. John Wiley & Sons, New York.

Rowland, S., Donkin, P., Smith, E., and Wraige, E. 2001. Aromatic hydrocarbon "humps" in the marine environment: Unrecognized toxins? Environmental Science & Technology **35**: 2640-2644.

Samis, S. C., von Schuckmann, S., and Wan, M. T. 1992. Guidelines for the protection of fish and fish habitat during use of glyphosate and other selected forestry herbicides in coastal British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences. 2176.

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

Shaw, R. W., Kent, M., and Adamson, M. L. 1998. Modes of transmission of *Loma salmonae* (Microsporidia). Diseases of Aquatic Organisms **33**: 151-156.

Skalski, J. R., Coats, D. A., and Fukuyama, A. K. 2001. Criteria for oil spill recovery: A case study of the intertidal community of Prince WIlliam Sound, Alaska, following the *Exxon Valdez* oil spill. Environmental Management **28**: 9-18.

Sloan, N. A. 1999. Oil impacts on cold-water marine resources: A review relevant to Parks Canada's evolving marine mandate. National Parks Occasional paper. 11. Parks Canada.

Sol, S. Y., Johnson, L. L., Horness, B. H., and Collier, T. K. 2000. Relationship between oil exposure and reprductive parameters in fish collected following the *Exxon Valdez* oil spill. Mar.Pollut.Bull. **40**: 1139-1147.

Spies, R. B., Rice, S. D., Wolfe, D. A., and Wright, B. A. 1996. The effects of the *Exxon Valdez* oil spill on the Alaskan coastal environment. *In* Spies, R. B., Rice, S. D., Wolfe, D. A., and Wright, B. A. (*eds.*). Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society Symposium 18. American Fisheries Society, Bethesda, Maryland. 1-16.

St-Hilaire, S., Ribble, C. S., Stephen, C., Anderson, E., Kurath, G., and Kent, M. L. 2002. Epidemiological investigation of infectious hematopoietic necrosis virus in salt water net-pen reared Atlantic salmon in British Columbia, Canada. Aquaculture **212**: 49-67.

Statistics Canada. 2003. Population Statistics. http://www.statcan.ca/.

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

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

Strong, D. S, Gallagher, P., and Muggeridge, D. 2002. British Columbia offshore hydrocarbon development: Report of the scientific review panel. Report of the Scientific Review Panel. BC Ministry of Energy and Mines.

Stucchi, D. J, Sutherland, T. F, Levings, C. D., and Helfield, J. M. 2002. Wide area and near-field dissobed oxygen variations in the Broughton Archipelago. *In* Hargrave, B. T. (*eds.*). Environmental studies for sustainable aquaculture (ESSA): 2002 workshop report. Canadian Technical Report of Fisheries and Aquatic Sciences.2411. v-117.

Sutherland, T. F, Martin, A. J., and Levings, C. D. 2001. Characterization of suspended particulate matter surrounding a salmonid net-pen in the Broughton Archipelago, British Columbia. ICERS Journal of Marine Science **58**: 404-410.

Tester, M., Ellis, D. V., and Thompson, J. A. J. 1996. Neogastropod imposex for monitoring recovery from marine TBT contamination. Environmental Toxicology and Chemistry **15**: 560-567.

Thompson, J. A. J. and Stewart, C. 1994. Organotin compounds in the coastal biota of British Columbia -an overview. Canadian technical report of hydrography and ocean sciences. 155. Department of Fisheries and Oceans Canada. Sidney, BC.

Thomson, R. E. 1981. Oceanography of the British Columbia Coast. 56. Canadian Special Publication of Fisheries and Aquatic Sciences. Ottawa, Ontario.

Totland, G. K., Hjeltnes, B. K., and Flood, P. R. 1996. Transmission of infectious salmon anaemia (ISA) through natural secretions and excretions from infected smolts of Atlantic salmon (*Salmo salar*) during their presymptomatic phase. Diseases of Aquatic Organisms **26**: 25-31.

Transport Canada. 2003. http://www.tc.gc.ca.

United States Environmental Protection Agency. 1997. Special report on environmental endocrine disruption: An effects assessment and analysis. EPA-630-R096-012. Prepared for the Risk Assessment Forum, U.S. Environmental Protection Agency. Washington, D.C.

United States General Accounting Office. 2000. Marine pollution: Progress made to reduce marine pollution by cruise ships, but important issues remain. Report to congressional requesters GAO-RCED-00-48.

United States Geological Survey. 2000. Water quality in the Puget Sound Basin. Circular 1216.

van Aggelen, G. 2002. Emamactin benzoate feed study on crabs and prawns. 2002 Pesticide Information Exchange. Environment Canada, Pacific and Yukon Region,

van Oostdam, J., Gilman, A., Dewailly, E., Usher, P., Wheatley, B., Kuhnlein, H., Neve, S., Walker, J. L., Tracy, B., Feeley, M., Jerome, V., and Kwavnick, B. 1999. Human health implications of environmental contaminants in Arctic Canada: A review. Science of the Total Environment **230**: 1-82.

Vancouver Port Authority. 2003. Press release: Port of Vancouver celebrates two decades of consecutive growth in cruise sector. http://www.portvancouver.com/media/news_2002_11_4.html.

Volpe, J. 2002. Super un-natural: Atlantic salmon in BC waters. David Suzuki Foundation. http://www.davidsuzuki.org/.

Waldichuk, M. 1979. Ecological impact of logs. Marine Pollution Bulletin **10**: 2-4.

Waldichuk, M. 1983. Pollution in the Strait of Georgia: A review. Canadian Journal of Fisheries and Aquatic Science **40**: 1142-1167.

Waldichuk, M. 1984. Sewage pollution in British Columbia in perspective. Presented at the workshop on municipal marine discharge; Vancouver, BC; 14-15 February 1984. Fisheries and Oceans Canada,

West Coast Offshore Exploration Environmental Assessment Panel. 1986. Offshore hydrocarbon exploration: Report and recommendations of the west coast offshore exploration environmental assessment panel. (105/37).

West, J., O'Neill, S., Lippert, G., and Quinnell, S. 2001a. Toxic contaminants in marine and anadromous fishes from Puget Sound, Washington: Results of the Puget Sound ambient monitoring program fish component, 1989-1999. 98501-1091. Washington Department of Fish and Wildlife. Olympia, WA.

West, J. E., O'Neill, S. M., Lomax, D., and Johnson, L. 2001b. Implications for reproductive health in rockfish (*Sebastes* spp) from Puget Sound exposed to polychlorinated biphenyls. The Puget Sound Water Quality Authority. Bellevue, Washington.

West, P., Fyles, T. M., King, B., and Peeler, D. C. 1994. The effects of human activity on the marine environment of the Georgia Basin: Present waste loadings and future trends. *In* Wilson, R. C. H., Beamish, R. J., Aitkens, F., and Bell, J. (*eds.*). Review of the Marine Environment and Biota of Strait of Georgia, Puget Sound and Juan de Fuca Strait: Proceedings of the BC/Washington Symposium on the Marine Environment, January 13 & 14, 1994. Can. Tech. Rep. Fish. Aquat. Sci. 1948: 9-35.

Whitehead, P. W. 1989. Toxic chemicals in the great blue heron (*Ardea Herodius*) in the Strait of Georgia. *In* Vermeer, K. and Butler, R. W. (*eds.*). The Status and Ecology of Marine Birds in the Strait of Georgia, British Columbia.

Whitney, F. and Robert, M. 2002. Structure of Haida eddies and their transport of nutrient from coastal margins into the NE Pacific ocean. Journal of Oceanography **58**: 715-723.

Wilington, R. P. 1987. Forestry herbicides and the aquatic environment. The Forestry Chronicle 250-252.

Williams, E. H. and Quin, T. J. II. 2000a. Pacific herring, *Clupea pallasi*, recruitment in the Bering Sea and north-east Pacific ocean, I: Relationships among different populations. Fisheries Oceanography **9**: 285-299.

Williams, E. H. and Quin, T. J. II. 2000b. Pacific herring, *Clupea pallasi*, recruitment in the Bering Sea and north-east Pacific ocean, II: Relationships to environmental variables and implications for forecasting. Fisheries Oceanography **9**: 300-315.

Williamson, C. J., Levings, C. D., Macdonald, J. S., White, E., Kopeck, K., and Pendray, T. 2000. A preliminary assessment of wood debris at four log dumps on Douglas channel, British Columbia: Comparison of techniques. Canadian manuscipt report of fisheries and aquatic sciences. 2539. Fisheries and Oceans Canada. Burnaby, BC.

Wu, R. S. S. 1995. The environmental impact of marine fish culture: Towards a sustainable future. Marine Pollution Bulletin **31**: 4-12.

Yunker, M. B. and Cretney, W. J. 1996. Dioxins and furans in crab hepatopancreas: Use of principal components analysis to classify congener patterns and determine linkages to contamination sources. *In* Servos, M. R., Munkittrick, K. R., Carey, J. H, and Van der Kraak, G. J. (*eds.*). Environmental Fate and Effects of Pulp and Paper Mill Effluents. St. Lucie Press, Delray Beach. 315-325.

Yunker, M. B., Cretney, W. J., and Ikonomou, M. G. 2002. Assessment of chlorinated dibenzo-*p*-dioxin and dibenzofuran trends in sediment and crab hepatopancreas from pulp mill and harbour sites using multivariate- and index-based approaches. Environmental Science and Technology.

Zacharias, M. A., Howes, D. E., Harper, J. R., and Wainwright, P. 1998. The British Columbia marine ecosystem classification: Rational, development, and verification. Coastal Management **26**: 105-124.

Appendix I. Queen Charlotte: Who was she?

In writing this report, the primary author, became very curious about just who Queen Charlotte was. After reading and writing about Queen Charlotte Strait, Queen Charlotte Sound, Queen Charlotte Islands, Queen Charlotte Basin, Queen Charlotte City, and not to mention other various things named after this region, she just had to know: Who was Queen Charlotte? In case any readers had similar inquiries, here is the answer.

Sophie Charlotte, 1744-1818

A young princess, Sophie Charlotte, from the tiny German principality of Mecklenburg-Straits, married King George III from England in August of 1761, at the age of 17. During the reign of George III (1760-1820) England developed into a far-reaching empire through the colonization of Australia, New Zealand, and India, and by conquering Canada and the West Indies. However, this empire also suffered the loss of the American colonies (1776), the tremors of the French Revolution (1789), and countered Napoleon's threatening advances with the victories at Trafalgar (1805) and Waterloo (1815).

The following narrative about her life is edited from:
http://www.people.virginia.edu/~jlc5f/charlotte/charlotte.html

In the first twenty-one years of her marriage, Queen Charlotte gave birth to fifteen children, nine sons and six daughters. In contrast to most European Royal houses, George III and Charlotte had a harmonious marriage. On the other hand, during their lifetimes the English court had the reputation of being the dullest in all of Europe because of their notoriously frugal, plain, and pious life-style.

In 1788, a shadow fell on the happiness of the Royal family. It became evident that George III had started his slow and violent descent into the madness caused by the inherited malady porphyries. His suffering lasted for thirty years until his death in 1820. The Royal Marriage Act, pushed through Parliament by George III in 1772, placed another heavy burden on his family. It stipulated that none of his descendants could marry before the age of twenty-five without the King's consent, and even then they might only marry Protestant princes or princesses. The result of this rather strange law was that his children sought refuge in secret marriages and illicit love affairs or stayed unmarried. Queen Charlotte's court in later years was also called "The Nunnery."

In 1790, the queen bought her last residence--"Frog more House"--a small country palace located one-half mile southwest of Windsor Castle. She called this beloved home of her old age her "little paradise" where she could study her favorite subject, botany, and find peace from the constant disturbance caused by her consort's illness. Her oldest son George, Prince of Wales, finally was named regent in 1812, at the age of fifty and, in 1820, upon the death of his father, ascended the throne as George IV, King of Great Britain and Hanover. Queen Charlotte died on November 17, 1818, at Kew Palace.

To show their appreciation of being conquered by the British, the countries and colonies (or at least the explorers and map makers) honored the Queen by naming various things after her. In addition to many of the "Queen Charlotte's" in British Columbia, there are also many "Queen's Counties" in the Maritimes, Queen Charlotte place names in New Zealand and Australia, as well as Charlotte, VA, and Charlottesville NC, in the USA (despite the American revolution). The scientific name of the Bird of Paradise plant, *Sterilities Regina*, was also named in her honor. Mozart dedicated his Third Opus to her.