# Economic and Biophysical Impacts of Oil Tanker Spills Relevant to Vancouver, Canada

## *A Literature Review*

2013

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# 1 EXECUTIVE SUMMARY

In anticipation of potentially substantial increases in oil tanker traffic in Burrard Inlet in the coming years, the City of Vancouver and Vancouver Economic Commission commissioned the University of British Columbia in 2013 to prepare a literature review of likely economic and biophysical impacts of oil spills, to provide an objective and scientifically sound platform to inform future planning, policy development and decision-making. Some 400 published papers and reports were reviewed, covering aspects of oil spills ranging from impacts on marine life to effects on human health, and economy. Emphasis was placed on key oil spills with traits relevant to potential oil tanker spills in the Vancouver context.

The literature review did not identify any studies that investigated a situation with similar economic, biophysical, geographical and political traits to the Lower Mainland. However, studies on key global oil spills, as well as available research on background factors in the Vancouver region, suggest several key findings. The review that follows elaborates on these.

**Oil, Bitumen and Spills**

- Though small oil spills happen routinely, globally, the risks of a major tanker spill have been decreasing. Due to the Port Metro Vancouver's strict regulations regarding tanker traffic, there has been a history of tanker safety in Burrard Inlet. However, there is no way to eliminate oil spill risk completely, so continued focus on oil spill prevention is necessary.

- Oil can also enter the environment from operational discharges. Such discharges historically have played a larger role in ship-based pollution than accidental spills and have been shown to present a greater threat to the environment globally than individual tanker spills.[1]

- Every oil spill is a unique event, with most analyses of oil spills including the following five factors as key determinants of spill impact: 1) type of oil, 2) location of the spill, 3)

[1] Canada and International regulatory bodies are addressing this issue through regulation of discharges in territorial waters. Vancouver has specific regulations for local waters as well (Vancouver Fraser Port Authority, 2010).

amount of oil spilled and spillage rate, 4) weather and conditions at the time of the spill, and 5) the response capacity and clean-up strategy.

- Although the potential movement of oil from a spill along the Burrard Inlet is highly challenging to predict accurately, the only previous hydrodynamic model (produced in 1991 shows that under some tidal and other conditions, oil released by a spill at Second Narrow Bridge could be flushed from the inner harbour by currents and tides within 9 hours, making containment difficult.

- No two types of crude oil or diluted bitumen are exactly the same, making accurate predictions of impact impossible given current data, as the chemical constituents will behave differently in different contexts.

- A quick response time and multilayered response methodology are both critical to minimizing the impacts of an oil spill. However, there appear to be significant challenges in the structure of the current response framework in British Columbia. In addition, serious questions remain regarding the adequacy of current capacity to respond to and clean up a spill on the West Coast of Canada.

- Almost paradoxically, oil spill clean-up efforts are likely worse for marine ecosystems than natural degradation of oil. All clean-up activities will increase immediate injury to marine ecosystems (although the magnitude of increase will vary among clean-up techniques used) and consequently will slow recovery time.

**Economic Impact**

- Liu and Wirtz (2006) suggest that there are five categories of total oil spill costs, including: environmental damages, socioeconomic losses, clean-up costs, research costs, and other expenditures. However, the full costs of an oil spill are rarely compensated, and are usually limited to terms of "admissible claims" accepted by compensatory regimes. Additional costs above those that are admissible are generally borne by society.

- Canada participates in an international treaty (the Convention on Civil Liability for Oil Pollution Damage of 1992) which limits the liability of the tanker owner to $140 million.

No other party (such as the oil company chartering the tanker) may be held liable. Including the tanker owner's liability, additional funds from the international conventions, and Canada's own "Ship-source Oil Pollution Fund", total resources for the response and recovery of an oil spill total $1.34 billion CAD. This amount would cover the admissible claims for almost all oil spills on record, but would not cover the value of a catastrophic spill like Exxon Valdez.

- Because Canada is a signatory to an international convention which limits the liability of tanker owners, it is not clear that Vancouver would have the jurisdiction to institute an insurance requirement over and above the treaty-mandated liability limit. Moreover, it is highly unlikely that an insurance company could provide a product that would cover the total cost of a catastrophic spill.

- While the risk of a tanker spill has decreased over time, clean-up costs and associated impacts have risen due to rising costs of labor and technology, as well as higher expectations from the citizenry. Some estimates of clean-up costs alone for an oil spill in Canada have been as high as $60,000/tonne.[2] The environment would be cleaned, but under international conventions is not required to be brought back to pre-spill levels.

- Marine-based industries adjacent to an oil spill, like commercial fisheries and tourism, are most likely to be compensated. Commercial fisheries can suffer product decreases, fisheries closures, and brand damage, which may affect businesses throughout the supply chain. Tourism businesses are highly sensitive to brand damage, which may affect subsectors like accommodations, transportation, retail, and other services. In addition to the initial impacts, long-term rebranding campaigns and industry support activities may be required (which may or may not be compensable).

- Other marine-based businesses with direct damages could be eligible for compensation, as well as a small number of businesses that are directly impacted by oil pollution. These may include port-related businesses and agriculture, although these are generally a much

[2] There are many different ways to measure oil, the most common of which includes litres, gallons, barrels, and tonnes. In this section of the paper, tonnes will be used whenever possible to keep consistency between different measures. There are different conversion factors based on the type of oil (e.g. heavy crude, etc.), but in general 1 tonne is approximately 7.14 barrels, or 318 gallons.

smaller portion of total affected businesses.

- The majority of businesses that experience pure economic loss (i.e. loss with no apparent oil pollution damage) would not be compensated. Losses in retail revenues, real estate value, the financial sector, work stoppages from health-related problems, and sales taxes would not be compensated. Intangible losses like cultural value, recreation, passive use, and opportunity costs would not be captured.

- Although Metro Vancouver's commercial fishing industry is relatively small, tourism, retail, real estate, and the Port of Vancouver contributes billions of dollars to the local economy. A thorough economic impact analysis would be necessary to predict potential losses.

- First Nations can be particularly impacted by oil spills, with losses to wages, jobs, subsistence resources, and cultural uses/practices. There are some examples of subsistence claims being compensated, however, losses to way of life are not compensable. Food, social, and ceremonial uses of the environment, in addition to direct economic losses, could be a significant risk for Vancouver-area First Nations.

- Local governments usually experience a wide range of losses that may or may not be compensable. Legal and research costs, increased administrative costs, costs for managing volunteers and supporting work crews, and increased pressures on public works are typical expenses for affected localities. Municipal/regional brand damage, the cost of lost opportunities, and political fallout for elected leaders could be significant and non-compensable. Vancouver's "Greenest City" goal and its general reputation for environmental sustainability and liveability could potentially be at risk from an oil spill.

- Since adjacency is such a critical factor in terms of compensation, a potentially catastrophic scenario would be a regional oil spill (e.g. Vancouver Island, Georgia Strait, etc.) that generates pure economic losses for Vancouver's local industries and brand, but would be far enough away to preclude compensation for local businesses.

- Some mitigating factors such as an economic "boom" from the clean-up, compensation payments from compensation regimes, and conservation benefits from reduced economic activity could soften the economic impact of an oil spill. However, there would likely be socioeconomic inequalities in impact and compensation, thus creating classes of "winners" and "losers".

**Biological Impact**

The waters, shoreline and surrounding environment of the Burrard Inlet form a biodiverse habitat, with ecosystems that support a variety of wildlife, including many endangered and threatened species, as well as many economically important species such as salmon. The Burrard Inlet is a well-flushed waterway, except for Indian Arm, and currently has many sources of pollution already. Comprehensive baseline assessments of natural resources and economic entities in the region are essential for policy development and decision-making – however, these not currently available. Such assessments would not only inform economic impact studies and recovery plans, but would also ensure accurate monitoring after a spill has occurred.

- There is little knowledge of how a bitumen spill will affect marine life, even for the most well-studied species, and on what happens to bitumen in a marine environment.
- An oil spill in Burrard Inlet would result in immediate injury to many local marine species. Assuming a bitumen spill behaves similarly to past spills, it is expected that the most severe impacts would be to shore birds, marine mammals, and intertidal and shallow sub-tidal plants and animals. Planktonic communities and deeper sub-tidal communities should be least impacted.
- That said, it is important to note that ecological communities are structured by complex interactions among many species. Accurate predictions of community-level impacts are limited both by a lack of data on oiling effects for many local species and also by our incomplete understanding of how oiling events might change species interactions.
- Recovery of ecological communities depends on the degree of disturbance, habitat characteristics, the species in question and how recovery is defined.
- While species extinction does not seem likely in the Burrard Inlet, recovery rates of top-

level predators such as mammals and birds, as well as intertidal habitat can take decades to recover from an oil spill (based on evidence from Exxon Valdez spill of 1989), while other parts of the ecosystem take weeks to months. Although recovery times vary drastically among species, all species are expected to recover eventually.

- Even without an oil spill, normal operational spillage could damage local marine ecosystems. It is not currently known at what concentrations bitumen is toxic to local marine species, which makes it impossible to assess the impacts of normal operational spillage on marine ecosystems.

**Human Health Impact**

- In the Kalamazoo spill (Marshall, Michigan, July 25, 2010), when dilute bitumen entered the aquatic environment, it broke apart into its constituents, (lighter VOC – Volatile Organic Carbon - gases and heavier bitumen tar), within hours. Hundreds of residents within one mile of the Kalamazoo River had to be evacuated because of acute health symptoms. VOCs (short-term) and PAHs (Poly-Aromatic Hydrocarbons) (long-term) are the most toxic parts of any component in oil.

- There are various types of VOCs (benzene, toluene, xylazene), with some possessing (with sufficiently elevated concentrations) carcinogenic (cancer-causing), mutagenic (alters DNA causing mutation of cells leading to a whole host of potential pathways for damage), and teratogenic (malformation of embryo or fetus, like having a two-headed frog) qualities along with immediate acute effects (especially from inhalation) and long-term reproductive and nervous system effects. More research is needed in this area to fully assess the impact on the environment from all the components of crude oil and dilute bitumen.

- Little to nothing is known about the constituent concentrations used and toxicity levels of dilute bitumen. Effects of crude oil on animal species are diverse and dependent on species, type of food consumed, life history stage, current physiological demands, amount of exposure, and type of oil. Although crude oil, VOCs, and PAHs studies have been performed and numerous negative health effects have been documented they do not necessarily translate directly to other species found within the inlet.

### Future Work

This review reveals the complexity of attempting to predict, model and/or manage the economic and biophysical impacts of an oil tanker spill. It also reviews gaps in data and understanding of the underlying systems that would be affected. The review suggests that the following future work would be useful for informing policy development and decision-making.

- Perform baseline assessments of natural resources and economic entities to inform economic impact studies and recovery plans, and ensure accurate monitoring after a spill has occurred.

- Develop a socioeconomic recovery plan using the assesments recommended above, to address existing inequalities in impact and compensation. Such a plan would focus on involving NGOs and diverse revenue streams to provide a comprehensive recovery program for those who do not benefit from the standard recovery mechanisms.

- Develop a dynamic model of a spill in key areas of Burrard Inlet to determine dispersal rates and pathways. This would include further research into the differences in behaviour of light crude, bitumen and dilbit when spilled.

- Develop a model of proposed increases in tanker and industrial traffic in Burrard Inlet to assess the risk of an incident and inform proposed mitigation strategies.

- Investigate legal limitations for municipalities regarding liability coverage, requirements, responsibility, and clean-up governance. How much can the City of Vancouver do legally to mitigate economic risk?

- Perform an audit of actual spill response capacity on the West Coast of Canada to identify potential gaps.

- Review procedures and management of a spill response at the municipal and provincial levels within BC to generate clarity for responsibility and resources required.

- Conduct further research to better understand the toxic effects of components of bitumen and crude oil on local marine species in Burrard Inlet and the surrounding region, as information required to manage operational and accidental exposure of flora and fauna.

# 2 INTRODUCTION

This research project was commissioned by the Vancouver Economic Commission (VEC) to examine possible impacts and risks to the City of Vancouver associated with a potentially substantial increase in oil tanker traffic in Burrard Inlet and the coastal region of Vancouver. Specifically, the City sought objective guidance to inform the development of a liability bylaw to indemnify the City of Vancouver (as described in City Council Minutes from May 2, 2012). More broadly, the purpose of this project was to provide an objective and scientifically sound platform for future planning, policy development and decision-making.

In response to the request by VEC, a research team consisting of the authors was formed. Given the complexity and scope of the issue, the team recommended that the VEC take a multi-phased approach to generating the research and recommendations required. This literature review is the first phase, designed to provide an objective and comprehensive review of available studies relating to the topic. Opportunities and suggestions for future research and planning activities to develop specific guidance for the City are discussed in *Section 7*.

After consultation with the VEC and the City, the following question was established as the focus of this research.

**What are the likely economic and biophysical impacts of an oil spill in the coastal region of Vancouver, given a potential increase in oil tanker traffic?**

## *2.1 Rationale*

Issues of economic, biological and environmental risk, liability and impact related to spills of fossil fuels during production and transportation are of interest to all levels of government, industry, academia and civil society in Canada. Specifically, the City of Vancouver has a need to inform policy development and decision-making in the short and long term. This need is driven by several current and relevant issues, examples of which are identified below.

### 2.1.1 Relevant industry projects

Perhaps most importantly for the reader in British Columbia, several potential pipeline projects are under consideration that could significantly affect the City of Vancouver and South Coast region in general.

Trans Mountain Pipeline ULC (Trans Mountain), operated by Kinder Morgan Canada Inc. and owned by Kinder Morgan Energy Partners, is expected to file a proposal late in 2013 for a pipeline project that would transport bitumen for export from the Athabasca oil sands to marine terminals in Burnaby, BC. The proposed project would increase the capacity of an existing pipeline between Edmonton and Burnaby from 75,000 barrels/day (bpd) to 850,000 bpd. The expansion represents a capital investment of $5.4 billion. If approved, it is expected that the project would be operational in 2017. Implications of this project for Metro Vancouver extend beyond the pipeline, as a significant increase in oil tanker traffic through Burrard Inlet en route to and from the Burnaby marine terminals would be expected (CRED, 2013).

The Enbridge Northern Gateway Pipelines Project is a proposal to construct twin pipelines from Bruderheim, Alberta, to Kitimat, British Columbia. The eastbound pipeline would import natural gas condensate and the westbound pipeline would export diluted bitumen from the Athabasca oil sands to a new marine terminal in Kitimat, where it would be then transported to Asian markets by oil tankers. The project was proposed in mid-2000s and has been postponed several times. The pipelines would be developed by Enbridge Inc., a Canadian crude oil and liquids pipeline company. Successful completion of this project would also generate a significant increase in British Columbia coastal tanker traffic (Enbridge, 2013).

A third proposal is the Keystone XL Pipeline (owned by TransCanada Corporation), which would ship synthetic crude oil and diluted bitumen from Alberta to Steele City, Nebraska. The pipeline would extend current capacity of the existing Keystone Pipeline system. It has received approval from the National Energy Board (NEB) in Canada and, as of the time of writing, awaits American approval (TransCanada, 2013).

In addition to these pipeline projects, two other industrial initiatives appear to be relevant currently. One is the construction of a proposed refinery in Kitimat on the coast of BC to process Alberta heavy crude oil shipped via the Enbridge pipeline referenced above. At the time of writing, the proposal has strong private financial backing and conditional support from the provincial government (Kitimat Clean, 2013).

The other relevant, non-pipeline project is the expansion of the existing coal terminal in North Vancouver, BC (a waterfront complex). The project, which received Port Metro Vancouver approval early in 2013, will combine with other activities at the terminal to increase the facility's coal handling capabilities to 18.5 million metric tonnes per year. Approximately one additional train per day and one additional ship per week are expected to call on the terminal following the project's completion (Port Metro Vancouver, 2013).

### 2.1.2 Recent reports

As an indication of current interest in these issues, it is worth noting that several offices and organizations have released comprehensive reports recently, in an attempt to educate the public and/or influence policy development and decision-making. These include:

- *"Report of the Commissioner of the Environment and Sustainable Development"*, published by the Office of the Auditor General of Canada in December 2012, and based on several audits by the Commissioner's Office (Office of the Auditor General of Canada, 2012).

- UBC Fisheries Centre Research Report on *"Potential economic impact of a tanker spill on ocean-based industries in British Columbia"* published in 2012. This commissioned work looks specifically at implications of the proposed Enbridge Northern Gateway pipeline and shipping project for the North Coast region (Hotte & Sumaila, 2012).

- Port Metro Vancouver's *"Fraser River Tanker Traffic Study"*, completed in June 2012. Det Norske Veritas Canada Limited (DNV) performed a risk assessment of the possible introduction of liquid bulk shipments in the Fraser River, to provide a traffic and risk baseline to be used in the review of future liquid bulk developments, and to identify possible risk reduction options that could be implemented to ensure safety related to liquid bulk shipping operations (Port Metro Vancouver, 2012).

- Pembina Institute Report, *"Beneath the Surface: a review of key facts in the oilsands debate"*, published in January 2013. The report looks at the oilsands in terms of climate and air; water; tailings; land and wildlife; and economics (Grant, Huot, Lemphers, Dyer, & Dow, 2013).

- West Coast Environmental Law Report, *"Financial Liability for Kinder Morgan"*, released early in 2013. It explores the impacts of increased tanker traffic and pipeline growth (Georgia Strait Alliance; Living Oceans Society; West Coast Environmental Law; Wilderness Committee, 2013).

- Conversations for Responsible Economic Development Report, *"Assessing the risks of Kinder Morgan's proposed new Trans Mountain pipeline"*, released in February 2013. This document attempts to identify gaps and concerns with the current proposed pipeline expansion (CRED, 2013).

One other factor to consider when reviewing the impact of industrial expansion is that the region is already exposed to the cumulative effects of multiple and on-going small scale leaks and spills of fossil fuels from a variety of sources. In addition, these new projects will generate increased industrial traffic, both marine and land-based, which will carry its own risks and liability.

### 2.1.3 Relevant government activities

In response to widespread increases in interest and activity related to oil transportation, several government initiatives are also underway.

- At the time of writing, the federal government has committed to the introduction of "significant" legislation to address inadequacies in existing rules and laws related to oil spill liability ((de Souza, 2013)).

- The City of Burnaby produced a Council Report in May 2012 that recommends denying the expected Kinder Morgan pipeline proposal, based on concerns by citizens and businesses in terms of the "economic, social and environmental risks to the well-being of the community" (City of Burnaby, 2012).

#### 2.1.4 Current events

Finally, the topics of pipelines, oil spills, refineries and tankers remain top of mind for many Canadians, as stories of accidents and spills have become weekly media occurrences. In March 2013 alone, three significant pipeline spills involving Alberta fossil fuels were reported in North America. Pressure from civil, environmental and industry organizations on all sides of pipeline and energy industry debates continues to grow, which increases the need by all levels of government for access to unbiased, thorough research and insight.

### *2.2 Approach & Framework*

As identified above, this paper attempts to offer a scientific and objective review of published studies related to oil spills, to provide a research foundation for liability planning and decision-making by the VEC and City of Vancouver. The research process to generate the findings that follow was typical of an academic literature review.

To ensure that the review would have appropriate rigour, depth and breadth, a research team at the University of British Columbia was assembled. The team was supervised by Drs. Stephanie Chang and Moura Quayle, with the bulk of the research performed by three graduate research assistants (Kyle Demes, Marina Piscitelli and Jeremy Stone). Oversight and project management support came from Denise Withers, a strategic consultant.

Literature reviewed includes academic, government and industry papers and reports about the causes and types of oil spills, costs, financing of clean-up, and short and long-term environmental and societal consequences, with an emphasis on economic impacts. Though most papers dealt with spill events, several also explored the impacts of oil through laboratory studies.

In consultation with research staff at the VEC and City of Vancouver, the team generated a comprehensive framework for the review. This includes an overview of oil spills (with a focus on risks and responses), relevant science of the physical and biological impacts of oil, a brief look at the impacts of oil spills on human health, and an in-depth review of the economic and other socio-economic impacts of spills.

### 2.2.1 Reference events

It is important to note that no literature is available on the impacts of an oil spill in an area directly comparable to Metro Vancouver. (See *Section 2.3* for more on these limitations). As such, insights presented here are limited to the data and findings provided by reports and papers on other global spills. Although the literature reviewed covers a broad range of oil spills, the following six were the most prominent events, primarily due to the large size of the spills and/or the intensity of the clean-up effort. The Kalamazoo spill was also included because, although a pipeline rather than marine incident, it is the only spill of bitumen on record.

***Prestige***: The *Prestige* oil spill occurred off the coast of Galicia, when the single-hull tanker sank in 2002. The spill was triggered by damage to one of the tanks during a storm and exacerbated by the refusal of French, Spanish and Portuguese governments to allow the ship to dock at their ports. Inevitably, it sank, leaking an estimated 77,000 tons of oil. The spill caused the largest environmental disaster in the history of both Spain and Portugal and forced the closure of offshore fisheries for six months.

**BP**: On April 20, 2010, an explosion on the Deepwater Horizon MC252 drilling platform in the Gulf of Mexico caused the rig to sink, and oil began leaking into the Gulf. Before it was finally capped in mid-July, almost 5 million barrels of oil were released into the Gulf. The massive spill caused significant impacts to wildlife and the fishing community along the large coastal areas of Louisiana, Mississippi, Texas, Alabama, and Florida.

**Exxon *Valdez***: In March of 1989, the Exxon *Valdez* ran aground in Prince William Sound, spilling an estimated 257,000 to 750,000 barrels of crude oil in Alaska.

***Hebei Spirit***: The MT *Hebei Spirit* oil spill in South Korea occurred in December 2007 when a crane barge being towed by a tug collided with the anchored crude oil carrier, *Hebei Spirit*. The collision resulted in a spill of 10,800 tonnes of oil, in a region that is home to 445 sea farms, as well as South Korea's most beautiful and popular beaches, a national maritime park and one of Asia's largest wetland areas.

**Kalamazoo**: This spill was caused by a rupture in the Enbridge Energy pipeline near Marshall, Michigan in 2010. The failed pipeline leaked 877,000 US gallons (3,320 $m^3$) of dilute bitumen originating from Canada (Alberta and Saskatchewan) into Talmadge Creek in Michigan, which flows into the Kalamazoo River. The US Environmental Protection Agency (EPA) later estimated the spill to be in excess of 1 million US gallons (3,800 $m^3$). This pipeline spill was chosen as a reference spill because it has been the only dilute bitumen spill to date.

**Amoco *Cadiz***: This very large crude carrier ran aground and ultimately sank 5 kilometres off the coast of Brittany, France, in 1978, resulting in the largest oil spill of its kind in history to that date - 1,604,500 barrels (219,797 tons) of light crude oil plus 4,000 tons of fuel oil.

## *2.3 Limitations of Review*

As this project was commissioned to inform the work of the City of Vancouver and Vancouver Economic Commission, the research team attempted to focus its investigation on impacts relevant to the coastal area of Vancouver. However, even with this limited geographic focus, the issues of economic and biophysical impacts are tremendously complex.

Many interacting factors dictate the impacts of an oil spill, making it difficult to forecast precisely how an oil spill will affect a specific region. Although some predictions for economic and biophysical impacts of an oil spill in Burrard Inlet can be made based on data on the aforementioned spills, each of these spills has as many (or more) dissimilarities with the Burrard Inlet as it does similarities. The Burrard Inlet has unique geographic, demographic, and jurisdictional features, which distinguish it from areas previously hit by oil spill events.

One key difference is the contained and restrictive geography of the region. To reach the Kinder Morgan terminal, tankers must travel through the Burrard Inlet, passing the Lions Gate and Second Narrows bridges (See Figure 1). In addition to the navigating these narrows, shallow depths in parts of the Inner and Central Harbours restrict tanker traffic to certain tidal windows. At the broader, regional scale (See Figure 1), the Burrard Inlet flushes into the Strait of Georgia. Were spilled oil to enter the Strait of Georgia, it would conceivably impact shorelines in other jurisdictions (e.g. the Gulf Islands, Vancouver Island, the US San Juan Islands, Puget Sound, Washington state, etc.). The interconnectedness of our waterways also highlights that a spill event outside of the Burrard Inlet could impact the City of Vancouver.

Another important distinction between the Burrard Inlet and most of the regions that have been previously hit by an oil spill is the densely populated surrounding areas. More than two million people reside in the Greater Vancouver area. Expected human health consequences of a spill event in the Burrard Inlet, would likely expose a human population greater than any previous reported spill to associated risks.

Given this complexity, and the desired breadth of scope defined by the project mandate, the literature review does not explore the many facets of each of these issues in depth. It does, however, attempt to identify those most significant to the challenges faced by the City. The economic impacts specifically are described in *Sections 6.6 through 6.8*.

As mentioned earlier, this review provides a scan and synthesis of published literature only; the team did not conduct any expert interviews or gather any other primary data. Nor does it make specific recommendations related to the development of policy, legislation or other governance tools at this time. In *Section 7* at the end of the review, the research team does identify research gaps, unanswered questions and opportunities for future investigation to inform planning and decision-making by local, provincial and federal governments.

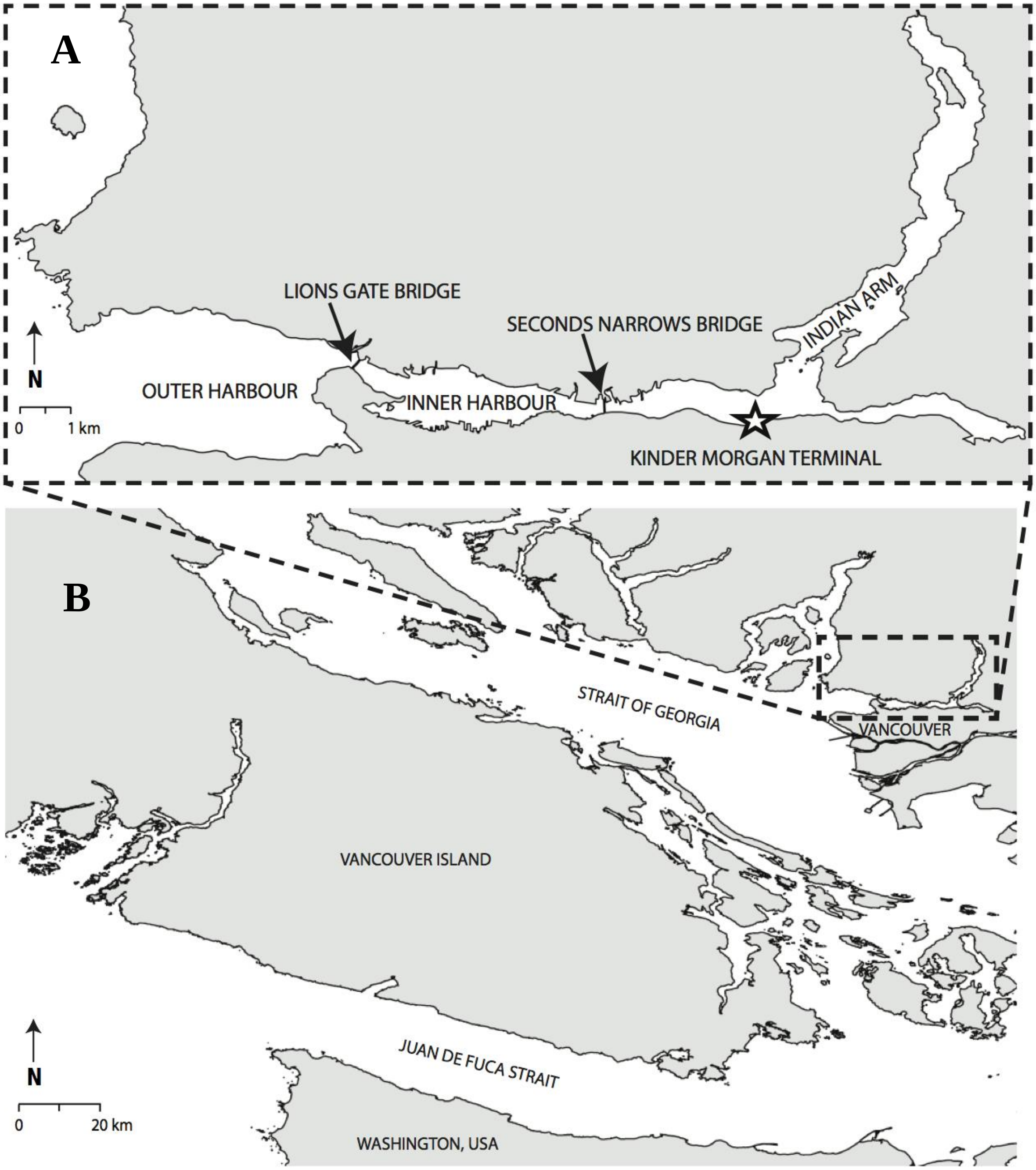


**Figure 1. Reference Area**

# 3 OIL, BITUMEN AND SPILLS

As described above, oil spills are tremendously complex events. In this section, the review attempts to provide a high-level view of relevant aspects of oil spills, specifically as they may relate to the Vancouver context. This background information provides important references for interpreting the economic impacts of a spill described in *Section 6*. For more detailed definitions of various terms used throughout the review, the US Environmental Protection Agency (EPA), has published introductory references to and a glossary for oil spills: http://www.epa.gov/osweroe1/docs/oil/edu/oilspill_book/gloss.pdf

## *3.1 Causes of Spills*

Oil spills from tankers are generally high-profile events that define the way that oil industry risks for the environment and economy are conceptualized. However, oil enters the environment from a wide variety of sources, with approximately 50% of all oil being released by natural seeps (Burgherr, 2007; Pearson et al., 1998; Brody et al., 2012). Oil from accidental tanker spills account for only 5 to 8% of oil in the environment (Burgherr, 2007; Brekke and Solberg, 2005).

Traditionally, operational discharges have played a larger role in ship-based pollution than accidental spills. When oil tankers discharge their cargos, they take on ballast water for their return trip. The resulting oil and water mixture has usually been discharged when returning to port (Burrows et al., 1974). Similarly, ships can often lose oil when loading and unloading cargo (ITOPF, 2011). Most operational discharges are small by comparison to accidental spills (i.e. 7 tonnes or less), but they account for the majority of ship-related pollution worldwide (Alló and Loureiro, 2013; White and Baker, 1998; Brekke and Solberg, 2005; Burrows et al., 1974). In a sense, the greater threat to the environment globally is from routine operations than from individual tanker spills.[3]

[3] Canada and International regulatory bodies are aggressively addressing this issue through regulation of discharges in territorial waters. Vancouver has specific regulations for local waters as well (Vancouver Fraser Port Authority, 2010).

Moreover, although accidental tanker spills account for far more oil pollution than pipeline, platform, and storage facility spills combined, the incidence rate of tanker spills over 7 tonnes have significantly decreased since the 1970s (ITOPF, 2012; Burgherr, 2007; Kontovas et al., 2010). Figure 2 below shows the decrease in both spill numbers and volume spilled by decade. There were nearly 800 spills that released 3.2 million tonnes of oil during the 1970s, while there were less than 200 spills that released approximately 212,000 tonnes of oil in the 2000s (IOTPF, 2012).

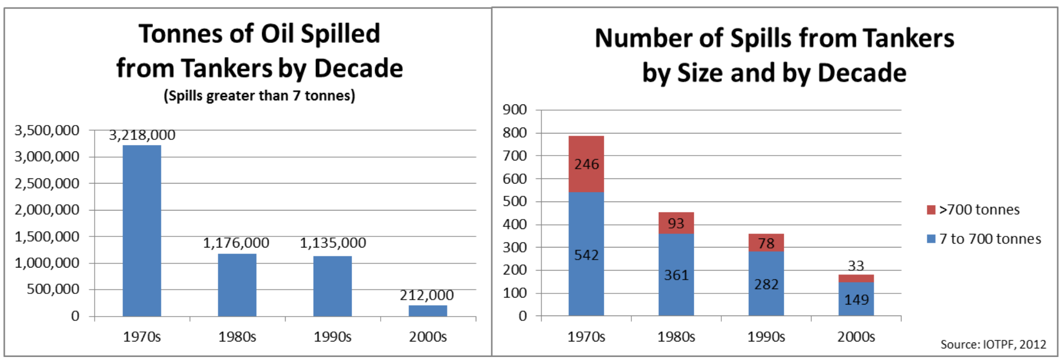


**Figure 2.Tanker Spills (IOTPF, 2012)**

The causes of spills are varied, but 50% of all spills over 700 tonnes occur when anchored or in port, while 50% occur while "underway" in open waters (IOTPF, 2012). For those in open water, 59% occur from allision, collision, or grounding, while 35% occur from hull failure, equipment failure, or fire/explosion. The decrease in tanker spills internationally has been directly correlated with a series of regulatory and technological changes that have continued to address these tanker safety issues over the years (Moore et al., 1998; Burgherr, 2007; Eckel et al., 2012).

For example, The International Maritime Organization's (IMO) "International Convention for the Prevention of Pollution from Ships (MARPOL)" has mandated improvements to ship hulls, navigation systems, and other aspects of tanker safety. Single-hulled vessels have proven to be significantly more accident-prone than double-hulled vessels, and there have been mandatory requirements both under MARPOL and in Canada to convert all tankers to double hull by 2015 (Burgherr, 2007).  Double-hulled vessels have also been shown to have smaller and less costly spills, with no spill over 3000 tonnes (Burgherr, 2007; Nyman, 2009; Alló and Loureiro, 2013). However, there have been numerous challenges to the reliance on double hulls as a “panacea” for tanker safety. Double hulls have been shown to be less cost effective than improving navigational systems, and have been described as structurally unsound and over-promoted (Di Jin et al., 1994; Devanney, 2010; Terhune, 2011).

In addition to ship safety, other factors have been correlated with the risk of tanker spills. “Flags of Convenience (FOC)” refers to the registration of ships in third-party countries in order to avoid regulations or taxation in the ship-owner’s country. FOC tankers have been strongly correlated with more tanker spills and larger damage impacts than non-FOC tankers (Alló and Loureiro, 2013). Interestingly, another correlated factor in tanker spills is the Saturday Effect. Whether due to lack of staffing and surveillance, or a general “weekend psychology”, there has been a higher number of, and greater damage associated with, tanker spills on weekends (Goodstein, 1992; Alló and Loureiro, 2013). A final issue to consider is geography. Certain areas of the world have traditionally exhibited a higher risk of oil spills than elsewhere. Whether this is due to particularities of the marine environment, or of the regulatory environment regarding marine travel, some areas present greater risks. These include the Northern European Atlantic, the Eastern Mediterranean, the Gulf of Mexico, the Caribbean and parts of the Southern Atlantic down to Venezuela and Brazil, the Southern tip of Africa, the Persian Gulf, and areas around the Strait of Malacca (Burgherr, 2007).

*P. Burgherr / Journal of Hazardous Materials 140 (2007) 245–256*

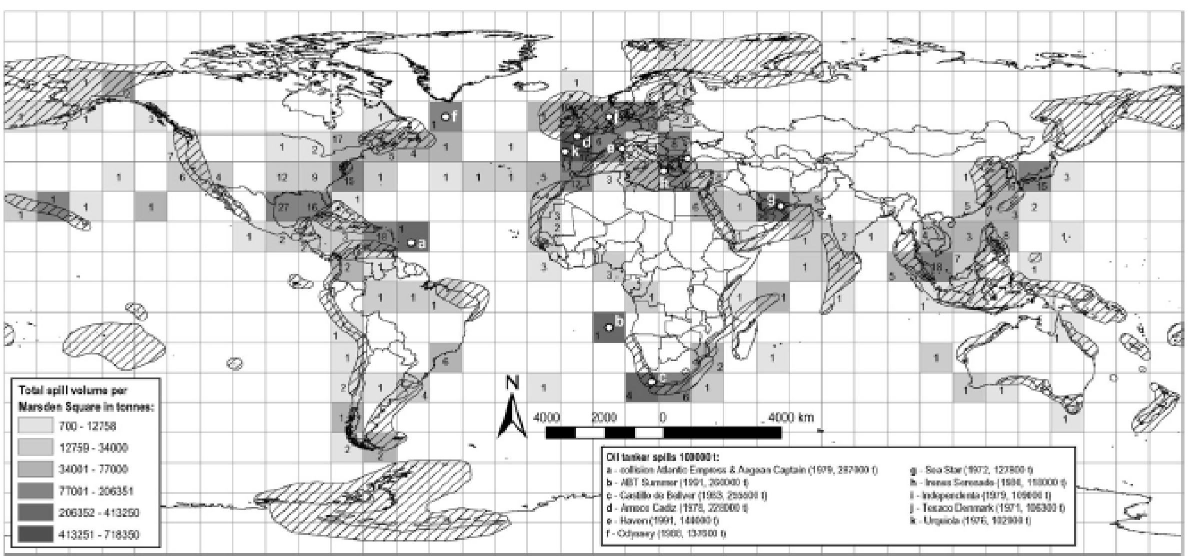


Fig. 7. The worldwide distribution of oil tankers involved in spills of at least 700 t for the period 1970–2004 is shown on the map. Individual Marsden Squares (10° latitude by 10° longitude) are shaded in different intensities of gray according to the total spilled volume in tonnes, with class breaks corresponding to Natural Breaks (see Chapter 2 for details). Small numbers within each Marsden Square represent the number of spills that occurred within that particular grid cell. Additionally, spills resulting in releases of at least 100 000 t are labeled (a–k) and briefly described (for details see Table 4).

**Figure 3.Worldwide Distribution of Large Tanker Spills 1970 – 2004. (P. Burgherr, 2007)**

## *3.2 Factors Determining Spill Impact and Cost*

Every oil spill is a unique event. The breadth, depth, and cost of the impacts related to each spill will be subject to a wide variety of variables, which will produce different outcomes. However, most analyses of oil spills include the following five factors as key determinants of impact: 1) type of oil, 2) location of the spill, 3) amount of oil spilled and spillage rate, 4) weather and conditions at the time of the spill, and 5) the response capacity and methodology (Etkin, 2004; Burgherr, 2007; Kontavos et al., 2010; White and Molloy, 2003; US Department of Commerce, 1983).

### 3.2.1 Type of oil

One of the most important factors that determine the impact and cost of an oil spill is the type of oil spilled (White and Molloy, 2003; Etkin, 2004). Light refined products and light crude disperse more easily and do not persist on the surface of the sea, but they are more toxic and can have greater effects on sea life and humans (see *Sections 4* and *5*). Clean-up costs are therefore lower while potential third-party liability claims could be higher (White and Molloy, 2003). Heavy crude and fuel oils are less toxic, but are much harder to clean, and can travel farther. The *Erika* and *Nakhodka* spills were relatively small, but due to their heavy crude cargo, they were exceptionally expensive (Etkin, 2004; White and Molloy, 2003).

The dispersing ability and effects of spilled oil in the marine environment depend both on its composition and on the environmental conditions at the time of the spill. A general model of potential outcomes of oil in the aquatic environment is illustrated in Figure 4. During the first few hours up to days after a spill, low molecular weight gases will potentially evaporate, leaving behind thick foamy emulsions and heavy residues on the surface (Geraci and St. Aubin, 1990). This debris can potentially mix with sand and sediments to form tarry aggregates that sink or wash ashore. The slow process of biodegradation and oil-eating bacteria eventually recycle the compounds (Hazen et al., 2010; Gutierrez, 2011). In colder waters, such as that found in Burrard Inlet, the process may take longer to recover (e.g. Exxon *Valdez* has taken decades) (Bodkin et al., 2003). How oil (either crude oil or diluted bitumen) would flow in Burrard Inlet would depend on multiple physical, chemical, and biological processes (e.g. season, time of day, prevailing winds, currents, tides, water temperature, salinity), as well as the size and duration of the spill, and the type of oil spilled (see also *Section 3.2.1.2*). This information would be important to consider for the type of response in clean-up and to determine the extensiveness of effects on habitat and wildlife.

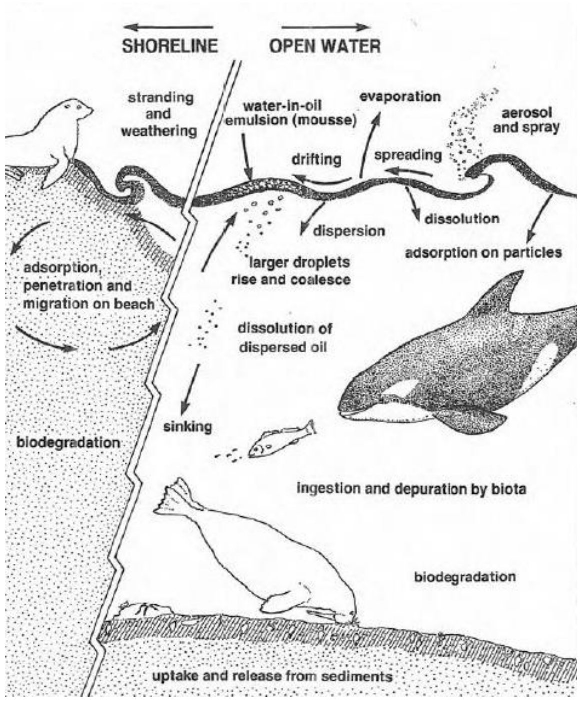


**Figure 4.General processes and potential outcomes of oil in aquatic environments (Geraci and St. Aubin, 1990).**

### *3.2.1.1 Composition of Crude Oil & Bitumen*

Bitumen is a kind of crude oil found in natural oil sands deposits and is the heaviest crude oil produced today (Stubblefield, McKee, Kapp Jr, & Hinz, 1989). The oil sands, also known as tar sands, contain a mixture of sand, water and bitumen. The tar sands region of Alberta, Canada is the third largest petroleum reserve in the world (Oceans, 2012). Tar sands bitumen is dense and crumbly in its natural state and is 40-70 times more viscous than North American conventional crude oil (D. McCay & Whittier, 2003; Upreti et al., 2007). Bitumen is too thick to be pumped from the ground or through pipelines, and thus must be mined or extracted by injecting steam into the ground (Upreti, Lohi, Kapadia, & El-Haj, 2007).

Crude oil, unlike bitumen, is a liquid that can be pumped from underground deposits, and then shipped by pipeline to refineries where it is processed into gasoline, diesel and other fuels. In contrast, extracted bitumen has the consistency of peanut butter and requires extra processing before it can be delivered to a refinery. There are two ways to process bitumen (Upreti et al., 2007). Some tar sands producers use an on-site upgrading facility to turn bitumen into synthetic crude, which is similar to conventional crude oil (Upreti et al., 2007). Other producers dilute bitumen using either conventional light crude or a mixture of light volatile gases or solvents (VOCs) such as benzene and toluene (Upreti et al., 2007). For example, the Kalamazoo spilt diluted bitumen was composed of 70% bitumen and 30% diluent (CRED, 2013; Oceans, 2012). There is little scientific research on diluted bitumen (also known as dilbit). The resulting diluted bitumen then has the consistency of conventional crude (considered to be a heavy crude oil) and can be pumped through pipelines.

The exact composition and relative concentrations of these VOC chemicals used to dilute the bitumen is considered a trade secret. The diluents vary depending on the particular type of dilbit being produced. The mixture often includes benzene, toluene, and naphtha, all of which are known environmental toxins with some level of toxicity (see *Section 3.2.1.3*) (Stubblefield et al., 1989; Upreti et al., 2007). The diluent naphthenic acid is a mixture of several cyclopentyl and cyclohexyl carboxylic acids. These acids are obtained by oxidation of naphtha fraction during the crude oil refining process (Upreti et al., 2007). The composition varies with crude oil composition and with the conditions during the refining and oxidation process. Naphthenic acids are present within crude oil and lead to corrosion of pipes and transporting container issues. Crude oils with a high content of naphthenic acids are referred to as high total acid number (TAN) crude oils or high acid crude oil (HAC) (Swift, Casey-Lefkowitz, & Shope, 2011; Upreti et al., 2007). Naphthenic acids are the major contaminant in water used for extraction of oil from tar sands (Swift et al., 2011). Naphthenic acids have both acute and chronic toxicity to fish and other organisms (Stubblefield et al., 1989; van den Heuvel, Power, MacKinnon, & Dixon, 1999) (see *Section 4*). Bitumen may also contain sulphur, paraffins, asphaltics, trace metals, and many other compounds (Toor, 2012; Upreti et al., 2007). Furthermore, tar sands diluted bitumen normally has organic acid concentrations up to 20 times higher than conventional crude oil, and contains up to 10 times more sulphur (Shang, Kim, Haberl, & Legzdins, 2013; Stubblefield et al., 1989; van den Heuvel et al., 1999). Both bitumen and crude oil contain polycyclic aromatic hydrocarbons (PAHs), a group of chemicals that are toxic and tend to persist in the environment for long periods (Geraci & St. Aubin, 1990). Crude oil specifically is comprised of 25–35% PAHs (Head et al. 2006). Based on PAHs toxicity, persistence, and ability to accumulate in fat stores of animals and plants, PAHs are recognized as a priority pollutant to the environment (Agency for Toxic Substances and Disease Registry 2007).

#### *3.2.1.2 Fate of Bitumen in the Water Column*

In the atmosphere and aquatic environment, this compound of diluted bitumen naturally separates back into its original constituents (heavy tar-like bitumen and its diluents) (CRED, 2013; Oceans, 2012). A large percentage of volatile gases that make up the diluent, once separated from bitumen, can then be dispersed into the air, and if inhaled by a mammal, can cause acute symptoms such as headaches, nausea, dizziness, coughing and fatigue (See *Section 5*). A smaller percentage of the volatile gases and a much larger percentage of polycyclic aromatic hydrocarbons (PAHs) will dissolve in the water column and build up in fat storing animals such as fish and marine mammals (see *Section 4*). Once the lighter properties evaporate, the heavier tar-like bitumen remains and can either float at the surface, sink to the bottom, or mixed within the water column depending on its density compared to the surrounding seawater density, temperature, and salinity (see *Section 4.1*).

The industry classifies different crude oils as light, medium or heavy, based on their densities. There is debate over the cut-offs for these categories and where bitumen lies within this hierarchy. In general, the density of dilute bitumen can vary widely and range from heavier than water to lighter than water (Upreti et al., 2007). However, density alone does not determine whether a particular type of crude oil will sink or float. Weather and other conditions (wave action, currents) can change the buoyancy of crude oils. For example, crudes that are lighter than water can sink if they mix with sediment. Bitumen may or may not float depending on the environmental conditions (Herrington, Ball, & O'Halloran, 2006; D. McCay & Whittier, 2003). Bitumen when introduced into the water column may also mix with grains of sand and other particles in the water, with the weight of these sediments increasing the density of bitumen and causing it to sink (D. McCay & Whittier, 2003). Without more information on the chemical characteristics of the diluent or the synthetic crude, it is difficult to determine the fate and water transport of any spilled oil in the aquatic environment. In the case of the Kalamazoo River spill, diluted bitumen initially floated on the water's surface, and then within hours it began separating into its different components (CRED, 2013; Oceans, 2012). Most of the diluents evaporated into the atmosphere, leaving behind the heavy bitumen, which sank under water. According to the US National Transportation Safety Board it took nine days for most of the diluents to evaporate or dissolve into the water during this spill.

Conventional crude oil can also sink in water but to a much smaller extent than bitumen, and instead usually floats on the surface with an initial thick layer (as much as five inches thick) before dispersing (Geraci & St. Aubin, 1990; D. McCay & Whittier, 2003). If left on their own, the light components will evaporate into the air with the remaining residues dispersing and biodegrading. The vast majority of the chemicals found in conventional oil consist of medium to light densities, so that they are light enough to float but too heavy to gas off into the atmosphere (Herrington et al., 2006; Stubblefield et al., 1989). Diluted bitumen has very few of these mid-range density compounds and instead, the component chemicals tend to be either very light (the diluents that become aerosolized) or very heavy (the bitumen itself). Because pure bitumen makes up 50 to 70% of the composition of diluted bitumen, at least 50% of the compounds in the diluted state may sink in the water, compared with less than 10% for most conventional crude oils (Herrington et al., 2006).

The chemical composition and nature of the diluents may have significant implications for response as they may negatively affect the efficacy of traditional floating oil spill response equipment or response strategies. A greater degree of difficulty was involved in recovering bitumen during the Kalamazoo River spill (CRED, 2013; Nowlan et al., 2012; Oceans, 2012). The National Transportation Safety Board's report found two days after the spill, the denser oil fractions had sunk to the bottom of the riverbed. One year later a reassessment still found a moderate-to-heavy contamination of 80 hectares on the river bottom (Nowlan et al., 2012).

Studies investigating the distribution and concentration of PAHs in the wake of the Deepwater Horizon oil spill demonstrated a spatial and temporal distribution of dissolved and dispersed aromatic hydrocarbons in the water column. Low molecular-weight PAHs predominated at discrete depths in deep waters (1,000– 1,400 metres), whereas higher molecular-weight PAHs were predominant in surface waters (Hazen et al., 2010; Diercks et al., 2010; Camilli et al., 2010).

#### *3.2.1.3 Toxicity*

Oil toxicity depends on a multitude of factors, including the oil composition and characteristics (physical and chemical), condition (i.e. weathered or not), exposure routes and regimen, and bioavailability of the oil. Hydrocarbon toxicity is dose-dependent, and if levels are over a threshold concentration, then PAHs can be highly toxic and carcinogenic (Herrington et al., 2006). In particular, PAHs are the major contributors to toxicity, with different metabolic pathways producing metabolites, which have oxidative and carcinogenic properties due to their ability to attack and bind to DNA and proteins (Aguilera et al., 2010; Brandt et al., 2000; Gist & Burg, 1997; Ha, Lee, Lee, & Cheong, 2008; Rodríguez-Trigo et al., 2007; Solomon & Janssen, 2010). The acute toxic effects can be additive for mixtures of chemicals that cause toxicity by the same cellular mechanism. For crude oils, the LC50 for the PAHs in the fuel mixture varies over several orders of magnitude for various species and life stages (BPAUST, 2005; Devon, 2010; Petro-Canada, 2012; Syncrude Canada, 2006). (LC50 is the concentration of the chemical that kills 50% of the test animals in a given time). Furthermore, toxicity varies with duration of exposure, with the LC50 decreasing as exposure time increases, due to the accumulation of toxicant over time, up to a critical body burden (tissue concentration) that causes mortality (Devon, 2010; BDH, 2005; Chevron Phillips Chemical Company, 2011). From models, the dissolved PAH exposure dose lethal to sensitive species has been estimated to be about 500 ppb/hour (D. McCay & Whittier, 2003).

To further study these effects, an acute oral, dermal, ocular and inhalation toxicity study was performed using bitumen (bitumen diluted with naphtha) from the Alberta oil sands (Devon, 2010; Stubblefield et al., 1989). No rats and mice died following a single oral dose of 5 grams/kilogram (g/kg). No rabbits died following a single dermal dose of 3.16 g/kg. The rabbits did experience moderate skin irritation and desquamation along with slight eye irritation with conjunctival redness. No mortalities of rats occurred following a 6-hour inhalation exposure to 1.46 g/m3, however, lung discoloration and decreased lung weight was observed (Stubblefield et al., 1989).

To assess chronic effects, several epidemiological studies have been performed and results indicate that there are no differences in the general health of bitumen workers as compared to the general public (Burstyn, Kromhout, Kauppinen, Heikkilä, & Boffetta, 2000; Meo, Al-Drees, Meo, Al-Saadi, & Azeem, 2008). In a mouse skin-painting study (twice/day for life), hair loss, dryness and scaling of the skin and papiloma formation was reported (WHO, 1982). Mice were exposed to heated asphalt fumes for 6 - 7.5 hours per day, five days a week for 21 months. Peribronchial round cell infiltration, bronchitis, pneumonitis, abscess formation, loss of cilia, epithelial atrophy and necrosis were common in the mice. Squamous cell hyperplasia was also observed (Simmers, 1964).)

There is inadequate evidence of carcinogenicity in humans and limited to sufficient evidence in animals. Bitumen is not considered to be carcinogenic to humans, but does contain carcinogenic components (Royal Society of Chemistry, 1992). Results from several epidemiological studies indicate that there is no difference in the number of skin and/or lung cancers attributed to working with bitumen (WHO, 1982). Although many of the studies show an increased risk of cancer, they do not show a casual relationship between exposure to bitumen and development of cancer. Nearly all the studies suffer from a lack of data on exposure and/or potential confounders (Chiazze et al., 1991). An evaluation of the dermal carcinogenic potential of bitumen from the Athabasca oil sands was conducted. Mice were dermally applied three times per week (52.50 mg/wk) for life. Out of 50 animals, two developed tumours with a mean latency of 145 weeks. This was not significantly different from the controls. The authors concluded that the bitumen from the Athabasca oil sands produced weak evidence of carcinogenic potential, but was consistent with conventional petroleum - derived bitumen (McKee et al., 1986). An evaluation of the dermal carcinogenic potential of bitumen from the Cold Lake oil sands was also conducted. Mice were dermally applied three times per week (56.25 mg/wk) for life. Out of 50 animals, 13 developed tumours with a mean latency of 106 weeks (McKee and Lewis, 1987). This was significantly different from the controls. The authors concluded that this result is consistent with conventional petroleum-derived bitumen (McKee and Lewis, 1987).

Bitumen has given negative or marginally position positive findings in most mutagenicity assays conducted (CONCAWE, 1992). Adult and fetal human skin were treated with bitumen and analyzed for the presence of DNA-adducts. Levels of 3 and 15 grams of bitumen significantly increased the number of DNA-adducts (Schoket et al., 1988). The genotoxic activity of bitumen was tested using *Salmonella typhimurium* and DNA damage in rats. No mutagenic activity was noted in the absence or presence of metabolic activation with *Salmonella typhimurium*. Bitumen gave negative results for in vivo DNA damage (Pasquini et al., 1989; reviewed in (Syncrude Canada, 2006)).

Dispersants, such as Corexit 9527A and 9500, which were both used in the Deepwater Horizon Oil Spill, contain a toxic solvent, 2-butoxyethanol, which can potentially injure red blood cells (hemolysis), and damage kidneys and liver (Barron, 2012; Castranova, 2011; Judson et al., 2010; Sriram et al., 2011). Corexit 9500 contains propylene glycol, which can be toxic to people and is a known animal carcinogen (Solomon & Janssen, 2010; Ylitalo et al., 2012). The Institute of Neurotoxicology and Neurological Disorders, has found reports among Gulf residents and clean-up workers of breathing problems, coughing, headaches, memory loss, fatigue, rashes, and gastrointestinal problems that match the symptoms of blood toxicity, neurotoxicity, adverse effects on the nervous and respiratory system, and skin irritation associated with exposure to the chemicals found in Corexit. Both aerosolized effects of dispersants and control burns of the oil had known negative effects on health. Pulmonary changes after 1 and 7 day acute inhalation exposure included inflammation, airway contraction, and airway hyper-reactivity (Meo et al., 2008; Roberts et al., 2011). Results indicate that acute pulmonary and dermal exposure to the dispersant caused measurable alterations in normal physiological function (Goldsmith et al., 2011; Roberts et al., 2011; Solomon & Janssen, 2010). NIOSH is currently conducting studies to evaluate responses to a more extended inhalation exposure (5 hr / day for up to 9 days) (Castranova, 2011).

### 3.2.2 Location of the spill

There are a number of locations and geographic factors affecting spill impacts and cost, including the natural features of the coastline affected, the remoteness of oil spill, and the environmental sensitivity of the area (White and Baker, 1998; Sumaila et al, 2012).

Distance to shore is also a significant variable. Two of the largest recorded oil spills, the *ABT Summer* in Angola in 1991 (260,000 tonnes) and the *Atlantic Empress* off the coast of Tobago (287,000 tonnes) in 1979, had no impact on human populations because they occurred hundreds of miles off shore (White and Molloy, 2003). However, one study estimates that while large spills offshore of the United States might cost $300 USD/tonne to clean, small spills close to shore might cost $29,000 USD/tonne to clean (Kontavos et al., 2010). This may say something about economies of scale in clean-up as well (see below), but the fact remains that the distance from shore can be a critical variable in oil spill impact and cost (White and Molloy, 2003).

### 3.2.3 Amount of oil spilled and spillage rate

No relationship has been found between the size of tanker and oil spill cost. Small tankers can create very expensive spills (White and Molloy, 2003). However, there is a positive correlation with increasing spill size such that an increase of the spill by 1% increases damages by about $0.718 million (Alló and Loureiro, 2013).

Another important factor is the rate of spillage. If there is one complete spill of oil, there is generally only one clean-up. However, if the tanker is immovable or sinks, it can continue to release oil for months or years. The *Prestige* spill in Spain leaked 60,000 tonnes over a number of months causing multiple small spills that required several waves of response (Loureiro et al., 2005; Punzon et al., 2009). Similarly, although the *Betelgeuse* sinking in Ireland only spilled 1,500 tonnes, it lasted for 21 months causing increased long-term costs (White and Molloy, 2003).

### 3.2.4 Weather and sea conditions at the time of the spill

Weather and sea conditions not only impact the break-down and dissipation of oil, but also impact the clean-up and recovery activities. Wind and storms can either enhance or impede response (Wirtz et al., 2007). In the *Castillo de Bellver* accident in South Africa, up to

190,000 tonnes of oil were spilled, but due to shifting winds and sea currents, the majority of the slick moved off-shore (Moldan et al., 1985). However, during the *Sea Empress* spill in Wales, high winds prevented at-sea recovery operations, and only 3% of the spilled oil was recovered (Law and Kelly, 2004).

Similarly, seasonality is also a factor. Spills in tropical waters dissipate very quickly thus having less effect on the environment, while spills in cold water or during winter can decrease total damage costs by €188.58 million (Pearson et al., 1998; Alló and Loureiro, 2013). The latter effect may be attributed to seasonal differences in fishing patterns: in the winter season less commercial fishing activity is carried out, and less fish and crustacean species are in-shore (Garcia Negro et al., 2009; Law and Kelly, 2004)

### 3.2.5 Response capacity and methodology

The response capacity and methodology, including response management, technology used, and other factors, are critical to reducing oil spill impacts (White and Molloy, 2003). A few response factors are described below:

#### *3.2.5.1 Timing of response*

Responding as quickly as possible to collect oil at the source is critical. According to one oil spill expert, the cost of shoreline clean-up is ten times more expensive than collecting the oil at sea, and one hundred times more expensive than pumping the oil from the damaged vessel (Nyman, 2009). This is partially due to the fact that once oil leaves the hull of a ship, it begins absorbing water and becomes an emulsified "mousse", which can increase its total volume by 400% (White and Baker, 1998; White and Molloy, 2003). During the Amoco *Cadiz* disaster in France, some 60,000 tons of oil made it to shore, primarily in the form of 245,000 tonnes of emulsified mousse (US Department of Commerce, 1983). This increased the amount of shoreline affected, and the cost of clean-up.

Another factor is the declining productivity of clean-up efforts over time. Work crew efficiency erodes over time, and the weathering of oil makes it more difficult to clean. Therefore a prompt and vigorous response can decrease impacts (Grigalunas et al., 1986; US Department of Commerce, 1983).

#### *3.2.5.2 Governance*

Contingency planning, an administrative structure for response, and a single on-scene commander are important for the mobilization of resources (Ritchie, 1995; White and Molloy, 2003; US Department of Commerce, 1983). Having disaster response procedures in place with key response personnel who are familiar with those procedures, has been shown to be a “best practice” in oil spill response (Rodin et al., 1992). Communication and familiarity between responders and officials in various government agencies also helps facilitate decision-making and resource mobilization (Rodin et al., 1992)

#### *3.2.5.3 Response technology*

Response technologies, especially at sea, have mixed results. Skimmers, booms, and other marine collection devices rarely recover more than 10-15% of the oil spilled. Only 9% was recovered after the Exxon *Valdez* spill in Alaska, and only 4% was recovered in the Seki spill in the UAE (White and Baker, 1998; Pearson et al., 1998). In contrast, the use of chemical dispersants has been credited with exceptional efficiency in reducing the amount of oil reaching shore (Moore et al.,1998; Trudel et al, 1998; Cheong, 2012; Franklin and Warner, 2011). However, there are ongoing concerns with how dispersants affect organisms (*Section 4*), and their use is limited in some cases (US Department of Commerce, 1983; Franklin and Warner, 2011).

#### *3.2.5.4 Human capital and volunteers*

Following the 10,000 tonne *Hebei-Spirit* spill in South Korea, the total clean-up operation included 1,820,000 volunteers, military personnel, and police, 242 helicopters, 3,313 ships, and 11,531 fishing boats (Cheong, 2011).

Following the *Nakhodka* spill in Japan 500,000 volunteers joined in, and after the *Cadiz*, *Erika*, and *Prestige* spills there were large mobilizations of thousands of soldiers and volunteers (Tucker and Obrien, 2011; Fourcade, 2011; Loureiro et al., 2005).

Clearly human capital is crucial for dealing with the myriad impacts of an oil spill.

Volunteers and members of response organizations can bring the skills, knowledge, and labour necessary to clean-up affected areas (Tucker and O'Brien, 2011). However, volunteers present liability, control, and efficiency problems that can add costs and time to a response effort. Moreover, they tend to create more waste than professional responders, which adds to disposal costs (Tucker and O'Brien, 2011).

As one can begin to appreciate, determining the impact of even a small spill in a complex environment such as Vancouver presents a challenge. The next section offers a baseline view of the physical and biological environment of concern, and attempts to address potential impacts of a spill.

# 4 BIOLOGICAL IMPACT

This section offers a scientific foundation of relevant environmental and biological issues that underpin economic effects of an oil spill incident. As well, it serves as context to understand current gaps in data and knowledge about ways in which oil could affect this ecosystem, which can inform future work for policy development and decision-making. As most research in this field has been conducted on the effects of oil (versus bitumen), the findings in this section reflect that emphasis.

## *4.1 Biophysical Environment of Burrard Inlet*

Burrard Inlet is comprised of a collection of diverse and sensitive marine and estuarine ecosystems surrounding Canada's largest port. Changes in these ecosystems over time provide a glimpse of the complex anthropogenic interactions that can occur, and thus, provide valuable insight for management strategies. In this section, we will characterize the physical conditions experienced on a typical day in Burrard Inlet.

### 4.1.1 Description of Body of Water

Burrard Inlet is located on the mainland coast of southwestern British Columbia (BC), just north of and paralleling the Fraser River estuary. Both Burrard Inlet and the Fraser River estuary are among many of BC's main waterways that are also economically and ecologically important for a diversity of species, including salmon migration and reproduction and bird habitat. The mouth of Burrard Inlet opens into the Strait of Georgia, the water body between the Coast Mountains and Vancouver Island.

One of the most common marine ecosystems in Burrard Inlet is the rocky intertidal shoreline (BIEAP, 2010). Physical conditions such as tides, wave action, substrate, and salinity attract many marine organisms that form the bottom of a complex food chain. These same physical conditions will also, in part, determine how an anthropogenic pollutant, such as crude oil, would be dispersed within the Inlet.

Burrard Inlet differs from most inlets along the BC coast in that it lacks a sill at its seaward entrance and the land adjacent to the Inlet is of moderate relief rather than a steep slope (Haggarty, 2001). The Inlet is relatively shallow, and receives considerable fresh water input from mountain streams and the Fraser River. The Inlet is a tidal, salt water fjord with 23km of developed residential and industrial land, as well as lots of land and water areas devoted to parks and wildlife refuges (Haggarty, 2001).

#### *4.1.1.1 Waterway Usage*

Burrard Inlet is the location for Vancouver's port, acts as Canada's principal gateway for trade with the Pacific Rim (Vancouver Port, 2001). (Since 2008, the assets and jurisdictions of the former Fraser River Port Authority, North Fraser Port Authority, and Vancouver Port Authority have been operated by the Vancouver Fraser Port Authority, also known as Port Metro Vancouver.) In 1999, 71.2 million tons of cargo were transported through this Inlet (Haggarty, 2001). The port has held distinctions such as the "busiest port in foreign export in North America" with a diversity of exporting products such as container, bulk and general cargo terminals of coal, grain, sulphur, potash, and wood pulp (Vancouver Port, 2001). This Inlet and port is also the home of a cruise ship terminal transporting over a million passengers (many tourists) in the year 2000 (Vancouver Port, 2001). On average, port activities generate approximately $45 million / year (Vancouver Port, 2001). Burrard Inlet is also used in a variety of ways by the urban sector, including but not limited to (1) water utilized for auxiliary fire fighting in downtown Vancouver, (2) recreational use of waterways (kayaking, boating, fishing, scuba diving and swimming), beaches, and seawall by locals and tourists, and (3) the watershed of Burrard Inlet providing drinking water for the lower mainland (see *Section 6.7*).

#### *4.1.1.2 Bordering Municipalities & Population*

Burrard Inlet watershed is one of the fastest growing urban areas in Canada (Haggarty, 2001). The current population of Greater Vancouver is approximately 2.3 million, with over 1 million residing in Burrard Inlet's drainage basin (Vancouver, 2013). Eight municipalities border the Inlet, including: the cities of Vancouver, District of West Vancouver, Burnaby, North Vancouver and Port Moody, the District of North Vancouver, and the villages of Anmore and Belcarra (Jacques Whitford AXYS Ltd., 2008).

#### *4.1.1.3 Connecting Waterways*

Burrard Inlet has three freshwater inputs from the Capilano, Seymour, and Indian Rivers as well numerous small streams (Figure 1) (L. W. Davidson, 1979). Mountain streams feeding the Inlet provide essential nursery habitat for juvenile salmon and the watershed as a whole acts as a significant fish migration corridor annually for millions of Pacific salmon returning to the Capilano, Seymour, and Indian Rivers (see *Section 4.2*). Covering 11,300 hectares (Ha), Burrard Inlet extends 30 km westward from the head at Point Atkinson (in the north) and Point Grey (in the south) to Port Moody Arm and Indian Arm (BIEAP, 2011). The Inlet can be divided into five distinct water basins: the Outer Harbour (5,600 Ha), False Creek (77 Ha), Inner Harbour (also called Vancouver Harbour) (1540 Ha), Central Harbour (890 Ha), Port Moody Arm (560 Ha), and Indian Arm (6,900 Ha) (Figure 1) (Jacques Whitford AXYS Ltd., 2008).

#### *4.1.1.4 Drainage & Run-Off*

Burrard Inlet has 190 kilometres of marine foreshore with a drainage basin of 98,000 hectares (Jacques Whitford AXYS Ltd., 2008). Runoff from the North Arm of the Fraser River is the main source of brackish water in the outer portion of Burrard Inlet, and it is this discharge that is tied to snow melt and peaks in May and June each year (Haggarty, 2001). Additional freshwater inputs into Burrard Inlet include the Indian River, at the head of Indian Arm, which discharges from Buntzen Lake, and other local streams and larger creeks around the Inlet; however, these inputs contribute an order of magnitude less than the Fraser, Seymour and Capilano Rivers (Haggarty, 2001). The Seymour River provides the main local source of freshwater to the Inner Harbour, while the Capilano River provides inflow to the Outer Harbour (L. W. Davidson, 1979). Flow of these rivers is closely tied to precipitation and is usually greatest in autumn and winter; however, it rarely exceeds 1% of the maximum discharge of the Fraser River into the Inlet (L. W. Davidson, 1979).

#### *4.1.1.5 Depth*

Burrard Inlet possesses a shallow, irregular depth profile that is distinctly different from most of BC's coastal inlets (L. W. Davidson, 1979; Haggarty, 2001). The Inlet reaches a maximum depth of 100 metres in the mid-channel south of Point Atkinson (Figure 1) (Haggarty, 2001). There are several very shallow areas throughout the Inlet, including (1) a mean depth of 21 metres between the First Narrows and the head of Port Moody Arm, and (2) the extension of Port Moody Arm has a mean depth of 9 metres (Haggarty, 2001). Indian Arm River is a fjord with steep sides with a larger average and maximum depth of 120 metres and 245 m, respectively (De Young, 1986; (Haggarty, 2001). A broad shallow sill exists at the mouth of the Indian Arm that restricts the exchange of salt water with Burrard Inlet, and thus during each neap tide cycle only about 20% of the Indian River Arm water is mixed with Burrard Inlet water (De Young, 1986). Inferences have been made that suggest tankers exiting the port through the shallow First and Second Narrows channels must coordinate with a short high tide cycle of approximately 20 minutes, which provides loaded tankers with less than two metres of under-keel clearance. Although one cannot fully evaluate the authenticity of such a statement, this suggestion paints a picture of a potential snapshot of time that may be experienced given a certain time of year and moon-tide cycle.

#### *4.1.1.6 Tides*

Tide prediction stations are found at both Point Atkinson and the Inner Harbour. Tides in the Inlet are mixed, mainly semi-diurnal with a strong declination variation over a two-week period (Haggarty, 2001). There is a slight increase in tidal range east of the Second Narrows, and a delay of the higher high water by approximately 30 minutes in Port Moody relative to the tide station in the Inner Harbour. Mean tidal range is 3.3 metres, with tidal ranges ± 5.0

metres (Haggarty, 2001). Time series from the moorings show that during spring tides, deep currents in the Inlet are as high as 1.5 m/s (Isachsen & Pond, 2000). Small flooding events bring outside water through the narrows with little mixing, which thus sinks to depth (Isachsen & Pond, 2000). In contrast, larger floods result in an increase of highly mixed, low density water. During neap tides, currents in deeper water are generally small with a gradual decrease in density and turbulent vertical diffusion (Isachsen & Pond, 2000). Additionally, there is a strong presence of vertical velocities downstream of each First and Second Narrows, especially during larger flood events (Isachsen & Pond, 2000).

#### *4.1.1.7 Currents*

Strong currents can increase up to 11 km/hr at both the First and Second Narrows during both the falling and incoming tidal flows (Haggarty, 2001). The strong falling tidal currents aid in flushing the Inner and Central Harbours as the surface water flows seaward (Haggarty, 2001; Li & Hodgins, 2004). During the rising tide, water flows into the Inlet through the First Narrows at great speeds but drops to 0.9 – 4.6 km/hr in the wider space of the Inner Harbour (Li & Hodgins, 2004). A resulting counter-clockwise eddy develops to the north of the main flow with an additional clockwise eddy that develops to the south (Haggarty, 2001). Water speeds again increase as the water flows through the Second Narrows and then decrease to about 1.8 km/hr as it enters the wide Central Harbour (Haggarty, 2001). Again, a counter-clockwise eddy is present at the north, and two clockwise eddies are apparent to the south of the water flow. During the falling tide, the water flows towards the sea and the eddies' directions reverse. As a result of eddy formation at both the First and Second Narrows, these regions have become important natural upwelling zones that bring nutrients up from the bottom and attract a diversity of foraging marine organisms (L. W. Davidson, 1979). In addition to the tidal currents, currents within the Inlet are also driven by freshwater runoff, in the direction of the Inlet mouth, and strong winds (Haggarty, 2001; Li & Hodgins, 2004).

Li and Hodgins (2004), curious about sewer discharge flow into Burrard Inlet, created a complex water circulation-outfall plume model to predict three-dimensional circulation and dispersion with a variety of specific Burrard Inlet parameters in mind (e.g. circulation, turbulent mixing, discharge rate sewage). This study demonstrated that both the strength of the currents through the First Narrows and the discharge rate have dominant roles on determining plume trapping and dilutions throughout Burrard Inlet. The model had a number of significant predictions, including discharge plumes that generally stayed below 8 metres depth, with short-lived surfacing events occurring during times of slow currents. When the currents were strong, trapping of the plume was generally deep, with vertical mixing, bringing the outflow water into contact with the seabed. Discharge rate was the second primary factor that altered the plume depth and dilution capabilities. Increases in the rate of discharge produced shallower plume trapping and reduced the initial dilution of discharge. Overall, tidal flushing of Burrard Inlet was very effective in transporting discharge out of the waterway (Li & Hodgins, 2004).

##### *4.1.1.8 Temperature & Salinity*

Temperature and salinity vary seasonally and are affected by conditions in the Strait of Georgia, local run-off levels, influx of water from the Fraser River, as well as the tides and winds (L. W. Davidson, 1979). A synchronous thermocline and halocline exists in the Inlet, where 5 metres of relatively warm, low salinity water lies on top of colder, more saline water (L. W. Davidson, 1979).

Water temperatures in Burrard Inlet are highest from July through early August, reaching up to 20ºC on the surface of shallow areas in the Outer Harbour and Port Moody Arm and 15ºC in the Inner and Central Harbours (L. W. Davidson, 1979). A shallow thermocline exists, where water temperature may decrease by 5-10ºC within the top 5 metres of the surface. Winter temperatures generally range between 6-8ºC (L. W. Davidson, 1979).

Throughout the year, salinity below 10 metres is uniform at 29-30% (L. W. Davidson, 1979). However, surface salinity can be as low as 10% when it receives freshwater input from the Fraser River into the Outer Harbour (L. W. Davidson, 1979).

From south to north across the Inlet, salinity increases, reaching up to 20% near the north shore of Vancouver. East of the First Narrows, surface salinity ranges between 18-20% in the summer and 20-26% in the winter (L. W. Davidson, 1979).

### 4.1.2 Species Diversity of Burrard Inlet

The Inlet is home to a diverse ecosystem. Over 1200 verified species are found here: mammals, birds, fish, reptiles, amphibians, tunicates, arthropods, molluscs, vascular plants, non-vascular plants, marine algae and sea grasses, fungi, plankton, species at risk, and invasive species. Many of these have both significant economic and ecological value to the region.

#### *4.1.2.1 Plankton*

Plankton is important as it provides the basis for the food chain. Over 85 taxa (categories) of phytoplankton (plant-based) from six major groups are found in Burrard Inlet (Haggarty, 2001). In the spring (mid-March to early April), phytoplankton will bloom, which is typically related to the onset of thermal stratification (or layering) in the water, as well as increased light and nutrient levels, with a maximum biomass reached by mid-May to early June. Estimated mean annual primary production for the Inlet is 350 grams of carbon per metre$^2$, with Port Moody Arm being the most productive basin and First Narrows being the least productive basin in the Inlet (Haggarty, 2001)

Peak zooplankton (animal-based) biomass lags behind phytoplankton peaks by several weeks. Dynamic water movements and flushing in the near-shore and estuarine areas of the Strait of Georgia lead to sporadic and massive recruitment of meroplankton (such as sea urchin larvae). Conditions that concentrate zooplankton, such as physical, chemical, and biological gradients, are important for planktivors such as juvenile Chum salmon, since high densities of prey require it to feed.

Phyto - and zoo- plankton abundance decrease in a seaward direction from a high amount in Port Moody to a low amount at Point Atkinson (Stockner and Cliff, 1979). Strong tidal mixing and increased turbidity in the outer Inlet caused by the Fraser River plume reduce productivity in the inner and outer harbour (Haggarty, 2001).

#### *4.1.2.2 Fish*

Near-shore, 63 species of fishes have been found in Burrard Inlet (Haggarty, 2001). An additional 12 species are listed to be present in the Port Moody Arm (City of Port, 2011). Some species spend their entire lives within the Inlet, while others, such as the salmon, migrate through from spawning grounds to the open ocean. Similarly, some fish spend their entire time at one depth, while others move diurnally or to follow prey throughout the water column. Commercially important herring, anchovy, lingcod, and other bottom fish such as English sole, rock sole, Dover sole, quillback rockfish, starry flounder and kelp greenling are all present in the Inlet (Haggarty, 2001). Chum and Chinook salmon (mainly juveniles) are the most abundant commercially significant fish species that use Burrard Inlet. Salmon are anadromous, meaning that they are born in freshwater, migrate to the open ocean, and return to their birthplace at the end of their lives to spawn a new generation. For example, a large run of pink salmon (60,000 individuals) make their way up the Indian Arm River on odd numbered years (Haggarty, 2001), while large numbers of Chum salmon and smaller numbers of Coho and Chinook salmon make their way up the Arm annually. With the concentration of salmon in the fall, large numbers of eagle and seals feeding on the fish are also found. The Pink salmon run starts in July and runs into October.

Furthermore, surf smelt is an important recreational fishery in the Inlet waters. Surf smelt spawn on beaches in the outer Inlet. Important nurseries and spawning bed for many species have been identified in the Inlet (Jacques Whitford AXYS Ltd., 2008). Eelgrass meadows are nurseries for small fish such as young salmon.

Juvenile salmon, both Chum and Chinook, are abundant in the near-shore areas of Burrard Inlet from early spring to fall (Haggarty, 2001). Both Pink and Coho salmon are also abundant in the Inlet, especially Indian River, every second year (Haggarty, 2001). Coho, Chum and Pink salmon and herring spawn in Inlet streams. Coho salmon use near-shore areas of the Inlet and are less abundant than either Chum or Chinook. Sockeye, steelhead and cutthroat trout are found with the lowest frequency of all. Chum salmon emerge in the spring and migrate from streams to the near-shore and estuarine areas shortly thereafter, sometime between February and October (Program, 1993). Peak abundance in the Inlet occurs between March and July (Program, 1993). After emergence, juvenile Chinook either remain in fresh water for a year or migrate directly to estuaries. Chinook that migrate directly to estuarine nurseries after emergence or after a short freshwater period (60-90 days) are termed ocean-type while those that remain in fresh water for a year are called stream-type. Juvenile ocean-type Chinook are present in the Inlet between April and September with their peak abundance between May and July (Program, 1993). As juvenile salmon grow, they move offshore into deeper water and migrate to the Georgia Strait and Pacific Ocean. Adult salmon have been observed returning to spawn in 17 streams that flow into Burrard Inlet (Haggarty, 2001). Most Chum salmon adult returns are to the Indian River while most Chinook adult returns are hatchery fish returning to the Capilano hatchery. An average of 20,118 Chum spawners returned to the Indian River between 1953 and 1997, while an average of 615 Chinook returned to spawn in the Capilano between 1971 and 1993, and 106 to the Seymour between 1973- 1993 (Haggarty, 2001). In 1999, a total of 639,781 Chum and 156,571 Chinook fry were released into the Inlet (Haggarty, 2001).

#### *4.1.2.3 Birds*

Resident birds of Burrard Inlet include over 53 species, such as murrelets, grebes, herons, sea ducks, common loons, red-throated loons, coots, alcids, plovers, black oystercatchers, kingfishers, golden-eyes, pigeon guillemot, bald eagles and osprey (City of Port, 2011; Oceans, 2012). Burrard Inlet has important habitat (such as muddy and rocky shorelines and sandy beaches) for birds and provides a migration corridor, feeding areas, roosting and nesting sites both on the ground and in the air (BIEAP, 2010; Jacques Whitford AXYS Ltd., 2008). Furthermore, Burrard Inlet is internationally recognized as an “Important Bird Area”, attracting tens of thousands of migratory birds along the Pacific Flyway each year (Jacques Whitford AXYS Ltd., 2008). All of the water birds are at the top of the food web in Burrard Inlet, where most species dive to obtain the small fishes and crustaceans that comprise their diet. Current population levels may be declining due to human activity and loss of habitat in the Inlet (BIEAP, 2011).

#### *4.1.2.4 Terrestrial mammals*

Terrestrial mammals that utilize the foreshore beaches along Burrard Inlet include river otters, black-tailed deer, black bears, coyotes, raccoons, Douglas squirrel, American mink, red fox, Norway rat, various bat species, voles, shrews and mice (Page, 2012). Effects on these animals from an oil spill will be similar to that described below and in *Section 5. (S*ee also *Appendix 2)*.

#### *4.1.2.5 Marine mammals*

Harbour seals, California sea lions, and Stellar sea lions are the most common pinniped species in the Inlet that utilize both sandy and rocky shorelines to haul-out for both resting and pupping, and utilize the water habitat for foraging and as home range to carry out daily activities (Jacques Whitford AXYS Ltd., 2008). Other marine mammals and sea turtles that utilize primarily the waterway as habitat include grey whales, killer whales, Pacific white-sided dolphins, harbour porpoises, leatherback sea turtles, and green sea turtles (Page, 2012).

## *4.2 Biological Impact of an Oil Spill in Burrard Inlet*

An oil spill in the Burrard Inlet would likely have a strong, immediate impact on local marine life. While responses to an oiling event would vary among species and habitat type, a general assumption is that most species would exhibit population declines from direct (mortality) and indirect (reduced growth, reproduction, and recruitment) effects of oil. Oiling events can result in rapid population declines, but usually do not eliminate entire populations, allowing population recovery after the disturbance subsides. Likewise, no extinction event has been reported as a consequence of an oil spill (Dulvy, Sadovy, & Reynolds, 2003). Furthermore, the scientific community is unaware of any species that are unique to the Burrard Inlet so even a local species extinction could eventually be replenished by neighbouring populations. The following sections review knowledge acquired from previous oil spills and experiments on marine species to summarize how an oil spill in Burrard Inlet would likely impact local marine assemblages.

### 4.2.1 Plankton

Plankton communities occupy the uppermost layers of the water column and therefore one might expect these assemblages to be largely impacted by spill events where oil coats the upper layers of marine waters. It is difficult to assess how previous spills have impacted plankton communities because historical baseline data of plankton communities are limited. However, a recent study after the *Deep Horizon* Oil Spill compared planktonic community structure after the spill to historical data but attributed an observed shift in composition to natural variability and found no decrease in planktonic health or diversity after the spill (Malik, 2012), concluding that the spill had a minor, if any, impact on these communities. Furthermore, controlled experimental release of oil to simulate spills showed no adverse effects of oiling on Arctic marine (Cross, 1987) or subarctic lake (Hellebust, Hanna, Sheath, Gergis, & Hutchinson, 1975) planktonic communities. Therefore, despite living in close proximity to the surface (where oil sits), planktonic communities seem resilient to oil spills, likely owing to their rapid reproductive abilities.

Sub-lethal studies have shown that hydrocarbons, especially the high aromatic fractions, can damage development and alter behaviour and physiology in planktonic organisms. Biochemical investigations have demonstrated both accumulation and depuration of hydrocarbons (including carcinogens) in plankton (Davenport, 1982). Field studies have revealed that there is no lasting damage to planktonic ecosystems caused by oil. Typically, oil spills are followed by rises in bacterial and yeast numbers (*Section 4.3.2*), temporary decreases in zooplankton densities, and increases in phytoplankton production. The bulk of hydrocarbons, even including polycyclic aromatic carcinogens (King, 1977) are produced by living biota, and thus, are a normal part of the chemical habitat for these organisms. Smith (1954) estimated that the yearly hydrocarbon production by marine phytoplankton amounted to some 5 tonnes/kilometre (t/km), while estimates of annual crude oil discharge into the world ocean have ranged from 0.002 to 0.15 t/km (Chandler, 1974; Wilson, 1974).

In enclosed habitats the potential for damage to biological life is increased because of reduced dilution capacity and low-energy nature of the environment. In such situations, enclosed lakes, rivers, shallow seas, lagoons or estuaries are exposed to high concentrations for longer periods of time and noticeable effects may persist for months and years. However, Burrard Inlet is well-flushed body of water, and probably would not suffer such effects.

### 4.2.2 Marine Plants

Like phytoplankton, marine plants lie at the base of the food chain and play the important role of converting energy from sunlight into sugars, which can be utilized by the animals that feed on them. Contrary to phytoplankton, marine plants also provide three-dimensional structures that house many other plant and animal species. Marine plants in the Burrard Inlet include seaweeds, kelps, and seagrasses. To briefly define these terms: seaweeds are large algae (most of the plant-like species in marine environments); kelps represent one group of large brown seaweeds that are particularly ecologically and economically important; and seagrasses are flowering plant species that live submerged in marine waters. (There are only ~60 species of seagrasses worldwide and 3 species in Burrard Inlet). Numerous species of invertebrates and fish rely on habitat and food provided by marine plants.

Unlike phytoplankton, which float at the surface of the water, marine plants (including seaweeds, kelps and seagrasses) remain attached to substrate, either on rock or within soft sediment. Likewise, many marine plants may escape direct exposure to oil if they grow at depths deeper than the oil infiltrates. Since most oil spills do not penetrate further than 1 metre into the water column, most sub-tidal (living below the low tide mark) species will not be exposed to high concentrations of oil pollution- an obvious exception being the bull kelp (*Nereocystis leutkeana*), whose fronds grow to the surface of the water. Bull kelp may be particularly sensitive to an oil spill since even short-term (4 hours) exposure of petroleum products to bull kelp blades resulted in impaired photosynthesis and tissue death (Antrim et al., n.d.).

Sub-tidal kelps in the Gulf of Alaska were only minimally impacted by the Exxon *Valdez* oil spill and recovered quickly (Dean & Jewett 2001). Short-term oiling experiments in the Arctic were unable to detect differences in sub-tidal seaweed communities at oiled vs. unoiled sites sub-tidal seaweed communities (Cross, Martin, & Thomson, 1987). Similarly, *Saccharina latissima* (a common shallow sub-tidal kelp in the Burrard Inlet) did not exhibit decreased growth after the *World Prodigy* Oil Spill in Rhode Island (Peckol, Levings, & Garrity, 1990). It seems reasonable to conclude that the sub-tidal kelps of Burrard Inlet, other than the bull kelp, would not be heavily impacted by a surface oil spill.

The marine plants most likely to be directly impacted by a spill event are those living in the inter-tidal and shallow sub-tidal because of direct exposure to oil products. Information on the effects of oil on marine plants is mostly restricted to dominant, canopy forming species because of their ecological importance and greater likelihood of having pre-spill data. In Burrard Inlet, the rocky inter-tidal is dominated by seaweeds (like Rockweed, *Fucus* spp.), and sandy shallow sub-tidal environments are dominated by seagrass (such as Eelgrass, *Zostera marina*).

Seagrass species exhibit divergent responses to oil pollution. Experimental exposure to oil (for 12 hours) did not impair metabolism of seagrass species in Kuwait (Durako, Kenworthy, Fatemy, Valavi, & Thayer, 1993). Accordingly, seagrass species did not show declines after the Gulf War Oil Spill. On the other hand, the dominant local seagrass species in Burrard Inlet, eelgrass or *Zostera marina*, exhibited high shoot mortality following the Exxon *Valdez* (Dean, Stekoll, Jewett, Smith, & Hose, 1998) and Amoco *Cadiz* (Jacobs, 1989) oil spills. Plants were able to regrow shoots from their undamaged below-ground stems and recovered within weeks. Surprisingly, long-term consequences of the spill were not observed, even when measuring more subtle population traits, such as seed production and germination (Dean et al., 1998).

The dominant seaweed in local rocky marine communities (Rockweed or *Fucus*) is broadly distributed throughout temperate oceans, including many regions that have been hit by oil spills in the past. Because of its ecological importance in temperate rocky intertidal habitats, *Fucus* serves as a proxy for measuring damage to and recovery of inter-tidal marine communities. Accordingly, there is a strong body of literature examining impacts of oil spills on Rockweed. Although the magnitude of impacts of an oiling event on *Fucus* populations is site specific (Stekoll & Deysher, 2000), the general expectation is an immediate decline in abundance. There is no consensus in the literature concerning recovery dynamics. Recovery times in the literature vary from 1-2 years to over a decade. Although sites vary in their recovery time, the ten year discrepancy in the literature is likely a result of differential definitions of ‘recovery’ and limitations of the sampling design used to determine it (Paine et al., 1996). For instance, abundance data may return to pre-oiled values within two years, but shifts in other demographic traits, such as reduced reproductive competence (Stekoll &

Deysher, 2000), reduced recruitment (De Vogelaere & Foster, 1994), and increased infection by epiphytic algae (Stekoll & Deysher, 2000), may decrease the resilience of the population to further disturbances (discussed in *Section 4.3*).

### 4.2.3 Invertebrates

Invertebrate refers to an animal that lacks a spine. It is important to note that, in fact, most species of animals (98%) on the planet are invertebrates and there is much greater diversity of form, function, and ecological traits among invertebrate species than among vertebrates. The marine environment is no exception and there are over 2,500 species of marine macroinvertebrates living in the Strait of Georgia (Macdonald et al. 2010). This level of diversity obviates a concise and exhaustive summary of invertebrates in the Burrard Inlet. However a quick reminder of the broad-scale diversity among invertebrate species in the local area is useful to give context to how diversity of invertebrate species increases complexity of ecosystems.

Instead of classifying species by their relatedness, ecologists often group species by their role in the ecosystem. All invertebrates obtain energy from other organisms in one form or another (as they cannot produce their own energy like plants) and most species are commonly eaten by other predatory species (including invertebrate and vertebrate species). Microscopic invertebrates compose the zooplankton, which swim in the water column feeding on phytoplankton and are consumed by larger animals (i.e. fish and whales). On the seafloor, suspension-feeding invertebrates filter microscopic food and particulate energy out of the water; grazers feed directly on marine plants; omnivores (more than half of the local species, Macdonald et al. 2010) consume plants as well as animal material; carnivores prey upon other animal species; detritivores obtain energy from decaying organic matter, and; parasites acquire nutrients/energy directly from their hosts. The diversity of ecosystem roles played by marine invertebrates highlights their importance in the complex marine ecosystems of Burrard Inlet.

Discussing species in terms of their ecosystem roles is a useful way to reduce such a diverse group of species into more easily manageable groups, but it hides the diversity of invertebrates. Listing a few of the major groups of familiar species may help contextualize the diversity of invertebrate species in local marine waters: crustaceans (crabs, barnacles, and amphipods), gastropods (snails, limpets, and sea slugs), bivalves (mussels, clams, scallops, and oysters), worms, amphipods, sponges, sea squirts, anemones, octopus and echinoderms (seastars, sand dollars, and sea urchins),

As with the local marine plants, most sub-tidal marine invertebrates should be relatively unaffected by an oil spill in Burrard Inlet, assuming that the oil products float. Accordingly, most of this section focuses on inter-tidal and shallow sub-tidal invertebrates. However, two experiments investigated the impacts of an oil spill on sub-tidal faunal communities and warrant a brief discussion.

Experiments exposing natural sub-tidal marine communities in the Arctic to a simulated oil spill showed little effects on sediment-dwelling (Cross & Thomson, 1987) and mobile invertebrate populations (Cross et al., 1987). The only detectable negative impacts were on bivalves (filter-feeding and deposit-feeding species), a species of Polychaete worm (where abundance declines were still observable at least two years after the experiment), and on Amphipod species. Although only these few species groups showed measurable demographic impacts from the oiling event, seastars and sea urchins (important predators and grazers driving community level processes) displayed visible behavioural deficits as a consequence of the oil exposure: individuals were initially paralyzed (Cross et al., 1987). These data represent the only experimental tests of oil spills on marine sub-tidal fauna and, the review indicates that similar experiments have not been conducted on intertidal systems. Below is a summary of findings from previous oil spills and laboratory experiments on invertebrate species, with a focus on intertidal species.

Barnacles are one of the most abundant invertebrates in the area covering the mid to high intertidal in nearly 100 percent cover in some rocky areas. Research on the responses of barnacles to previous oil spills suggests that they are not likely to be severely impacted by a large spill event- even when covered with oil (as long as their respiratory organs are not smothered, barnacles appear healthy) (George, 1961). Incidents of barnacles attaching to oiled surfaces have been documented shortly after spill events (Nelson-Smith, 1971; 1973).

Inter-tidal crabs were particularly highly impacted in salt marsh communities after the *Deepwater Horizon Oil Spill*, with crab populations reduced, even in areas that seemed to escape heavy oiling (McCall & Pennings, 2012). Although crabs seemed to recover within a year in these salt marsh, and other communities (North, Neushul, & Clendenning, n.d.), the decline in crabs from eelgrass beds after the Exxon *Valdez* Oil Spill was still not fully recovered six years after the spill (Jewett & Dean, 1997).

Amphipods' vulnerability to and delayed recovery from oil spills is one, and perhaps the only, similarity on the impacts of oil spills on invertebrate communities, as revealed by the data. Several field studies in different regions and different habitats have reported declines in amphipod abundance, diversity, or reproductive output after a spill event (Cross et al., 1987; Hartog & Jacobs, 1980; Jacobs, 1980; Jewett & Dean, 1997; Jewett, Dean, Smith, & Blanchard, 1999). It is important to note that in these studies, amphipods took longer to recover than most other invertebrate species. Their delayed recovery potential is likely linked to limited dispersal resulting from females brooding eggs.

Snail species (even when closely related) show varying degrees of sensitivity to oil pollution. For instance, one species of *Littorina* (the dominant inter-tidal genus in the Burrard Inlet, with multiple representative species) was eliminated by a spill while another persisted at the same site (North, 1973). *Littorina littorea*, a recent non-indigenous addition to the fauna of Burrard Inlet (Harley et al., 2013), was the least susceptible of three conspecifics to oil-induced mortality. By preferentially damaging the native species, an oil spill in Burrard Inlet could conceivably increase the success of the *L. littorea* invasion.

Bivalves, including mussels, clams, and oysters, have been a major focus of oil impacts on marine communities because of their tendency to accumulate oil in their tissues and because of their ecological and economic importance. Oil enters bivalve bodies during feeding and therefore uptake rates vary among species with respective to feeding mode. Once oil enters bivalve tissue, they may experience DNA damage (Pérez-Cadahía, Laffon, Pásaro, & Méndez, 2004) and severe impacts to immune functioning (Dyrynda et al., 2000). Declines in bivalve populations had not recovered six years after the Exxon *Valdez* Oil Spill (Jewett & Dean, 1997) and oyster contamination by oil residuum was still detected seven years after the

Amoco *Cadiz* spill (Berthou, Balouet, Bodennec, & Marchand, 1987). Law & Hellou (1999) summarise effects of oiling on shellfish and list several harvesting bans on shellfish which lasted longer than five years because of hydrocarbon contamination.

Seastars are important predators in local marine systems that can fundamentally alter community structure and ecological dynamics (Paine, 1969). Despite their ecological importance, there is a paucity of data on how they are impacted by oiling events. The garlic seastar (*Dermasterias imbricata*) and the sunflower seastar (*Pycnopodia helianthoides*) were both suppressed after the Exxon *Valdez* Oil Spill. However, recovery of the sunflower seastar was achieved within four years, while the garlic seastar had still not recovered within six years (Jewett & Dean, 1997). There is currently a lack of data on adult ochre seastar, *Pisaster ochraceus*, which may be the most abundant seastar in Burrard Inlet; however, it is known that oil pollution is toxic to its larvae (Chia, 1973).

Despite the varied responses of adult invertebrates, larval stages of most species are thought to be particularly vulnerable to oil pollution (Chia, 1973; Wells, 1972). Pelagic larvae of invertebrate species usually occur in seasonal episodic pulses, so the timing of an oil spill will dictate whether or not invertebrate larvae are impacted by a spill, but mass mortality of larvae during a spawning episode will likely scale to adult population declines, since recruitment in sessile invertebrates is associated with the delivery of competent larvae (Gaines & Bertness, 1992).

#### 4.2.4 Fish

Contrary to stationary invertebrates and marine plants, most fish are fairly mobile and may be able to escape prolonged exposure to oil. Additionally, most fish either live in the water column or on the seafloor and do not need to travel to the surface (where the majority of the oil remains), unlike marine mammals, which must come to the surface regularly to breathe. Unless specific characteristics of a spill (submarine release or sinking pollutant) result in greater than normal vertical migration of oil pollutants into the water column, most fish populations are likely to remain unaffected by a spill. For a sobering perspective on relative impacts of oil spills on fish populations, it is noteworthy that hundreds of thousands of deaths were reported for birds and mammals as a result of the Exxon *Valdez* Oil Spill; in contrast, only ten fish deaths were directly attributed to the spill (Paine et al., 1996). Although adult fish are not especially vulnerable to oil spills, fish populations could still be injured by an oil spill through mortality at early developmental stages or indirect effects (i.e. through habitat loss).

Fish see oil as floating food and ingest it, which may kill them. If they survive, they will be contaminated and other animals higher up the food chain will eat them, thus transferring the contaminant effects to higher-level predators. Eggs and larva are disproportionately affected, leading to health impacts that can last generations (Kazlauskienė & Taujanskis, 2011; Kazlauskiene, Vosyliene, & Ratkelyte, 2008). Four years after the Exxon *Valdez* spill in 1989, the herring population off the coast of Alaska suddenly declined by over 90%, though it was difficult to know exactly why or if the spill was to blame (Hose et al., 1996; Jewett et al., 2002; Norcross, Hose, Frandsen, & Brown, 1996; Thorne & Thomas, 2008). Jewett et al. (2002) found that up to that year the herring population had still failed to recover (Jewett et al., 2002). Some studies indicate that petroleum is detrimental to fish eggs. However more research is needed in this area to fully understand harmful impacts.

As with invertebrates, early developmental stages (eggs and larvae) of fish are particularly susceptible to injury by oil pollutants (Rice et al., 2001; Kazlauskiene, Vosyliene, & Ratkelyte, 2008). After the Exxon *Valdez* oil spill, increased Pink Salmon egg mortality was observed at oiled sites compared to control sites that were not directly oiled (Bue, Sharr, Moffitt, & Craig, 1993). However, increased egg mortality did not translate into population declines as the following two years represented record Pink Salmon harvests (Paine et al., 1996). Lethal (Carls, Marty, & Hose, 2002), (McGurk & Brown, 1996) and sub-lethal (Hose et al., 1996; Norcross, Hose, Frandsen, & Brown, 1996) impacts were also recorded on early developmental stages of Pacific herring populations after the oil spill, but attributing populations declines to these damages was not possible (Carls et al., 2002).

### 4.2.5 Birds

Direct acute effects of oil are most important for mammals and birds (the Exxon *Valdez* Oil Spill was associated with 250,000 dead seabirds and 3,000 dead sea otters) (Bodkin et al., 2003). When oil penetrates birds' feathers, it degrades the insulating properties of their outer layers and makes them extremely vulnerable to changes in temperature (Szaro, 1977). As a result, they lose buoyancy, causing them to sink in the water and drown. Oil-slicked birds that make it to shore are unlikely to be able to fly and make easy prey for predators. If birds continue to preen themselves, their first instinctual response when covered by oil, they will ingest chemical compounds that cause severe, often fatal damage to the kidney and liver and disturb the digestive tract (Geraci and St. Aubin, 1990; Szaro, 1977). Many of the same impacts have been recorded in marine mammals such as seals and otters (Ormseth and Ben-David, 2000). The damage to the bird's internal organs is impossible to reverse, and if that damage is not enough to kill the bird, the extreme stress caused by the cleaning can be. In the *Prestige* oil tanker spill (2002) approximately a quarter of a million birds were affected. Though thousands were recovered and cleaned, only around 600 survived long enough to be released back into the wild (Barron, 2012; Columbia, 2010). Median survival time of the released birds was seven days, while 99% of the cleaned birds died soon after release (Barron, 2012). Numerous environmental groups and biologists recommend humanely killing birds instead of putting them through the long and stressful ordeal of cleaning.

#### 4.2.6 Marine mammals

Marine mammals and sea turtles are likely to be affected by oil through a variety of mechanisms, including external oiling, ingestion of oil either directly or through food, and inhalation of oil; each will be discussed below.

External oil can either stick to the skin or fur of marine mammals or in the case of baleen whales, stick to their hairy feeding apparatus. Oil has the capability of sticking tenaciously to vital insulating hairs of sea otters, polar bears, and seals and sea lions, and thus, it can destroy the animal's ability to maintain thermal balance. Oiling of seals, particularly the young, presents an additional risk, as thick, viscous petroleum can mat the hair, prevent limbs from moving freely, and thus affect swimming performance. Some baleen whales forage at the surface, a behaviour called skim feeding (Wursig et al., 1982). When feeding in an area of an oil slick or tar balls, they may foul the feeding apparatus. Tarry residues in particular could coat the baleen plates (Brownell, 1971) (Geraci & St. Aubin, 1990). Combined evidence from a multitude of studies suggests that a spill of heavy oil, or residual patches of weathered oil, could interfere with flow of water between the plates of baleen and thus reduce the feeding efficiency of the fouled plates for several days. This impact would be greatest at times of year when baleen whales are feeding intensively to prepare for migration.

The skin of cetaceans seems relatively impermeable to oil (Geraci and St. Aubin, 1982). Petroleum compounds, especially the short-chain fractions in gasoline, typically irritate skin and mucous membranes (Dutton, 1934; Hansbrough et al., 1985). This irritation is due in part to solubilizing and removing cutaneous lipids (Wolfram et al., 1972; Cornish, 1980), triggering an inflammatory response which first appears as reddening of the skin (Hansbrough et al., 1985). Persistent contact causes necrosis (Walsh et al., 1974) and inflammation. Through a series of controlled experiments where different types of oil were rubbed into the skin of captive bottlenose dolphins, it was discovered that the thick skin of cetaceans acts as a very good barrier to noxious substances found in oil. In a typical mammal the oil would normally damage the skin by permeating the intercellular spaces and dissolving protective lipids. An important finding was that following a cut, newly exposed epidermal cells degenerate to form a zone of dead tissues, which shields the underlying cells from seawater during healing. These oil substances had no effect on the healing process; whereas, lead-free gasoline caused an exaggerated inflammatory response, which by 24 hours subsided and was indistinguishable from control cuts.

In oiled waters, cetaceans seem to spend less time at the surface, respiring less frequently and faster in attempts of avoiding the oil. Through a series of control experiments performed on live captive dolphins, it was discovered that dolphins do have the ability to sense and detect oil (down to 1mm thick films) (Geraci and St. Aubin, 1990). When dolphins do surface in the middle of an oil film they can feel the oil (through the cutaneous tactile sensory system) and react with a startle response and then refuse to enter the oiled area for days. Marine mammals encountering fresh oil are likely to inhale volatile gases and /or hydrocarbons evaporating from the surface slick, which have many toxic properties (Appendix 2). Inhalation of concentrated petroleum vapours may cause inflammation of mucous membranes, lung congestion, or even pneumonia (Hansen, 1985). Volatile hydrocarbons, such as benzene and toluene that are inhaled, are transferred rapidly into the bloodstream from the lungs. They may accumulate from the blood in such tissues as brain and liver, causing neurological disorders and liver damage (Geraci and St. Aubin, 1982). They can also irritate and damage soft tissues such as mucous membranes of the eyes (Carpenter et al., 1977) and airways. Depending on the concentration of vapours and duration of exposure, their effects range from mild irritation (Valpey et al., 1978) to sudden death (Wang and Irons, 1961). Vapour concentrations of VOCs could reach critical levels for the first few hours after a spill. A whale or dolphin unable to leave the scene during that time would inhale vapours and might be harmed. For a given exposure, the effect would depend on the health of the animal and its immediate response to stress (Thomson and Geraci, 1986). A panicking whale or swiftly moving dolphin would breathe rapidly and probably inhale more vapours. If this behaviour were aggravated by excessive release of adrenalin, sudden mortality could result, as has been observed occasionally in humans (Bass, 1986). More likely, the animals would experience some irritation of respiratory membranes and absorb hydrocarbons into the bloodstream, a process that might be enhanced in cetaceans because they dive with lungs full of air and/or toxic gas. Whatever the mechanism, it is clear that for the short time they persist, vapours are one feature of an oil spill that can threaten the health of a marine mammal.

Most marine mammals do not drink large volumes of seawater, so significant accumulation of toxins or oil by this route is unlikely (Geraci and St. Aubin, 1990). Fur-bearing marine mammals such as fur seals, polar bears, and sea otters may ingest oil during grooming. The limited data available indicate that oil is not particularly toxic, at least to pinnipeds, when taken in by this route. Geraci and Smith (1976) showed that seals experienced no acute damage when they ingested 75 millilitres of oil over a short period of time. However, ingestion of oil during grooming may have contributed to the death of heavily oiled polar bears (Oritsland et al., 1981) and sea otters (Geraci and Williams, 1990).

Oil compounds are systemically harmful, the degree depending on their chemical composition. Those with low viscosity and surface tension irritate the gastrointestinal tract and induce vomiting, which leads to aspiration of the material into the lungs, causing pneumonia and death (Appendix 2) (Zieserl, 1979). Larger quantities, as much as 140 times the aspirated dose (Gerarde, 1964), can be tolerated if the substance remains in the gastrointestinal tract. Hydrocarbons can be directly toxic to the mucosal epithelium (Rowe et al., 1973) and, when absorbed, travel throughout the body and produce their greatest effects on the central nervous system. There has been some speculation that cetaceans could consume oil while feeding. Fraker et al. (1978) suggested that bowheads, because of their feeding behaviour, could ingest damaging quantities of oil. Hansen (1985) affirmed that baleen whales that skim the surface and water column are more likely to ingest oil than gulp-feeders or toothed whales. Gray whales, because of their versatile feeding habits, could conceivably consume floating tar balls (Calkins, 1979) or contaminated bottom sediments (Hansen, 1985). Virtually any species might ingest oil by feeding on contaminated prey. However, the literature consists of only a sparse notation that "hydrocarbons" were found in the intestines of two bottlenose dolphins along the coast of France (Duguy and Toussaint, 1977).

There has also been a study to determine how small quantities of refined petroleum oil consumed over a fairly long period of time would affect the health of bottlenose dolphins (Caldwell and Caldwell, 1982). It was an attempt to establish whether machine oil accidentally seeping into an aquarium pool might have been responsible for an increase in mortality of captive dolphins. The only notable clinical finding was elevated circulating levels of the enzyme glutamic pyruvic transaminase, suggesting that the liver might have been injured. Seals had also shown no effect after ingesting similar quantities (Geraci and Smith, 1976). In fact, the amount of substance considered to be critical is higher than one would reasonably wish to administer to a cetacean. In mice, it is in the order of 5 to 25 mL/kg for heavy fuel oils, and 14 to 20 mL/kg for lighter crude oils (Elars Bioresearch Laboratories, Inc., 1979a,b, 1980a-d). Let us assume that a cetacean would be at risk after taking a quantity of fuel oil at a midrange concentration of 15 mL/kg. To achieve that, an adult harbour porpoise would have to consume 1 L, a bottlenose dolphin 3-4 L, and a pilot whale 30 L. A forty-ton whale would require an estimated 600 L, or roughly 150 U.S. gallons. A dolphin may drink 500 to 1500 mL of seawater daily (Ridgway, 1972). If contaminated, only a small portion of that would be oil.

Dolphins, porpoises, and whales are predators that normally would not scavenge oil-killed fish. Lessons from captivity suggest that they would probably disregard tainted fish. Baleen whales in the area of a spill are more likely to ingest oil-contaminated food, particularly zooplankton, which actively consume oil particles for days to weeks. Assuming toxic oils comprise 10% of the estimated 1600 kilograms of food consumed in a day by a 40-ton fin whale, the total quantity of ingested oil would be 160 kilograms. This approaches the critical dose calculated for highly toxic fuel oils.

Petroleum hydrocarbons persist in the food chain, particularly in species that have a low capacity to detoxify them. Molluscs and other benthic invertebrates can accumulate residues from bottom sediments and remain contaminated for many years (Gilfillan and Vandermeulen, 1978). Gray whales and other bottom-feeding cetaceans might therefore ingest petroleum long after a spill has dissipated. Irrespective of how the animal ingests the toxic compounds, marine mammals appear to have the liver enzymes required to sequester and metabolize these toxins that persist in tissues of fish and other prey (McCain et al., 1978), because they possess cytochrome P-450 enzyme, an iron containing protein in liver cells that is involved in this metabolic process (Geraci and St. Aubin, 1982; Goksoyr et al. 1986). However a recent study has shown that such toxins are linked to lower reproductive survival of offspring, because these toxins may be passed from the mother through the placenta on to the fetus (Schwacke et al., 2002). A pilot study on rats has shown that oil is a potent inducer of cytochrome P-450 (Geraci and St. Aubin, 1982), and one would expect it to have a comparable effect in a cetacean. Using P-450 enzyme as a biomarker, highest levels of naphthalene were detected in the blubber of small odontocetes, with considerably lesser values in baleen whales. The pattern of accumulation seems to be consistent with the habitat and target prey of the animals. For example, beluga whales and narwhals, which had the highest concentrations, live in a cold environment that retards hydrocarbon metabolism in fish (Collier et al., 1978), potentially leaving more available to be consumed. Baleen whales generally feed on organisms that accumulate and eliminate hydrocarbons relatively rapidly (Neff et al., 1976). Alternatively, the difference in the levels of naphthalene residues in odontocetes and baleen whales could reflect specific hydrocarbon detoxification capabilities in the two groups.

Zooplankton is a particularly important food resource for baleen whales. Copepods, euphausiids, and mysids become contaminated by assimilating hydrocarbons directly from seawater and by ingesting oil droplets and tainted food (Corner, 1978). Copepods are one of the few taxa in which hydrocarbon uptake appears to be easier from food than from water

(Corner et al., 1976). There is an inverse relationship between ambient temperature and rate of accumulation of petroleum hydrocarbons by copepods (Harris et al., 1977); polar and boreal species store more lipids, and therefore hydrocarbons, than those from warm environments. Planktonic crustaceans can transform aromatic hydrocarbons to polar metabolites that may be excreted or bound to tissues (Malins, 1977). For a few days or weeks, un-metabolized or metabolized hydrocarbons in zooplankton could be transferred to predators (Comer et al., 1976). Marine fish also take up hydrocarbons from water and food. The compounds induce the hepatic MFO system (Stegeman, 1981), and within a few days after exposure, aromatic hydrocarbons are oxygenated to polar metabolites and excreted. For this reason, most fish do not accumulate and retain high concentrations of hydrocarbons, even in heavily oil-contaminated environments, and so are not likely to transfer them to predators. Fish may nevertheless be tainted with metabolites bound to tissue macromolecules, including DNA. The metabolites are so reactive, it is unlikely that they would be released in a toxic form during digestion by the consumer and so would not pose a serious threat.

By removing spilled oil from the sea surface, dispersants obviously reduce the risk of contact (Geraci and St. Aubin, 1990). The remaining oil would be less sticky, and therefore less likely to adhere to fur, skin, baleen plates, or other body surfaces. However, the surfactants in dispersants may remove natural oils from marine mammal fur, thereby decreasing its insulating properties. Cleaning oiled beaches and rocky shores with dispersants may be an effective means of preventing oiling of pinnipeds that may wish to haul out there, while destroying everything else. More work needs to be done in this area of study before adequate assessment of whether dispersant should be used such habitats.

### 4.2.7 Ecologically important species

Most populations of animals are large or dispersed enough as not to be jeopardized by a single spill. There are a few highly endangered populations of animals that include the small California stock of sea otters, the Mediterranean and Hawaiian stocks of monk seals, North Atlantic Right Whales on the east coast, and beluga whales in the St. Lawrence River to name a few. These species will experience different impacts depending on what critical stages in the life history they are experiencing at the time of the spill (e.g. different times of the year and life cycle are devoted to mating, migrating, birthing, or moulting). Several populations, some local, such as the northern fur seal and Steller's sea lion, are declining for a number of reasons, some of which are anthropogenically related. For these species, the disruption associated with oil spills could be one more hindrance to their recovery (Matkin, Saulitis, Ellis, Olesiuk, & Rice, 2008).

Burrard Inlet is home to several endangered or threatened species. The Province of BC is currently defining habitats to sustain Marbled Murrelet populations within the Burrard Inlet and Indian Arm watersheds, while the provincial Spotted Owl Management Plan also creates two special resource management zones to increase the protection of critical spotted owl habitats within the upper watershed of the Seymour River (BIEAP, 2011). In addition, the Conservation Area at Maplewood Flats is an important part of the Pacific International Flyway and supports over 200 species of birds and numerous species of wildlife within 141 hectares of land that includes salt and fresh water marshes, deciduous forest, meadow habitats, shoreline and mudflats (BIEAP, 2011). This area is home to species at risk such as the Western Grebe, red listed, the Great Blue Heron and Double Crested Cormorant, both blue listed, and the Osprey, yellow listed. The federal Species at Risk Act has also created a role for Environment Canada and Fisheries and Oceans Canada in managing endangered species, recovery planning and implementation (BIEAP, 2011).

#### 4.2.8 Ecological interactions

Ecological communities are structured by complex interactions among many species and their environment. The previous sections highlighted the diversity of responses to oil pollution exhibited by marine organisms. It is important to recognize that direct effects of oil pollution on a species may not accurately depict a population’s response to a catastrophic oiling event if interacting species are also impacted. Species interact with other species in numerous ways (e.g. consumption, competition, facilitation, parasitism) and so many community level responses beyond individual predicted effects can be observed after an oil spill. Changes in interactions among species in response to an oil spill can also have large cascading impacts on an ecosystem, significantly delaying recovery (Peterson et al., 2003).

It was previously mentioned that some marine plants (especially Rockweed and Eelgrass in Burrard Inlet) play important protective and nutritive roles for other plant and animal species in a community. Consequently, the immediate injuries to these populations that have been observed after oil spills (See *Section 4.2.2*) are likely to have cascading effects on species that rely on these plants for food and nursery functions. Although the indirect effects of habitat loss on marine species are easy to conceptualize and are clearly important, few data exist that are able to disentangle these indirect effects from the direct negative impacts of oiling. Because most species have such immediate severe direct responses to oiling events, indirect effects through habitat loss may be more important in determining recovery times than in initial impact. For instance the recovery rate of Rockweed populations is accelerated if at least some canopy remains (Speidel, Harley, & Wonham, 2001; Van Tamelen, Stekoll, & Deysher, 1997) to protect early developmental stages from environmental stressors.

Otters are foundation species, which limit urchin abundances through predation and therefore indirectly increase the abundance of important habitat forming seaweeds (Estes & Palmisano, 1974), which otherwise would be devoured by urchins. Otters suffered long term impacts of oil spills and populations were initially cut in half (Paine et al., 1996). Accordingly, an increase in abundance of large urchins was observed in areas with otter declines after the Exxon *Valdez* Oil Spill (Dean, Bodkin, Jewett, Monson, & Jung, 2000); however, the predicted further cascade to decreased kelp abundance was not observed. Although sea otters are not present in Burrard Inlet, local seastars are important predators of sea urchins and reductions in seastar populations may have similar consequences.

Some species may benefit indirectly from an oil spill through release of competitive and consumptive interactions. For instance, *Ulva* spp. are not likely to benefit directly from oil pollution, but reduction of grazers and dominant algae seems to have relieved them of consumptive and competitive pressure, and allowed them to take over (Bellamy, Clarke, John, Jones, & Whittick, 1967). Furthermore, the recovery of Rockweed populations after an oil spill has been linked to grazing pressure (Paine et al., 1996). If grazer populations are not hit as hard as plant populations, they may impede recovery of the plant populations by grazing all new recruits. Further consumptive indirect effects occur when oil enters into higher trophic levels many years after the spill through accumulation of oil residuum by prey species, especially clams and mussels (Bodkin et al., 2012); however, these indirect effects seem minimal (Boehm, Page, Neff, & Brown, 2011).

## *4.3 Clean-up Impact*

Significant clean-up efforts invariably follow oil spill disasters with little discussion about justifications for initiating oil cleaning procedures. The common conception is that oil in the ocean damages the marine environment and that clean-up measures are necessary to repair the environment. However, clean-up efforts usually do not repair damages done to the environment and in most cases increase their severity. Clean-up decisions are rarely based on ecological ideas and may only occur as a political response to ensure the public that action is being taking to attempt to remedy the situation (Foster, Tarpley, & Dearn, 1990). Because Vancouver is densely populated with significant “green” goals, it seems unavoidable that a large scale clean-up would be launched after an oil spill. The next section details how clean-up actions do further damage to marine ecosystems and identify the ecological arguments against large-scale clean-up efforts.

### 4.3.1 Clean-up Strategies

Many procedures are used to clean up oil spilled in marine environments: chemical dispersants can be applied to the oil to break down the oil; oil can be combusted via scorching; oil can be mechanically removed; oil can be washed off the shoreline using high pressure hot water hoses, and; oil can be skimmed off the surface or absorbed. All of these procedures further damage marine ecosystems and, perhaps counter-intuitively, increase the amount of time required for the communities to recover from the oil spill (Foster et al., 1990). The chemical dispersants used to break down oil are toxic and the combination of oil and dispersant can have stronger negative effects on marine species than the oil alone (Cohen, Nugegoda, & Gagnon, 2001; De Vogelaere & Foster, 1994; George, 1961; Vosyliene, Kazlauskiene, & Jok as, 2005). Furthermore, chemical dispersants are not very effective in degrading oil in wave-sheltered areas, like the Burrard Inlet, because of a lack of hydrodynamic mixing (Owens et al., 1987). Mechanical removal of oil (i.e. via dredging or plant snipping), scorching, and high pressure flushing are physically destructive to marine communities and will cause mortality in individuals that otherwise might have survived the spill event. Even the seemingly less destructive measures, like using sorbents and skimmers, can increase mortality of organisms through trampling of large clean-up crews (Foster et al., 1990).

Diluted bitumen was more difficult to remove from waterways (sinking to depth) in the Kalamazoo River spill than the typical light crude oil in other spills. And existing clean-up procedures and equipment are designed to capture floating oil, not sinking bitumen. In British Columbia, preparations have been made to respond to an oil spill (BC Ministry of Environment, 2007; Ministry of, 2007). The Port Authority, Environment Canada, and Burrard Clean Operations have organized and currently coordinate an oil spill emergency response plan for Burrard Inlet (see *Section 6.7.1*). Many companies have minimized spill risk by developing management plans, building containment facilities and training staff in spill response (Jacques Whitford AXYS Ltd., 2008). Rapid response clean-up crews can use a variety of methods including, floating booms with skirts along the bottom to corral the oil, vacuums or skimmers to suck surface oil aboard ships with holding tanks, large sponges called sorbents to soak up oil, burning the oil at the surface and dredging the waterways to remove oil from the bottom. Chemical dispersants may also be used both at depth in the water column and sprayed into the air or surface water to break down the oil and its residues. The chemical dispersants cause the oil to evaporate or biodegrade more rapidly. When a spill occurs near a shoreline, the need to break down the oil before it reaches the tidal areas is considered an important ecological component of clean-up. The shore can be seeded with nitrogen and phosphorus to encourage the growth of micro-organisms that will consume and break down the oil.

Recovery time of an ecosystem is not a linear function of the percent of the population damaged. In *Fucus*, experimental disturbances resulting in 0-80% canopy removal had indistinguishable recovery time, while greater disturbance causing total canopy removal significantly delayed recruitment of new individuals (Speidel et al., 2001). Emulsifiers have been reported to kill all limpets and 80-95% of acorn barnacles (George, 1961), which are otherwise likely to survive an oiling event. Although oil spills can kill 50-90% of populations of marine species, recovery can usually be accomplished relatively quickly from the remaining population. Further, cleaning measures may impair the ability of plants to regenerate shoots/fronds after an oil spill by mechanical removing and/or chemically killing holdfasts and underground rhizomes that might otherwise have survived (De Vogelaere and Foster, 1994). By further increasing injury to populations, clean-up efforts may push mortality rates past thresholds beyond which unstable populations cycles occur. Foster et al. (1990) conclude that in the absence of information to the contrary, most shore clean-up methods will increase immediate ecological damage and delay recovery.

### 4.3.2 Nature's Cure: Oil-Eating Bacteria.

Polycyclic aromatic hydrocarbons (PAHs) are an important class of chemical pollutants that constitute a major component of total hydrocarbons in crude oils. Based on their poor water solubility, toxicity, persistence and potential to bioaccumulate, these compounds are recognized as high-priority pollutants in the environment and are of significant concern for human health (Geraci & St. Aubin, 1990). At oil-contaminated sites, PAH-degrading bacteria perform a critical role in the degradation and ultimate removal of these compounds (Gutierrez, 2011; Hazen et al., 2010). These microbial processes are the foundation of natural and anthropogenic oil-spill remediation. Ultimately, a critical understanding of these processes is at the heart of designing successful bioremediation methods that may be applied either immediately or after the onset of an oil spill.

Weeks to months following the Deepwater Horizon oil spill, intense research efforts were devoted to characterizing the microorganisms responsible for degrading the oil within the water column, particularly in deep waters (1,000 – 1,300 metres deep) where a large oil plume was found. This study identified certain bacterial species (e.g. Oceanospirillales) that were present in high numbers as a result of the hydrocarbons presence (Hazen et al., 2010). The role of these organisms in the degradation of the oil is unknown, although their relative abundance in the plume suggests it was significant (Gutierrez, 2011).

### 4.3.3 Recovery rates

Recovery rates vary drastically depending upon characteristics of the spill, clean-up efforts, habitat type, and species of concern. Most species and ecosystems will only begin to recover after the majority of the oil has subsided, so recovery depends initially on the amount of oil spilled and how long it afflicts the marine systems. The residence time of oil in a marine environment is a function of spill release (point release vs. continued release), local hydrodynamic regime (patterns in tides, currents, and waves), and degradation/removal processes. The Burrard Inlet is sheltered from oceanic waves by Vancouver Island, and its hydrodynamic patterns are largely driven by tides, currents, and wind waves, all of which vary in magnitude and direction on the order of hours, weeks, months, and years. Because the fate of oil from a spill event in Burrard Inlet will largely depend upon ambient hydrodynamic regimes (Hodgins et al., 1991; Sheng Li & Hodgins, 2004; David Suzuki Foundation, 2013), it is difficult to predict the dynamics of a spill without knowing when and where the spill will occur, but a previous oil spill model suggests that under some conditions, oil from a spill at Second Narrows Bridge may have escaped the Inner Harbour within 9 hours (Hodgins et al., 1991).

Many of the impacts upon marine ecosystems may not be known for years and are still not well understood. And although oil will start to degrade quickly in the marine environment, complete degradation/removal of oil can take decades. Oil is not removed quickly by natural processes. There is accumulating evidence linking residual oil to continuing injury to wildlife for decades (Bodkin et al., 2003; Wiens, Crist, Day, Murphy, & Hayward, 1996; Irons, Kendall, Erickson, McDonald, & Lance, 2000; Matkin et al., 2008). Near-shore vertebrate predators do not recover quickly (killer whales, sea otters, seabirds, harlequin duck) (Matkin et al., 2008). Rates can vary from 1-2 up to 20 years depending the pre-existing threats prior to the spill, duration and location of spill, efforts or lack there made in collecting contaminants, and the natural processes of the particular ecosystem in that area. From the Exxon spill, it can be said that invertebrate eaters appear to be more heavily affected in the long-term than the fish eaters (Bodkin et al., 2003). Visits to sites affected by the Exxon *Valdez* spill reveal that oil is still present decades later, with intertidal zones the most affected (Bodkin et al., 2003; Holland-Bartels, 2002; Monson et al., 2000). New paradigms on oil spills include (1) incorporating ecotoxicology, (2) potential persistence in the environment and in wildlife, (3) long-term toxicity, (4) chronic effects significant with multiple pathways, and (5) the potential for clean-up and ecological cascades to extend injury to wildlife for decades (Bodkin et al., 2003).

Once oil has reached the shoreline at a given site, the residence time of the oil (and therefore its impact on marine life) will depend on the substrate (rocky vs. sandy) and local hydrodynamic conditions at the site. Sites exposed to moderate to large waves exhibit somewhat rapid degradation of oil as the mechanical disturbance of the waves breaks down the oil. Burrard Inlet is protected from waves, and at wave-sheltered sites natural degradation is slowest (Owens, Robson, & Foget, 1987). Most of the shoreline along Burrard Inlet is characterized by fine sediments. Five years after the Exxon *Valdez* Oil Spill, 2% of the original oil remained on beaches and 13% in sediments. At some low wave energy sites in Alaska, oil was calculated to take 30 years to drop back down to background levels (Carls et al., 2001).

Degree of exposure, and therefore initial damage, will play a large role in dictating how long populations take to recover. Although this idea is intuitive and supported experimentally (Speidel et al., 2001), threshold values for relating degree of exposure to recovery are virtually absent from the literature (although see Silliman, 2012). Variation in recovery rates among species likely varies broadly as a function of generation time. Research on recovery of marine species in France after the *Amoco Cadiz* spill suggests that populations may take 3-6 generations to recover (Conan, Dunnet, & Crisp, 1982). Although such a number is not likely broadly applicable to all systems, it is useful to demonstrate the relationship between generation time and population recovery rate. For short-lived species, recovery is achieved in only a few years, while populations of perennial species take much longer to recover, resulting in communities dominated by short-lived species. Bivalves recovered as quickly as 5-10 years, while longer-lived bird and mammal species may take decades to recover from an oil spill. Dependence of recovery rates on generation time may also explain the resilience to oil spills of plankton populations, with generation times of hours to a few days.

Most marine plants have seasonal reproductive cycles putting their generation time closer to a year. However, recovery, as determined by abundance, (see last paragraph in this section for caveat), in Rockweed, Eelgrass, and Salt Marsh plants is achieved in 1-2 years, so the 3-6 generations rule over predicts how quickly plant populations recover. Faster than expected recovery of marine plants likely occurs through pathways other than sexual reproduction. Seagrasses and salt marsh plants seem to repopulate areas impacted by oil spill much faster by vegetative reproduction from rhizome (Jacobs, 1980; Silliman et al., 2012). Dormant seed banks colonizing new freed area may also play a factor in the quick recovery of marine plant populations after a spill.

Other factors dictating recovery time include indirect effects from shifting ecological interactions (*Section 4.2.8*) and clean-up procedures. However, it should be emphasized that one of the largest factors influencing recovery rate is how recovery is defined. Sampling community (multiple species) data at many replicated oiled and un-oiled sites at multiple time points requires significant time and money investments. As a consequence, abundance (number of individuals or percent cover of plants) is usually the default data collected because it takes the least amount of time to sample many species in a large area. However, important demographic data (reproductive output, recruitment, size-structure, etc.) is hidden by individuals' counts. Decreased reproductive effort and/or success has been reported in many taxonomically diverse species. Size structure data are less available, but have been reported in urchins (Dean et al., 2000) and Rockweed (Hawkins & Southward, 1992) and can have profound ecological consequences.

Paine et al. (1996) reviewed findings that although *Fucus* abundance is restored after 1.5 years, the age-size structure can take much longer to recover. After the oil spill disturbance kills most of the adult population, new recruits colonize at roughly the same time, resulting in a new population of individuals that are the same age. These individuals will then all die at approximately the same time (based on similar aging senescence) and the population will again be repopulated by new recruits. These unstable population cycles leave the population (and therefore supported community) more vulnerable to future disturbance (e.g. a warm year, grazer population bloom, storm events, etc.). Full age-size structure had not been achieved in *Fucus* population in Alaska nearly a decade after the Exxon *Valdez* Oil Spill (Driskell, Ruesink, Lees, Houghton, & Lindstrom, 2001) even though abundance data suggested complete recovery within two years.

#### 4.3.4 Ecosystem services

As highlighted above, ecosystems are complex networks of innumerable interacting factors. Although often viewed as peripheral to marine ecosystems, human activities are also linked to ecosystem functioning. *Section 6* addresses direct and indirect economic impacts of an oil spill in marine ecosystems, but it is worth mentioning here that ecosystems perform many other services that would be impacted by an oil spill that are difficult to put a monetary value on, including: coastal erosion protection (Silliman et al., 2012), carbon sequestration, and water quality amelioration.

### *4.4 Environmental Management*

Such a complex environment presents multiple management challenges for regulators. An intergovernmental partnership, including the BC Ministry of Environment, Environment Canada, Fisheries and Oceans Canada, Transport Canada, Metro Vancouver, and Vancouver Port Authority, coordinates the current environmental management and restoration of Burrard Inlet (Jacques Whitford AXYS Ltd., 2008; BIEAP, 2010; BIEAP, 2011). The Burrard Inlet Environmental Action Program (BIEAP) and the Fraser River Estuary Management Program (FREMP) have taken an ecosystem approach to develop a consolidated management plan for Burrard Inlet and its drainage basin. The management plan aims to reduce existing contaminant discharge, to control future discharges, to protect and enhance habitat values, and to provide remedial measures for existing environmental impacts, while overall coordinating activities within the Inlet with the intention to protect and improve the environmental quality of the water and sediments (BIEAP, 2011). Ultimately, these partners want to monitor and understand the losses and gains that have taken place as a result of anthropogenic influences on the Inlet.[4] Efforts such as surveying the entire foreshore of the Inlet from Point Atkinson to Point Grey to establish a baseline of species present for

[4] Recently, BIEAP-FREMP announced that "the evolving mandates of partner organizations have necessitated change. As a result, the BIEAP-FREMP office, located in Burnaby, will be closing its doors on March 31, 2013. All partners intend to continue the partnership and are establishing a new model based on renewed cooperation and ongoing collaboration." (http://www.bieapfremp.org/, accessed 4/19/13)

future monitoring, and using GIS to display habitat characteristics that may encourage development of fish and wildlife (BIEAP, 2010). Habitat types, intertidal vegetation, current erosion areas, number of bird nests, introduced plants, outfalls, docks, impervious surfaces, garbage/pollution, and pipe crossings have all been identified. These baseline data can be used to rank environmentally sensitive areas within Burrard Inlet to determine a hierarchy of response effort if an oil spill were to occur. These baseline data, however, have not addressed population levels of species within Burrard Inlet, which would be important for determining species most at risk.

### 4.4.1 Current Anthropogenic Pollution in Burrard Inlet

Water quality is monitored frequently in Burrard Inlet. Despite the input of a myriad of anthropogenic sources of pollution into the Inlet (e.g. permitted industrial and municipal discharges, combined sewer overflows, emergency overflows, storm-water outfalls, landfills, marinas and live-aboards sewage, recreational boater sewage, ship repair, fuelling facilities, ship loading and anchorages, and fish processing plants and aquaculture) (Hall, McCallum, Lee, & Macdonald, 1998), water quality is still considered to be acceptable due mostly to the fact it is a well-flushed waterway (Li & Hodgins, 2004; Jacques Whitford AXYS Ltd., 2008). However, a number of activities are prohibited or limited within the Inlet due to contamination (e.g. shellfish harvesting is prohibited in the Inlet due to high fecal coliform levels resulting from storm and sewer discharges, and summer swimming at certain locations can be limited) (Jacques Whitford AXYS Ltd., 2008). Metal levels within the water are below toxic levels, although sub-lethal metal levels may be affecting cell division and uptake of carbon in diatoms and dinoflagellates within the Inlet (Hall et al., 1998; Jacques Whitford AXYS Ltd., 2008).

Urban and industrial development along the shoreline of the Inlet has led to the discharge and accumulation of a wide range of contaminants in the sediments (Hall et al., 1998). A study by Sandwell Inc. and Castor Consultants Ltd (1992) showed concentrations of trace metals such as cadmium and copper that exceeded the ocean dumping criteria. Furthermore, histopathological conditions of economically important deep, bottom-feeding fishes such as English sole have been linked to exposure to toxic and carcinogenic chemicals in the water and sediment of the Inlet (such as waste water from petroleum refinery) (Goyette et al., 1988; Haggarty, 2001). Liver lesions of English sole varied depending on geographic region of the Inlet with a high prevalence (58.8%) in Port Moody Arm, moderate prevalence (20-30%) in the Inner Harbour, and low prevalence (8.3% - 13.3%) in the Outer and Central Harbours (Goyette et al., 1988).

### 4.4.2 Protection of Canadian Waterways

The Canadian federal government has a mandate to protect and maintain fish habitat. Fish habitat is defined in the Fisheries Act as “spawning grounds and nursery, rearing, food supply and migration area on which fish depend directly or indirectly in order to carry out their life processes” (Department of Fisheries and Ocean, 1986). The Department of Fisheries and Oceans’ (DFO) policy for the management of fish habitat, enforced by the Fisheries Act, is to conserve, restore and develop fish habitat (BIEAP, 2011).

Federal and provincial governments create marine protected areas intended to protect marine biodiversity areas. These areas are set aside to encourage scientific research, public appreciation and awareness, and recreation. Designated marine protected areas are representative of important ecosystems and are protected from certain development activities. There are two marine protected areas, one located off Lighthouse Park in West Vancouver, and the other Rockfish Conservation Areas in east Burrard Inlet and Indian Arm River (BIEAP, 2011).

### 4.4.3 Current United States Regulations

Many environmental groups are calling for an increase in dilute bitumen regulations; these groups include the Pipeline Safety Trust, the Natural Resources Defense Council and the Pembina Institute (CRED, 2013; Nowlan et al., 2012; Oceans, 2012). Some of these groups contend that diluted bitumen is more corrosive than conventional oil and causes more pipeline leaks. The industry disputes that theory, and there are no independent studies to support either side. In late 2011, US Congress passed a bill that ordered the Pipeline and Hazardous Materials Safety Administration (PHMSA) to determine if the components of diluted bitumen would increase the risk of spills (Nowlan et al., 2012). Results are expected sometime in the year 2013.

Diluted bitumen is not subject to any additional safety regulations in the U.S., and PHMSA does not track the specific kind of crude oil that flows through each pipeline (Nowlan et al., 2012).

Furthermore, oil from the tar sands is regulated differently when it comes to taxes. The oil industry pays an 8-cent-per-barrel tax on crude oil produced and imported to the U.S (Nowlan et al., 2012). This tax goes directly into the Oil Spill Liability Trust Fund, which provides emergency funds for oil spills. In early 2011, five months after the Kalamazoo River spill, the IRS ruled to exempt dilute bitumen and synthetic crude from paying this excise tax, because of a law created in 1980 that says bitumen from the "tar sands" is not considered to be crude oil (CRED, 2013; Nowlan et al., 2012). Arguably, advocates state that the oil from Canada's tar sands is so different based on its chemistry, behaviour and how it is produced, that it should not be considered crude oil.

## *4.5 Background data/knowledge limitations*

Predictions of how local marine species will be affected by spilled oil are reliant upon accessible data on relevant species, habitats, and spill scenarios. Such data come from laboratory experiments, field observations following a spill event or, in rare cases, field experiments mimicking oil spills in natural communities. In spite of the massive literature addressing oil pollution impacts on marine species from the past half century, researchers have recognized a lack of predictability of oiling effects on marine communities for 30+ years (Mann et al. 1978), and scientists are still constrained by the same limitations.

The easiest data to obtain on oil spill impacts on marine life, and therefore the most abundant data in the literature, are experiments exposing individual organisms to oil products in a controlled laboratory setting. An advantage to this method is that it allows for a more precise mechanistic understanding of how oil spills influence marine species (i.e. direct effects of oil on physiology), while controlling for other extraneous factors that may confound field studies. While it is tempting to trust data from controlled experiments and extrapolate them to impacts of oil in the field, there are important limitations to consider. Laboratory studies provide little predictive power because they cannot realistically replicate oil spill events and because they lack the ecological complexity found in nature (i.e. indirect effect of oil on species interactions). Nonetheless, controlled laboratory experiments can be particularly useful in identifying susceptible species as well as in determining dose-depend thresholds for lethal and sub-lethal effects.

More data exist, particularly on dilute bitumen; however, it is considered proprietary data and only available to oil companies that conducted the research. Future studies should have better access to data and data should be more accessible from oil companies.

Because oil spill events are accidents, and are therefore unpredictable, it is uncommon for sufficient data to exist to quantify changes in marine ecosystems directly due to oiling events. Studies are usually limited to either comparing biological communities at sites that were hit with oil with geographically proximate sites that were not or to comparing a historical data set at a given site with post-oiling data. In the first scenario, it is important to note that neighbouring communities can be different for a multitude of factors other than oiling. For instance, if two neighbouring sites differ in their hydrodynamic regime, oil may have arrived at one site and not the other because of underlying differences in water flow. However, differences in water flow alone are enough to drive variation in biological communities (Demes, Kordas, & Jorve, 2012), so comparing the two sites does not disentangle effects of oiling from other confounding factors. In some cases, historical datasets with yearly or near yearly data will exist for a site impacted by an oil spill. Even in these situations, it is difficult to isolate the effects of the oiling event from annual variation in other environmental factors (e.g. temperature, salinity, nutrients). An explicit test of an oil spill on marine ecosystems would require replicated before and after data at multiple control and impact sites (i.e. BACI design). These and other statistical design flaws have previously led to contradictory reports of ecosystem level shifts associated with oil spills (Peterson, McDonald, Green, & Erickson, 2001) and limit our understanding of oil spill impacts on marine communities. It is also important to note that ecosystems are inherently idiosyncratic and results from a spill in one geographic region may not accurately predict those in another. Despite these limitations, data on the impacts of oil spill events on natural communities are perhaps the most compelling because they encompass the natural complexities of marine ecosystems.

Field experiments simulating oil spill events in natural communities conceptually bring together the accuracy of laboratory experiments with the complexity of natural communities. However, data from previous oiling experiments (Cross et al., 1987; Cross & Thomson, 1987; Hellebust et al., 1975) are limited by an inability to realistically replicate oil spill scenarios. Adequately replicating an oil spill in natural communities is prohibitively logistically difficult and unethical, given the known toxicity of oil products to marine life.

In addition to causal limitations from pre-existing data, there is still a lack of fundamental data that are necessary for predictions of how an oil spill in Burrard Inlet would impact its marine life. Most importantly, there is little knowledge of the nuances of how a bitumen spill will vary in its impact on marine communities even for the most well studied species and on the fate of bitumen in a marine environment. Also missing are general oiling impact data on many local species (especially, the ecologically important seastars), oil concentration thresholds for all local populations, and of whether and how normal operational spill will affect marine species.

# 5 HUMAN HEALTH IMPACT

There is much debate over the extent of effects oil and its by-products may have on the mammalian body. There are numerous studies that support both sides of the argument and variations in result are related to individual variability, pre-existing conditions, exposure time to the toxin, reproductive status (pregnant) and age of the person (with children and elderly having weaker immune systems). Appendix 2 and Figure 5 describe both the specific acute and chronic effects and the worst-case scenario. (See also *Sections 3.2.1.3, 4.2.6*).

Crude oil contains high levels of volatile organic compounds (VOCs), including known carcinogens and chemicals affecting the central nervous system (Herrington et al., 2006; Jenssen, 1996). Chemical compounds found in crude oil, such as benzene and toluene, exist in very small quantities and are called VOCs. VOCs pose the greatest threat to human health (Ha et al., 2008). Most toxic chemicals found in oil are lipid-soluble and thus accumulate in organs that contain a lot of fat, like the brain of fish and mammals (Ormseth & Ben-David, 2000). Those with greatest exposure can develop permanent brain damage and dementia. Short term, exposure to VOCs can lead to chest pain, coughing, dizziness, headaches, respiratory distress and vomiting, as experienced after the Deepwater Horizon spill (Major & Wang, 2012; Rodríguez-Trigo et al., 2007). Acute symptoms, include eye irritation and nervous system problems leading to a loss of coordination, can also occur (Aguilera et al., 2010; Rodríguez-Trigo et al., 2007; Suárez et al., 2005). These symptoms were largely suffered by the clean-up workers in close contact with the oil for long periods. More than 300 people came forward with spill related symptoms in the few months after the rig exploded (Major & Wang, 2012). Some of the common complaints have included chest pain, coughing, dizziness, headaches, respiratory distress and vomiting. These symptoms are typical of acute exposure to hydrocarbons or hydrogen sulfide. In December 1999, the oil tanker *Erika*, carrying approximately 30 tons of heavy fuel oil, wrecked off the coast of Brittany (France), polluting the local beaches and rocks over a distance of some 500 km. The health risk for people involved in these cleaning activities and for tourists was evaluated with emphasis on the carcinogenic properties of this oil (Baars, 2002). The outcome indicates that the risks were limited to people who had been in barehanded contact with the oil. Firstly, they had an increased risk for developing skin irritation and dermatitis; however, these effects are in general reversible (Baars, 2002). Secondly, they had an increased risk for developing skin tumours, but since the dermal contacts with the oil were of relative short duration, this risk is considered to be very limited (Baars, 2002). Long-term health effects to humans are less well understood. Long-term chemical exposure to VOCs has suggested severe DNA degradation, which can lead to cancer, birth defects and irreversible neurological damage, and impaired cellular immunity (Aguilera et al., 2010; Matkin et al., 2008; Rodríguez-Trigo et al., 2007; Zock et al., 2007).

Two crude oil spills have occurred recently in Burnaby in 2007 and 2009. In 2007, a Kinder Morgan pipeline accidently ruptured, spilling crude oil that released 1,500 barrels of oil, of which approximately 400 barrels spilled into the Burrard Inlet via the Burnaby storm sewer system (Columbia, 2010; Oceans, 2012). Fifty homes were evacuated and $15 million was spent on the resulting clean-up that took up to a year to complete. More recently in 2009, a spill of 200,000 liters of crude oil on land at a Kinder Morgan storage tank near the Burnaby

Mountain tank farm occurred. Many local residents reported symptoms consistent with inhaling toxic fumes from crude oil (CRED, 2013).

Evidence on the relationship between exposure to spilled oils and the appearance of acute physical, psychological, genotoxic and endocrine effects in the exposed individuals is mounting as technological research tools advance. A recent review by (Aguilera et al., 2010) reported numerous acute effects including vegetative-nervous symptoms, skin and mucous irritations, and also psychological effects. Genotoxic damage and endocrine alterations were assessed only in individuals exposed to oil from the *Prestige* spill (Aguilera et al., 2010; Major & Wang, 2012; Rodríguez-Trigo et al., 2007). Further research is needed for biomonitoring human populations exposed to spilled oils, especially those individuals involved in the clean-up, in order to evaluate not only the possible immediate consequences for their health but also the medium- and long-term effects, and the effectiveness of the protective devices used.

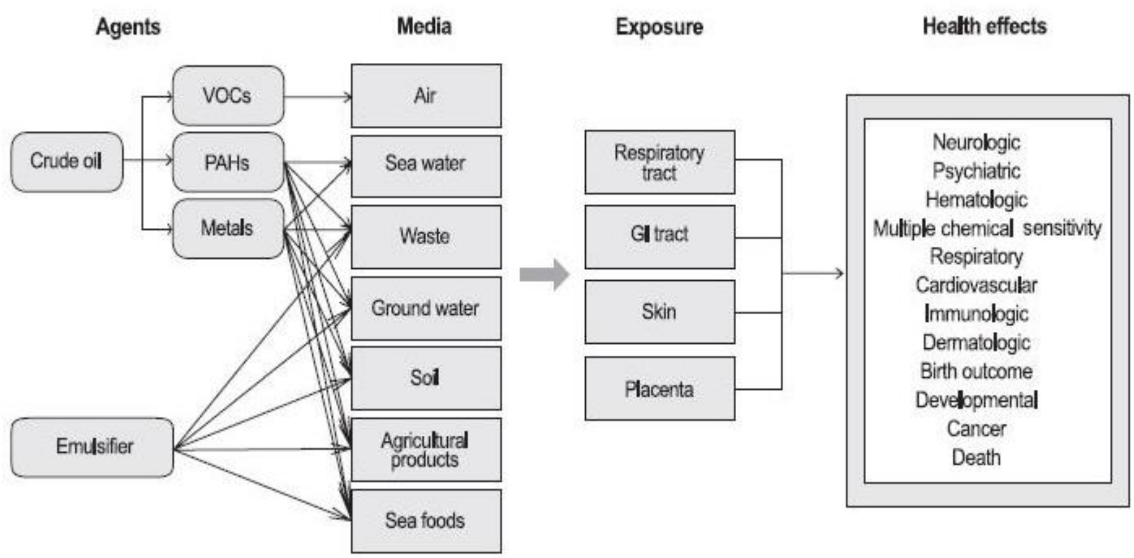


**Figure 5.Hypothetical pathways of agents, exposure and resulting health effects of both crude oil and emulsifer (also known as dispersant) on mammals. (Ha et al., 2008)).**

## *5.1 Air Quality Monitoring of Burrard Inlet*

Air quality in the Burrard Inlet area can be assessed by measuring the contaminants emitted into the air from local sources (BC Ministry of Environment, 2007; Vancouver, 2013). Short-and long-term exposure to air pollutants is harmful to human health, depending on how much and how long people are exposed. Asthma, bronchitis and exacerbation of pre-existing conditions such as diabetes and heart problems have been clearly linked with air pollution (C. I. Davidson, Phalen, & Solomon, 2005). In Canada, thousands of premature deaths per year, as well as increased rates of medical treatment and hospitalization, are associated with poor air quality (Vancouver, 2013). Pregnant women, children and the elderly are especially at risk (Aguilera et al., 2010). Several air pollutants are defined as Criteria Air Contaminants (CACs) as they affect human health (Jacques Whitford AXYS Ltd., 2008). Examples of those that may be released into the air as a result of an oil spill include, CO – carbon monoxide, $NO_x$ – nitrogen oxides, $SO_x$ – sulphur oxides, $VOC_s$ – volatile organic compounds, $O_3$ – ground-level ozone, PM10 – particulate matter (< 10 micron size), PM2.5 – fine particulate matter, (< 2.5 micron), and $NH_3$ – ammonia.

Air quality information can be accessed by Metro Vancouver, which manages the Lower Fraser Valley Air Quality Monitoring Network. CAC levels are recorded continuously and reported as hourly or longer averages. There are nine monitoring stations located within the Burrard Inlet area, five of which were used for this indicator (Jacques Whitford AXYS Ltd., 2008; Vancouver, 2013). These stations (Kitsilano in Vancouver, Kensington Park in Burnaby, Second Narrows and Mahon Park in North Vancouver and Rocky Point Park in Port Moody) were selected because they provide the most complete time series for CACs and best represent ambient conditions in the area (Jacques Whitford AXYS Ltd., 2008).

## *5.2 Who is most vulnerable?*

Danger posed by all these chemicals depends on three factors: health status, length of exposure and amount of exposure. Children, pregnant women, the elderly and the infirm are the most susceptible (Aguilera et al., 2010). Tourists, coastal residents and response workers are also exposed in increasing degrees. Those working directly on the clean-up efforts of an oil spill are likely to suffer the greatest harm, in large part because they will be exposed to the most VOCs evaporating from the light oil that floats to the ocean surface, as well as any compounds from chemical dispersants being used (Aguilera et al., 2010; Major & Wang, 2012; Park & Holliday, 1999). Those working farther from the source, such as volunteers cleaning animals and shoreline are more likely to come into contact with weathered oil, which clumps up and can coat beaches and animals, and can irritate the skin. Residents in the affected communities are also at risk for dermal exposure to either crude oil in the water or weathered oil on the beach (Aguilera et al., 2010). Inhalational exposure to chemicals or compounds is also important, such as those carried ashore by prevailing winds (Aguilera et al., 2010; Brandt et al., 2000; Goldsmith et al., 2011; Krajnak et al., 2011; Roberts et al., 2011; Sriram et al., 2011). Adverse health impacts via ingestion are also possible by eating potentially contaminated seafood, drinking contaminated water, or other forms of ingestion (Aguilera et al., 2010; Barron, 2012; Gohlke, Doke, Tipre, Leader, & Fitzgerald, 2011; Hofer, 1998; Law & Hellou, 1999; Matkin et al., 2008; Ormseth & Ben-David, 2000; Piatt, Lensink, Butler, Kendziorek, & Nysewander, 1990; Szaro, 1977; Webster et al., 2006).

Communities surrounding the spill site and 300 workers involved with the clean-up of the Deepwater Horizon spill (Major & Wang, 2012) reported symptoms described in Appendix 2.

Similarly, following the Exxon *Valdez* spill, some 270 clean-up workers reported health problems, including a greater prevalence of symptoms of chronic airway disease (Columbia, 2010; Jewett et al., 2002; Major & Wang, 2012). Damage could, however, run deeper than skin irritation and breathing difficulties. Clean-up workers from the 2002 *Prestige* oil tanker spill off the coasts of France and Spain found increased levels of DNA damage (Aguilera et al., 2010; Zock et al., 2007). The study discovered that the greatest health effects were found in workers who had not worn protective masks.

## *5.3 Personal Protection Gear*

The threat of adverse health impacts is believed to be lessened by wearing personal protective gear such as full face masks, goggles, respirators, boots, gloves and full body suits with the correct chemical code for the substance (BDH, 2005; BPAUST, 2005; Chevron Phillips Chemical Company, 2011; Devon, 2010; Hovensa, 2006; Petro-Canada, 2012; Science, 2012a, 2012b; Syncrude Canada, 2006).

The effects of an oil spill are not limited to the physical environment and species that use that environment as habitat. The next section reviews the economic impact of relevant spills, as well as the implications of these findings for Vancouver.

# 6 ECONOMIC IMPACT

While specific hazards may be natural or man-made, disasters themselves are generally human or social phenomena (Cannon, 1994; Quarantelli et al. 1978; Dynes and Tierney, 1994). Human vulnerabilities define the impact that hazard events like earthquakes or oil spills have on our communities. Similarly, our organizational and economic capacity to respond determines our ability to mitigate or cope with those impacts. The "disaster" itself is essentially embedded in how resilient our human systems are in response to a catastrophe.

This portion of the study will therefore provide the context necessary for understanding a Metro Vancouver-area tanker spill in terms of economic vulnerabilities and capacity.

## *6.1 Understanding "Cost" – The Mechanics of Valuation*

As described above, disasters are generally social phenomena. Our socioeconomic and cultural systems define the types and extent of disaster impacts. A quote on this subject is worth reproducing here:

> "Economic valuation is so revealing precisely because it is so much more than a process of monetary commensuration: it is, much more powerfully, a process of "definition" or social construction in a substantive sense, which incorporates all kinds of assumptions about social order and socially structured imaginaries about worth. Economic valuation, in other words, does not stand outside of society: it incorporates in its very making evaluative frames and judgments that can all be traced back to specific politico-institutional configurations and conflicts." (Fourcade, 2011)

Therefore, a primary determinant of the "cost" or "impact" of an oil spill is not simply a function of technical factors, but it is also a function of how society approaches economic valuation.

Liu and Wirtz (2006) suggest that there are five categories of total oil spill costs, including environmental damages, socioeconomic losses, clean-up costs, research costs, and other expenditures. Oil spills degrade natural resources and limit the "services" they provide us (e.g. commercial uses, recreational uses, pure enjoyment, etc.). Socioeconomic losses primarily consist of impacts on primary economic users (fishermen, hotel owners, etc.) as well as people throughout the economy suffering monetary or other losses. Clean-up costs include not only removal activities, but also storage, disposal, and other related costs. Research and other expenditures include assessment activities to estimate impacts, and preventative costs and other losses.

However, the way costs of an oil spill are determined is generally in terms of admissible claims accepted by compensatory regimes, which never cover the total costs of an oil spill (Liu and Wirtz, 2006). Insurance companies, governments, and international conventions all play a role in how claims are evaluated and justified (Mason, 2002; Schoenbaum, 2012). This discrepancy between “true” costs and admissible claims is not only a sociopolitical construction, but it also results from our limits in measuring impacts, proving causality, and establishing ownership.

In terms of measurement, it is difficult to determine impacts like fisheries losses without definitive biological data that circumscribes the total loss (Grigalunas et al, 1986). In some cases the baseline data are not available, while in others, more science is required to understand the impact (McCammon, 2003). Similarly, passive use and recreation values have no objective market costs, which make them difficult to convert into dollar values (Grigalunas et al, 1986; Garza-Gil et al., 2006; Loureiro et al., 2009). The value of summer vacations and ritual uses of salmon are in many ways priceless. Economists have developed tools to measure lost passive and recreational uses (which will be discussed in-depth elsewhere), but these are only approximations that may never capture an individual or societal estimate of value. More importantly, they are not recognized by major international conventions (Kiran, 2010).

In terms of proving causality, it is relatively straightforward to demonstrate how oil may have damaged someone’s property, but determining how oil spills affect profit and loss across an economy is much more difficult (Hill and Bryan, 1997). When upward or downward trends are already apparent, it is difficult to separate what is related to the oil spill, and what is an unrelated economic issue (US Department of Commerce, 1983). Moreover, "pure economic losses", the losses that occur independent of direct damage, are also problematic. Damages to one part of the economy create "ripple" or "ricochet" effects that depress earnings and wages throughout the economy (Perry, 2011; Palmer, 2011). On a case-by-case basis, though, it is difficult to establish how the oil spill created the loss, or to what extent the loss is attributable to the oil spill. Consequently, in most tort law frameworks, pure economic loss is not compensable (Palmer, 2011; Goldberg, 1994).

Finally, philosophies of ownership are important, especially in the valuation of communal goods. A compelling example is the different legal approaches that France and the United States took in pursuing damages following the Amoco *Cadiz* and Exxon *Valdez* spills (Fourcade, 2011). In the United States, the government owns the environment and wildlife "in trust" on behalf of the people, and were thus able to enter a legal claim of damage. However, in France the citizenry owns natural resources collectively, so there was no particular entity that would sue on its behalf. These philosophies of ownership tend to generate massive punitive damage valuations in the US, while reducing compensation to a single "symbolic franc" or public apology in France (Fourcade, 2011). Without an owner to establish damage, the full consequences of the oil spill may never be properly realized or enforced (Goldberg, 1994; Hill and Bryan, 1997).

In short, oil spill costs are not purely objective values that are readily quantifiable. They are products of social processes of valuation, which are limited by science, politics, and culture. In reviewing the literature related to oil spill impacts, it is important to consider how our current frameworks do or do not capture the "total cost" of an oil spill.

## *6.2 Direct Economic Effects and Costs*

International conventions like the Convention on Civil Liability for Oil Pollution Damage (CLC) and the International Fund for Compensation of Oil Pollution Damage (IOPC), to which Canada is a party, generally compensate direct economic losses for industries intimately tied to the coast (e.g. fisheries, tourism, etc.) (Kiran, 2010). This section will describe potential direct losses from an oil spill for those industries.

It is worthwhile to mention again how the effects and costs of an oil spill are subject to political, economic, and cultural factors beyond the objective release of oil into the environment. The following passage articulates the implications of this idea:

> How clean is clean? The answer depends on the goal of a clean-up, and that goal varies depending on the area in question. Is the area used principally for fishing, tourism, or conservation? Aquaculture, coastal fisheries, national parks, and beaches all exist along the same coast but demonstrate different functions. Tourism, if it involves largely beach activities, is nonextractive, and the major goal of a clean-up is to erase any visual traces of oil from the area and to restore the water quality to levels sufficient for swimming. For fisheries, on the other hand, clean-up processes are more complex, since they involve a consideration of fish habitats, food webs, and ecological impact (Cheong, 2012).

During a clean-up there will be a variety of decisions made that will impact the economic effects of the oil spill. After the *Hebei-Spirit* spill, the heavy use of dispersants benefitted the tourism industry by improving the water and beaches, but there has been some discussion of potential negative effects on the fisheries (Cheong, 2012). A response activity that benefits one sector can harm another. The framework of the initial response is therefore critical in understanding long-term economic effects.

### 6.2.1 Clean-Up Response and Costs

Table 1 below lists the top 10 accidental tanker spills by damage. These numbers include both clean-up costs and economic impacts. It is interesting to note that although the number of oil spills has been decreasing exponentially in the past few decades, the most expensive spills have mostly been occurring in the 1990s and 2000s. This is primarily a function of global pressure on governments and responsible parties to provide better responses to oil spill events. The demand for stricter laws and enforcement has produced larger clean-up costs and compensation claims (Wirtz et al., 2007). In fact, damage estimates for spills in the 2000s have been found to be $395 million higher than estimates in the 1960s and 1970s (Alló and Loureiro, 2013).

| Top 10 Accidental Tanker Spills By Damage | | | | |
|---|---|---|---|---|
| **Ship** | **Year** | **Country** | **Tons** | **Damage ($ 2010)** |
| Exxon Valdez | 1989 | United States | 40,000 | 4,262,060,000 |
| Haven | 1991 | Italy | 144,000 | 1,604,000,000 |
| Prestige | 2002 | Spain | 77,000 | 1,387,000,000 |
| Tasman Spirit | 2003 | Pakistan | 28,000 | 1,080,000,000 |
| Nakhodka | 1997 | Japan | 6200 | 373,180,000 |
| Aegean Sea | 1992 | Spain | 66,800 | 370,840,000 |
| Hebei Spirit | 2007 | Republic of Korea | 10,000 | 362,546,000 |
| Nissos Amorgos | 1997 | Venezuela | 3600 | 262,120,000 |
| Sea Prince | 1995 | Republic of Korea | 5035 | 257,260,000 |
| Erika | 1999 | France | 19,500 | 239,360,000 |

*Allo and Loureiro, 2012*

**Table 1.Top Ten Accidental Tanker Spills**

In the contemporary era, clean-up costs are steadily increasing, and are variable based on the country in which the spill happens (Fingas, 2013). A historical analysis of clean-up costs for major spills has been estimated at $10,467[5] USD/tonne (Kontovas et al., 2010). The current global average is estimated at approximately $16,000 USD/tonne, but the exact number can differ wildly based on the country (e.g. anywhere from $700 to $24,000 USD/tonne across European countries) (Nyman, 2009). In the Exxon *Valdez* disaster, the cost of the clean-up was approximately $2 billion USD, or roughly $50,000/tonne (McCammon, 2003). Recently, an estimate for Canadian oil spills suggested a potential clean-up cost of $50/litre, or approximately $60,000/tonne (Fingas, 2013). Although there have been no recorded tanker spills of bitumen, the bitumen-based pipeline spill in Kalamazoo, Michigan released 2660 tonnes of oil, and initially cost $787 million USD in clean-up costs (National Transportation Safety Board, 2010). This cost is approximately $295,000/tonne.

Figures such as these are a function of a number of direct costs including the following: (Fingas, 2013, US Department of Commerce, 1983)

- Oil containment and recovery – the use of booms, skimmers, pumps, and other methods to capture oil directly from the ship or while in the water;

[5] Unless noted, monetary figures have not been adjusted for inflation.

- Oil treating or elimination – the use of dispersants, sinking agents, in-situ burning, or other techniques to keep the oil from reaching shore;

- Surface cleaning – the use of power-washers and manual retrieval methods to clean beaches, marshes, and other areas;

- Subsurface cleaning – soil and bioremediation or other techniques;

- Storage, separation, decontamination, transport, and disposal – the various post-collection processes for preparing oil (and mousse) for eventual disposal. (Fingas, 2013, US Department of Commerce, 1983)

All of these aspects of clean-up require equipment to be rented or purchased, and necessary infrastructure like utilities and landfills to be provided. In addition, there are a number of indirect costs that support a clean-up operation. These include: (US Department of Commerce, 1983; Tucker and O'Brien, 2011):

- Readiness – Besides the investment into equipment like pumps skimmers and booms, the storage and maintenance of these items create costs even before the oil spill has happened.

- Administration – There are administrative costs in maintaining a spill response organization, and related training and planning, both before and during a spill.

- Staging – Work areas are required for response personnel, including food stalls, personal cleaning equipment, accommodation, medical resources, etc. This involves not only developing temporary spaces, but also another layer of staffing and administration. Estimates for the cleaning equipment alone during the *Prestige* spill was $60/volunteer per day, exclusive of food, drinks, accommodation, and medical.

- Prevention – As with every disaster, lessons learned spawn a new understanding of vulnerability, which leads to new investments for infrastructure and response capacity. (US Department of Commerce, 1983; Tucker and O'Brien, 2011)

In addition to these basic clean-up costs, it has been mentioned that the clean-up process itself can have negative impacts on the natural environment. In some cases, the clean-up will generate longer term coastal restoration costs that are not included in the original estimate (US Department of Commerce, 1983; Ritchie, 1995; White and Baker, 1998; White and Molloy, 2003, 2010).

### 6.2.2 Commercial fisheries and aquaculture

As has been described above, there are numerous aquatic species that are at risk of being harmed by an oil spill. These species, whether fished directly or within the food chain, can have dramatic effects on commercial fishing and marine-based aquaculture industries. However, biological effects are only a small part of a larger complex problem.

#### *6.2.2.1 Loss of product*

For commercial fisheries, the lethal effects to fish, crustaceans, and other species may or may not be significant. Oil spills tend can have serious consequences for relatively sedentary marine species (oysters, crabs, etc.), and they can harm the habitat or nursing grounds for a variety of species (Punzon et al., 2009; Moldan et al., 1985; Goodlad, 1996). Mortality (death) and morbidity (injury/illness) of commercial species had explicit economic effects on oyster, herring, and other populations in tanker spills like the *Cadiz*, *Castillo de Bellver*, and *Valdez* (Grigalunas et al., 1986; Moldan et al., 1985; Martin, 1999). Anecdotally, the dramatic collapse of the Alaska herring fishery has been attributed to the *Valdez* spill; however, there is a lack of conclusive scientific evidence demonstrating causality between the two events.

In other cases like the *Sea Empress* spill, the targeted species were primarily finfish, and due to their mobility there was little short-term damage to harvestable products (Law and Kelly, 2004). The mix of commercial species in a given environment will therefore be more predictive of loss of product than simply the size or type of oil spill.

For aquaculture, farmed species kept in open pens in the marine environment can also be destroyed, and generally don’t have the freedom to avoid the oil. Following the *Cadiz* and *Braer* spills, mortalities occurred during both culling and transportation of contaminated fish to holding facilities (US Department of Commerce, 1983; Goodlad, 1996). In the *Braer* case, 50% of the farmed salmon within the spill zone were culled. In the *Cadiz* case, not only was there the loss of product, but there were also transportation and holding costs for the rescued fish.

##### *6.2.2.2 Fisheries closures*

Arguably the most significant impact on commercial fisheries is the establishment of fisheries closures. Shortly after an oil spill has occurred, fishermen may initiate a closure voluntarily, or be directed to do so by the government (Moller et al., 1999). Even in a fishery with few short-term impacts, like the *Sea Empress* spill, comprehensive closures were initially established for major commercial species, and then expanded to collection of all species including cockles, mussels, etc. (Law and Kelly, 2004).

A fishery closure serves two purposes: preventing contaminated product from entering the marketplace, and reassuring the public that seafood is safe. Closures are therefore used to protect both supply and demand (Moller et al., 1999). However, closures can have significant effects on commercial fishermen and aquaculture producers. Closures for the *Seki*, *Braer*, *Hebei-Spirit*, and *Prestige* spills lasted from 20 days to 6 months (Loureiro et al., 2005; Punzon et al., 2009; Moncrieff and Simpson, 1993; Goodlad, 1996; Cheong, 2012; Pearson et al., 1998). Aquaculture closures in Scotland after the *Braer* spill resulted in the shut-down of 25% of the salmon farm industry (Moncrief and Simpson, 1993). This prevented fishermen and operators from earning income and using that income to pay fixed costs, invest back into their businesses, or meet debt obligations.

There is no standard for determining what level of oil contamination represents an acceptable risk in fisheries, and the most common method of checking for seafood tainting is through sensory testing (i.e. smelling and tasting) (Moller et al., 1999). Also, because of the mobility of fish, the fisheries closure zones do not adequately restrict the spatial effect of contamination (Sumaila et al., 2012). Moreover, the imposition of closure zones can push fishermen into adjacent areas, thereby putting biological and economic pressure on the fisheries and fishermen in those areas as well (Moore et al., 1998; Punzon et al., 2009).

While important, fisheries closures also represent an imperfect science that can potentially damage fisheries economies while not clearly delivering on preventative objectives.

#### *6.2.2.3 Market demand and brand damage*

Perhaps as significant as closures is the impact of brand damage on demand for seafood. Numerous studies of oil spills have shown that the fear of contaminated products has reduced both price and consumption for products from the affected zone (Moncrieff and Simpson, 1993; Pearson et al., 1998; Cheong, 2012; Surís-Regueiro et al., 2007; Garza-Gil et al., 2006). This impact is not simply limited to the affected area, however. After the Deepwater Horizon oil spill, public perception of Louisiana seafood dropped for the whole state, even though the oil spill impacts were localized (Danielson, 2011). Similarly, following the *Sea Empress* spill, fish were not accepted by European brokers, even if they were caught far outside of the spill zone (Moore et al., 1998).

These perceptions and their effects are driven by media reporting and public messaging by key stakeholders. The *Braer* case was exemplary in this regard. Although 90% of the demersal fisheries continued as before, 60% of shellfish grounds were not contaminated, and 75% of salmon production continued as normal, the decision by Marks and Spencer to drop area seafood products set off a global chain reaction against Shetland seafood (Moncrieff and Simpson, 1993; Goodlad, 1996). As one local fisherman described the phenomenon, “Our problem is not 85,000 tonnes of oil - It is 600 journalists and environmentalists.” (Goodlad, 1996).

Ironically, although fisheries closures create losses on their own, they reduce losses by limiting the impact on the reputation of local seafood products (Hill and Bryan, 1997). To further control reputational impacts, additional expense and investment may also be necessary to implement broad testing and marketing campaigns. BP dedicated $82 million to seafood marketing and testing after the Deepwater horizon spill (Finn, 2012). Following the *Braer*, *Cadiz*, and *Prestige* spills, the seafood industries also launched significant testing and marketing campaigns to try to turn their image around or to refocus on canned and processed products (Moncrieff and Simpson, 1993; Goodlad, 1996; Grigalunas et al., 1986; Loureiro, 2005). The Shetland seafood industry’s attempt has been described as follows:

> Two special buffet receptions for the press were held; one featured a menu of fresh and smoked salmon and the other featured a variety of shellfish and fish. The world's media were invited to feast on Shetland seafood only weeks after the Braer oil spill. The results were striking; quality was excellent and the media began to tell a different story - the story of how the Shetland seafood industry had survived the Braer oil spill. By taking this proactive approach, the seafood associations had managed to prevent a catastrophic collapse in the market for Shetland seafood. But serious damage had been done. (Goodlad, 1996)

#### *6.2.2.4 Landing, processing, and related businesses*

Besides the effect on commercial fishermen, there are cascading effects throughout the subsectors that rely on commercial fishing. These include docks, haulers, packers, processors, box-makers, ice-makers, bait dealers, large fish-storage freezers, fish markets, etc. (US Department of Commerce, 1983; Moncrieff and Simpson, 1993; Garcia Negro et al., 2009). Additionally, industry-based power and knowledge development are threatened by the losses of funds to fisherman's guilds, and impacts on research activities at marine institutes and universities, (although the latter may be buoyed by additional funds, the subjects of their research might be threatened) (Garcia Negro et al., 2009).

#### *6.2.2.5 Damage to property and assets*

Oil can directly damage boats, gear, nets, traps, and other equipment, generating direct property losses for commercial fishermen and related businesses (Punzon et al., 2009; US Department of Commerce, 1983). While this may be an obvious cost of oil spills, there are hidden costs as well, especially in the form of devaluing assets.

Depending on the fishery, boats, licenses, and quota can all be highly expensive inputs, and may form the collateral backing significant loans. After an oil spill, however, commercial fishing assets can lose market value. An example of this is taken from a marine supply storeowner after Exxon *Valdez*: "Before the spill, my dad bought a salmon permit for $320,000. He sold it three years ago for $30,000.Then he lost his boat. Basically, he's lost his entire retirement. He's 65 now, and living on Social Security" (Martin, 1999).

#### *6.2.2.6 Scale of fisheries losses*

This section has outlined the primary types of losses in commercial fisheries and aquaculture after an oil spill. The scale of these losses is variable based on the unique circumstances of each oil spill, and no single methodology can be used to encapsulate or predict the relative economic impact for oil spills on commercial fisheries in general. A few data points, however, should suffice in describing ranges of loss.

The market recovery time for most finfish species is from a few months to two years, while the recovery time for molluscs and crustaceans can be from one to six years (Sumaila et al., 2012). Studies following the Deepwater Horizon spill have shown that landed value for most fishing species in Louisiana (apart from oysters) have returned to near normal in the second and third years after the spill (Stone, forthcoming 2013a).

Landings in the most affected areas following the *Prestige* spill fell by 58%, while for the entire spill region landings fell by 17%. Employment over the same period fell by 4% (Loureiro, et al., 2006; Garcia Negro et al., 2007; Surís-Regueiro et al., 2007). The *Prestige* spill losses were exacerbated by the fact that prices had been at their highest levels in some time (Garcia Negro et al., 2007). Since commodities prices rise and fall over the years, “good” years like 2003 in Spain are especially crucial for commercial fishermen.

In Cordova, Alaska, following *Valdez*, the size of the fishing fleet dropped from 700 to 400, and three of the town’s five canneries closed, though two have reopened as smaller businesses (Martin, 1999).

For the Amoco *Cadiz* disaster (233,000 tonnes), total marine economic losses were calculated at $76.9 million USD; for the *Seki* disaster (16,000 tonnes) marine losses were calculated at $23.1 million USD; for the *Valdez* disaster (40,000 tonnes) marine losses were calculated at $561 million USD  (US Department of Commerce, 1983; Pearson et al., 1998; Martin, 1999).

### 6.2.3 Tourism

In some ways, tourism is even more susceptible to brand damage than commercial fisheries. This section reviews the effect of brand damage on core tourism businesses, and then discusses other related losses and costs.

#### *6.2.3.1 Brand damage and the tourism economy*

Tourism is not necessarily an industry itself, but rather a set of interrelated sub-industries that provide goods and services to tourists (in addition to other users) (Ardahaey, 2011). Transportation, lodging, food, entertainment, retail, activities, and other amenities compose the breadth of tourism offerings, and various bundles of those offerings are consumed by individual tourists. All of these businesses depend in part on a positive, enticing image that draws visitors from around the world to consume those goods and services.

Local brand damage from media reports is therefore highly detrimental to tourism economies, and can persist long after a crisis is resolved (Oxford Economics, 2010). Moreover, the tourism impacts from oil spills generally last longer than brand damage from terrorism, hurricanes, pandemics, tsunamis, etc. (Oxford Economics, 2010). Following the Deepwater Horizon spill a perception study found that the oil spill had a greater deterrent effect to New Orleans area tourism than Hurricane Katrina did (Danielson, 2011). This is striking in that Katrina practically destroyed the city, while the oil spill inflicted no physical damage to the city at all.

Following the *Cadiz* and *Braer* spills bookings and visitor numbers were all found to decline due to intense media coverage (Butler and Fennell, 1994; US Department of Commerce, 1983). An estimated loss of 245,000 visitors to Brittany was recorded after *Cadiz*, while a full 5% reduction in visitors to Spain was recorded after *Prestige* (US Department of Commerce, 1983; Garza et al., 2009). After the Sea Empress disaster, there was a 12.2% fall in accommodation bookings in Southwest Wales, with a knock-on effect of 7% in losses to restaurants and cafes (Hill and Bryan, 1997).

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All of these figures were adjusted for inflation to 2013 USD from their original figures in the text. The US Bureau of Labor’s inflation calculator was used (http://data.bls.gov/cgi-bin/cpicalc.pl).

In surveys after Exxon *Valdez,* 59% of tourism businesses in the spill area reported spill related cancellations (McDowell Group, 1990). Visitor spending decreased 8% in South Central Alaska and 35% in Southwest Alaska from previous summer spending, resulting in a loss of $19 million USD ($35.5 million USD 2013) in visitor spending (McDowell Group, 1990). In addition, areas outside of the spill zone experienced losses as well. Denali National Park in the interior of Alaska reported an 8% decrease in visitors, and more than half of the businesses surveyed outside of the spill area reported cancellations and lower inquiries (McDowell Group, 1990).

Interestingly, effects within the spill zone were partially affected by the monopolization of tourism infrastructure by the spill response. Accommodations, charter boats, taxis, and labour created shortages of inputs for tourism businesses, thus limiting access by visitors, and increasing the cost of doing business for tourism operators (McDowell Group, 1990). However, this also resulted in a short-term boom within the sector, thus offsetting some of the broader losses (which will be discussed more in *Section 6.4*).

In the long term, tourism losses are also driven by the lag time between "booking" and "visiting". If the timing of the oil spill is during the period when people are generally planning their tourism destinations for the following year, then the losses may be felt beyond the actual clean-up process itself (Hill and Bryan, 1997). Following Deepwater Horizon there were double digit drops in plans to visit the region, and following Exxon *Valdez* 16% of surveyed travelers indicated that the oil spill affected their trip planning, with 50% indicating that they avoided Prince William Sound (Oxford Economics, 2010; McDowell Group, 1990).

#### *6.2.3.2 Recreational Fisheries*

Although recreational fishing is technically a "fishery", it is primarily a tourism product. It relies on a similar infrastructure of accommodations, charter boats, and amenity services. Fisheries closures following the *Sea Empress* spill in Wales resulted in a 21% reduction of visits from anglers to the area (Moore et al., 1998). Similar to the broader issue of bookings in tourism, Welsh charter boat operators reported losses for the whole year, far beyond the timing of the fisheries closures, because the oil spill occurred during the peak booking time for charter trips (Moore et al., 1998). After *Valdez,* angler visits decreased by 13% and days fishing decreased by 6%, resulting in an estimated $31 million USD (58 million USD 2013) loss to sport fishing (McCammon, 2003). However, due to the fact that recreational fishermen are not solely fishing for consumption, but rather for sport, market recovery times for these fisheries are potentially shorter than commercial fisheries (Sumaila et al, 2012).

#### *6.2.3.3 Tourism-related retail*

Tourism-related retail may also suffer because of fewer expenditures by fewer visitors. Following the *Prestige* disaster, purchasing in souvenirs and gastronomic products declined by 15.7% (Loureiro et al., 2005). Also, workers in Britanny following *Cadiz* reported lower effective wages. This was especially the case for waiters/waitresses and other service workers who depend on gratuities for income (US Department of Commerce, 1983). As one bartender said after *Valdez*, “Before the spill, I'd pick up more money off the floor than I get in tips now. I used to make $300 a night. Now I'm lucky if I make $20." (Martin, 1999)

#### *6.2.3.4 Brand Campaigns*

Similar to commercial fisheries, there are also expenditures on brand revitalization campaigns. Significant municipal or regional brand campaigns were launched following multiple spills including *Hebei-Spirit*, *Sea Empress*, *Prestige*, and Deepwater Horizon. Following the *Prestige* disaster the “España Verde” (Green Spain) campaign was launched at an expense of €19 million 2005 (Loureiro et al., 2005). Daesan in Korea hosted numerous events after the *Hebei-Spirit* spill like beach volleyball tournaments, swimming contests, the West Sea cultural festival, the Marathon, the Flower Exhibition, and the Fisheries Festival – all in an effort to attract new visitors (Cheong, 2012).

Hundreds of thousands of dollars were spent in Wales to promote watersports after the Sea Empress spill, which resulted in a 2 to 3% increase (Moore et al, 1998). BP spent $150 million on US Gulf Coast marketing after Deepwater Horizon, which partially increased hotel occupancy rates 11% higher in Q1 2012 compared to Q1 2010 (in other words, 11% higher than before the oil spill happened) (Finn, 2012).

Success is not always assured, however. Fort Meyers, Florida, with a population 62,000 and far outside of the spill zone, has spent $1.25 million USD on marketing, but is still struggling to keep pace with competing cities (Finn, 2012).

Although not oil spill related, a Canadian example is the city of Toronto forming the “Toront03 Alliance” (T03) as an emergency tourism measure after the SARS epidemic impacted local tourism. T03 spent $11.2 million CAD on various activities including sponsoring the ‘Molson Canadian Rocks for Toronto with the Rolling Stones Concert’ (Black, 2004). A performance assessment following the campaign estimated that the investments limited losses by $285 million, and increased spending by a further $70 million (Black, 2004).

Marketing and rebranding portrays areas as recovered, which is essential for tourism (Cheong, 2012). It also benefits fisheries in the short-term by reviving demand. However, if the fisheries have not actually recovered, necessary resources and investment into the fisheries may dry up, thus impacting long-term recovery. Similar to the response stage, what is good for tourism in the recovery stage may have conflicting impacts on the commercial fisheries (Cheong, 2012).

#### 6.2.4 Port Closure

Since many major oil spills happen some distance offshore, marine transport losses only marginally contribute to the overall economic damage (Wirtz, et al., 2007). However, recent oil spills in the lower Mississippi River demonstrated the potential impacts of spills in smaller waterways. In 2008, an oil barge collision near New Orleans released 282,000 gallons (889 tonnes) of heavy fuel oil into the River (Sayer, 2012). In addition to triggering $65 million USD in clean-up costs, it blocked port operations for 6 days, creating losses for the city of $100,000/day (Nossiter, 2008; Sayer, 2012). Some 200 vessels were stranded, which created additional economic effects for petrochemical businesses waiting for supplies (Nossiter, 2008). Litigation of additional claims is estimated at approximately $40 million USD (Sayre, 2012). Subsequent oil spills have also resulted in river closures in 2012 and 2013, similarly stopping trade (Muskal, 2013; Farm Futures, 2013).

### 6.2.5 Other marine-based industries

Besides the primary marine-based industries, other industrial users of waterways can be affected, like those that use seawater for cooling or other industrial processes (White and Baker, 1998; Nossiter, 2008). Sand dredging was curtailed after the *Sea Empress* spill, and the Pembroke Power Station was affected because it could not get access to oil deliveries or use cooling water (Moore et al, 1998). Moreover, the expansion of the power station (which was critical in an area with 11.5% unemployment) was rejected because of its reliance on imported bitumen – another unforeseen cost of the oil spill (Edwards and White, 1999).

Ferry traffic can also be affected. Losses to ferry companies were up to $1.36 million USD 2013 after *Cadiz*, and were also recorded after the *Sea Empress* spill (US Department of Commerce, 1983; Moore et al., 1998). There were also damages to seaside buildings, equipment, and businesses after *Cadiz* (US Department of Commerce, 1983).

### 6.2.6 Oil industry

A tanker spill can also reduce business and revenues for the oil industry itself. This was experienced after both the *Sea Empress* and *Braer* spills (Moore et al., 1998, Moncrieff and Simpson). Governmental reactions to the oil spill can also affect the oil industry, as was seen after the institution of drilling moratoria in the Gulf of Mexico after the Deepwater Horizon incident. Job loss and small business impacts were recorded in the sector, although losses were less than predicted (Greater New Orleans Inc., 2011).

### 6.2.7 Agriculture

Although agriculture is typically not implicated in oil spills, marine-based agriculture can be affected, especially seaweed. After *Cadiz*, 75% of the seaweed industry was within the spill zone, and in Japan nori seaweed crops were destroyed as a preventative measure (US Department of Commerce, 1983; Moller et al., 1999).

In addition to marine-based agriculture, wind-borne oil mists can affect fields near the water. After *Cadiz*, cauliflower and spring potato crops were affected, and some fields were plowed under. Also, some crops were damaged through the movement of response equipment into the spill zone (US Department of Commerce, 1983). Agriculture losses for *Cadiz* were estimated at 49,000 francs 1978 (or approximately $41,850 USD 2013).

### 6.2.8 Pure economic loss to the broader economy

The majority of the losses described thus far are "consequential" losses: those losses that are a direct consequence of contamination by oil (Jacobsson, 2007). However, pure economic loss, the losses that occur independent of damage, are difficult to measure or prove (Perry, 2011; Palmer, 2011). Pure economic loss exists not only for individual firms in industries impacted by the oil spill, but also for unrelated firms across the economy.

The most common method employed by economists to measure pure economic loss is an input-output model that predicts the "indirect" and "induced" effects of oil spills or other disasters on the economy (Heen and Andersen, 1994). These effects are predicted through multipliers that suggest for every dollar lost in a primary industry (e.g. commercial fishing), there are a number of dollars lost from businesses that exchange with those businesses (indirect effect), and dollars lost from the individuals who are employed by those businesses (induced effect). For every dollar that a commercial fisherman loses from a fisheries closure, a certain percentage of that is lost by a supply business, and another percentage is lost by the deckhand or cashier employed by those businesses. None of those dollars will turn over into the broader economy through purchases of food, automobiles, etc. Multipliers are also used to predict job losses.

Following the *Cadiz* spill, Gigalunas et al. (1986) estimated the pure economic loss beyond the direct effects as 25 to 26 million 1978 francs. That is an additional 12 to 16% loss to the Brittany economy beyond the direct losses to fisheries, tourism, etc. Other input-output projections have been made for the Deepwater Horizon spill, but their accuracy remains to be seen (Sumaila et al., 2012; IEM and Stone, 2010).

### 6.2.9 Real estate and “pure stigma” losses

A reported effect of oil spills has an effect on real estate values. These “pure stigma” losses are related to the devaluation of coastal or regional property because of their adjacency to the disaster (Pickerell, 2012). These losses are difficult to prove, especially if no sale has yet been made. Losses in real estate value were reported after the *Hebei-Spirit* and Deepwater Horizon spills, but they were found to be negligible after the *Cadiz* spill (Cheong, 2012; Smith et al, 2010; Grigalunas et al., 1986). A real estate developer in the Florida panhandle estimated $4.3 billion USD in losses in real estate value. (Smith et al., 2010). Additionally, vacation rentals and other coastal investment properties can create losses of both value and income to owners, as well as broader losses to the real estate industry (Oxford Economics, 2010). However, claims for pure stigma losses have been dismissed in court proceedings against British Petroleum (Pickerell, 2012).

### 6.2.10 Losses to the financial sector and shareholders

In addition to impacts on earnings, there are potential losses to other forms of capital. Loans that undergird any industry can go into delinquency or default, which can then threaten the ability of local banks and economic development institutions to inject capital into the economy (Moncrief and Simpson, 1993). Also, shareholders in affected corporations can lose value in their shares, which can further impact local investment. For example, St. Joe Company, a real estate developer in North Florida, lost 42.4% of its share price from April 2010 to October 2010, following the Deepwater Horizon oil spill (Smith et al., 2010). However, due to other effects within the marketplace, it is difficult to determine how much of any share value loss is completely attributable to an oil spill. It is unlikely that these losses are compensable.

One final way to think of financial loss is inflation. Higher prices for goods and labour can increase costs across the board for businesses and residents alike. Inflation has been a problem for communities after oil spills, and can affect access to, and the value, of capital (US Department of Commerce, 1983; Palinkas et al., 1983).

## *6.3 Other Socioeconomic Costs*

Beyond the direct economic costs, there are various socioeconomic impacts following an oil spill. Some of these may be reimbursed by various compensation regimes, but most of them will be borne by individuals or society.

### 6.3.1 First Nations' Uses

Following Exxon *Valdez*, First Nations were especially hard hit on a multitude of levels. In addition to the general economic losses, they suffered losses to subsistence resources, land use, recovery resources, and other social and cultural assets.

Many Native Alaska communities supplement wage labour with subsistence hunting and fishing (Rodin et al., 1992). However fisheries closures had a dramatic effect on subsistence activities and basic food provision (Palinkas et al., 1993). This had consequent impacts on diet, including loss of appetite for non-traditional foods, and a breakdown of social relations (Ritchie, 2012). However, due to a lack of records to estimate consumption of subsistence resources, most received no compensation (Rodin et al., 1992). This was also a key point of contention for the Native-American and Vietnamese-American communities following the Deepwater Horizon spill (Rhoan, 2011; Esclamado, 2011).

Additionally, loss of land was a significant issue for Native Alaskans. Title to approximately 450,000 acres of land had been sold to the state or federal government as part of habitat protection programs. Conservation easements and timber rights had been sold on an additional 180,000 acres (Fall et al., 2001). A housing corporation coordinator said, "Many of the native corporations made the decision to sell because they're desperate, they're just trying to survive. It's a terrible position to be in." (Martin, 1999).

This is reflective of a deeper issue in the sense that Native corporations were engaged after the spill instead of tribal governments (Fall et al, 2001). The transfer of settlement monies and negotiating process to those entities weakened political structures, and may have bypassed more representative decision-makers. The lack of consensus-building approaches by Exxon eroded the power of village administration and political structures (Rodin et al, 1992). Also, due to a lack of socioeconomic status and technical and management expertise, the skills and organizational structures necessary for recovery were missing or underperforming (Rodin et al, 1992). This reduced potential sources of aid and recovery resources.

Overall, the *Valdez* spill put further negative pressure on Native Alaskan culture and ways of life:

> Since contact with Russian fur traders in the late 18th century, the cultural history of the Native communities in the region has been one of intensive pressure for sociocultural change. Central to this process have been: an increasing involvement in the wage-labour economy; dependence upon federal, state, and local government for personal welfare and community services; and exposure to the Euro-American sociocultural system through the educational system, media, and interaction with non-Native residents. (Palinkas et al., 1993).

The Exxon *Valdez* oil spill, and the recovery system that followed it, perpetuated these processes of cultural erosion and assimilation. Moreover, the loss of access to traditional foods and resources affected the passing of those traditions to the next generation. As one Native Alaskan said: "You can't teach your kid how to hunt and fish for traditional foods if you can't find those foods, or if you're afraid to eat them." (Martin 1999)

### 6.3.2 Passive Use and Recreation

There are a number of “non-market” losses following an oil spill. Recreation and passive enjoyment or use of the environment are generally held to be valuable to people, but it is extremely difficult to measure their losses. There are various examples of these types of losses in the literature. Recreational fishers, besides having an economic loss, also have a non-market loss of their enjoyment of fishing (McCammon, 2003). (See also Bodkins et al., 2003, for other estimates.) After the *Prestige* spill, there were 10,000 surfers who lost access to the water (Garcia Negro et al., 2007). On the passive use side, 21,000 murres, 1,100 marbled murrelets, 838 cormorants, 151 bald eagles, and 1,000 sea otters died after the Exxon *Valdez* spill (McCammon, 2003). Although society may not directly “use” bald eagles, it may value their existence, and thus their loss is valuable.

For each of these cases, economists use techniques to evaluate loss to recreationists or society at large. Contingent valuation, value transfer, and other techniques are used to gauge a community's "willingness-to-pay" (WTP) for the amenity that is lost (Assaf et al., 1986; Fourcade, 20112011; Garza et al., 2009; Carson et al, 2003; Loureiro et al., 2009;). The sum or mean of all hypothetical WTP is the assumed value of the lost resource.

Calculations for recreation and passive use losses can vary based on the culture of the community, and the approach used. Following the *Cadiz* spill in France, recreation losses were calculated as 340 million 1978 francs (or $290 million USD 2013). Two separate studies on the *Prestige* oil spill calculated Spain's WTP to avoid future oil spills as €1.23 billion Euro, and €574 million Euro, respectively (Garza et al, 2009; Loureiro et al, 2009). Updated studies of the *Valdez* oil spill have predicted lost passive use at $4.87 billion USD to $7.19 billion USD (Carson et al, 2003). A study of eagle losses following *Valdez* used several approaches with different price tags, including relocation (e.g. moving breeding pairs of eagles at ~$1000 - $1500 per eagle), replacement (e.g. raising new eagles and releasing them at ~$12,500 to $22,500 per eagle), and rehabilitation (up to $100,000 per eagle) (McCammon, 2003). Using these different approaches, the 151 lost bald eagles could be valued at between $151,000 to $15.1 million USD.

Because of the wide variability of these theoretical models, the international compensation regimes under the International Marine Organization (to which Canada is a party) do not compensate for recreational and passive use losses. However, since Exxon *Valdez*, the US has included it within the Oil Pollution Act (Garza et al., 2009).

### 6.3.3 Health and Psychological Costs

During an oil spill there is generally some casualty that causes injury or loss of life. Subsequent to that, there are deleterious health effects developed during the recovery simply from close proximity to toxic chemicals. (See *Section 5*). For years after the spill, there may be psychological impacts for victims as well (Sabucedo et al., 2009; Palinkas et al, 1993; Picou et al., 2004). These impacts not only have direct costs through hospital bills and related expenses, but they also have a broader social cost through work stoppages, shorter life expectancy, etc. (Loureiro et al., 1995; Moore et al., 1998).

A review of 130 disasters found that technological disasters in the US (like oil spills) were more psychologically stressful than natural disasters (Picou et al., 2004). The argument has been made that this can be predicted by participation in ongoing litigation related to oil spills. Being a litigant predicted "work disruption, stress from litigation, a lack of trust in institutions (recreancy), and perceptions of increased risk for future spills" (Picou et al., 2004).

Moreover, threatened livelihoods coupled with new flows of recovery money into the community have been associated with various forms of stress and social breakdown. Following *Valdez,* high rates of alcohol and drug use were associated with recovery jobs, especially in Native communities (Rodin et al, 1992; Palinkas et al., 1993). There were also higher rates of domestic violence and crime: in the city of Valdez alone there was a 140% increase in disturbance calls, a 124% increase in arrests, a 166% increase in accidents, and a 71 % increase in assaults (Rodin et al, 1992). This, in turn, led to increased demands on clinic, mental health, and rehabilitation programs. (Rodin et al, 1992; Palinkas et al., 1993). During this time Native Alaskans were 1.8 times more likely to commit suicide than non-natives (Palinkas et al., 1993).

The social fabric of communities was also threatened by the influx of outsiders, the unequal distribution of clean-up jobs, and shifts in family/community hierarchies (e.g. when sons became clean-up managers over their fathers, etc.) (Palinkas et al., 1993). Approximately 25% of surveyed respondents reported conflicts with friends, and more than 40% reported cases of friendships ending over clean-up issues (Palinkas et al., 1993).

### 6.3.4 Legal and Research Costs

At the core of any technological disaster is either some breach of law or public trust. Legal proceedings are then initiated in some form, which in turn generates costs for individual litigants or society as a whole (Loureiro et al., 2005). After Exxon *Valdez*, there were 100 law firms participating in over 200 suits, involving more than 30,000 claims (Goldberg, 1994). After *Cadiz* the legal and expertise costs were so large that the plaintiffs were on the brink of bankruptcy several times, and eventually had to be bailed out by the French government (Fourcade, 2011).

The Spanish government has been involved in litigation for over 10 years since the *Prestige* disaster, pursuing both criminal and civil penalties (of €4.33 billion Euro), with no resolution to date (Minder, 2012).

Additionally, there is a range of associated research costs. Natural resource damage assessments, economic impact studies, ongoing monitoring, and other studies are required for court cases, compensation payments, and post-disaster planning (Liu and Wirtz, 2006; LawLaw and Kelly, 2004; US Department of Commerce, 1983). Known research costs include €10 million Euro spent after *Prestige*, $13.5 million USD 2013 spent after *Cadiz*, and $250 to $280 million USD 1989 spent after *Valdez* (Liu and Wirtz, 2006; Grigalunas et al., 1986; US Department of Commerce, 1983). After *Valdez,* the passive use study alone cost $3 million USD 1989 (McCammon, 2003). For the *Braer* spill, multiple assessments by different stakeholders were required, and after *Hebei-Spirit* assessments were performed monthly, and are now being performed annually for 10 years (Cooper and Kinniburgh, 1993; Choeng, 2011).

### 6.3.5 Municipal/Regional Brand Damage

Some scholars assert that cities today are branded and have development cycles akin to products, and their growth is predicated on media images that attract capital, labour, and other resources (van den Berg, forthcoming 2014; Zukin, 2009). An intangible though highly prized asset of cities, provinces, and countries is the brand that their locale has cultivated. Disasters like oil spills may threaten these municipal or regional brands in the same way they threaten the brands of fishing or tourism products.

Although there are few mentions in the literature of this specific topic, there are some discussions of businesses referencing decisions that form a proxy for municipal and regional brand damage. For example, after Deepwater Horizon, much of the media coverage focused on small business impacts in the New Orleans area. When a perception study was done, it was found that 60% of respondents associated the phrase “too prone to disasters like Katrina or the oil spill” with New Orleans. Business site selectors also stated that Louisiana’s location within a hurricane or flood zone as a major deterrent (Danielson, 2011).

Surveys after Exxon *Valdez* found that respondents felt that Alaska's images as a "pristine wilderness" had been tarnished (McDowell Group, 1990).

### 6.3.6 Ramifications for local governments

Local governments are affected on many levels by oil spills. There are direct administrative costs for the response and recovery that the government usually pays out-of-pocket. Full time staff, office space, back-office systems, media, legal, and other resources must all be dedicated to the spill response (Moore et al, 1998; Rodin et al., 1992; Palinkas et al., 1993). Following *Valdez,* the collection of solid waste increased four to five times, and five to six years of landfill space was used, which all fell under the purview of public works offices (Rodin et al., 1992). Additionally temporary structure permit requests, building code enforcement, land use permits, land leases, water demand, and many other types of requirements put enormous pressure on local governments (Rodin et al., 1992).

While some of these services are reimbursed, some are not (Moore et al., 1998). At the same time, tax revenues drop from impacted industries and reduced buying power throughout the economy (Moncrieff and Simpson, 1993). This leaves smaller pots of money for municipalities to deal with larger sets of problems. Following the Deepwater Horizon spill, the State of Alabama claimed losses of $148 million USD in taxes, and had to reduce education spending by 2% in response (Leinwand, 2010; Addy and Ijaz, 2010). Five Florida cities submitted a combined $20 million USD of lost tax revenue claims related to lost tourism business (Tampa Bay Times, 2013; Dolac, 2013)

Another layer of loss is through the attrition of skilled employees to recovery jobs that require local knowledge. A governmental "brain drain" was experienced after *Valdez* when government employees took higher-paying jobs with recovery contractors (Rodin et al., 1992).

A further problem for governments is the threat to legitimacy that occurs with a disaster. Trust in local government leaders can diminish after an oil spill, especially when the public feels that their leaders are not carrying out their responsibilities (Picou et al., 2004). After the *Hebei-Spirit* spill, confidence in the local government of Taean dropped to 23.7%, and local confidence in the central government fell to 20.3% (Cheong, 2011). Immediate and constructive action can assuage concerns and reduce negative perceptions (Aldy, 2011; Cheong, 2011). Or, as in the case of the *Prestige* disaster, a poor response can lead to demand that the government be put on criminal trial for exacerbating the disaster (Minder, 2012).

#### 6.3.7 Opportunity Costs

A final socioeconomic cost to consider, both for governments and the rest of society, is the array of opportunity costs that result from responding to an oil spill. The time and money that is spent on disaster recovery is time and money that could be spent on other social and economic issues. Routine and preventative maintenance of roads, buildings, and heavy equipment were forgone or subcontracted after the *Sea Empress* and *Valdez* spills, which creates "hidden costs" for municipalities (Hill and Bryan, 1997; Rodin et al., 1992).

Moreover, when 1.8 million volunteers were involved in the *Hebei-Spirit* spill, or when 325,345 person-days were spent by volunteers after the *Prestige* spill, it must be questioned what value is lost to society through this apportionment of resources (Choeng, 2011; Loureiro et al., 2005). The lost potential for using these resources to address the pressing social issues – such as affordable housing, poverty, climate change, etc. – is immeasurable.

### *6.4 Mitigating Factors*

The previous material only covers costs related to an oil spill. However, there are mitigating factors after an oil spill that either reduce those costs or provide new revenue streams to lessen their impact.

#### 6.4.1 Economies of scale

An important finding by Dagmar Etkin is that there are economies of scale for an oil spill clean-up. The unit prices per gallon decreases regardless of the technology employed (Brody et al., 2012). For a crude oil spill less than 500 gallons, the per gallon cost is $199, while for a spill over 1,000,000 gallons, the per gallon cost decreases to $82 (Etkin, 2004).

While this does not mean that larger oil spills are less expensive than smaller oil spills, it does suggest that once initial costs are invested into a clean-up, marginal costs of additional oil decrease.

### 6.4.2 The recovery "boom"

For many communities that experience a major oil spill, there is a short-term increase in economic activity. This recovery "boom" is a function of the significant influx of recovery dollars from responding entities, and the consequent demand for goods and services by those entities (Hill and Bryan, 1997). For the major oil spills reviewed in this study, the primary areas of increased economic activity included the following:

- Tourism-related businesses typically experience increases in accommodation and transportation business for response workers, journalists, and experts who come to the area. This has knock-on effects for the food and hospitality sub-sectors as well (US Department of Commerce, 1983; Butler and Fennell, 1994; Cheong, 2011; McDowell Group, 1990).
- Tourism businesses also experience influxes of "disaster tourists" or "sympathy tourists" who travel to the site to see the damage, or show solidarity with the victims (McDowell Group, 1990; Moore et al., 1998; Loureiro et al., 2005; Danielson, 20112011). Interestingly, the submerged wreck of the *Haven* is now a popular scuba diving site, generating jobs and revenue for local guides (Diving World, 2013).
- Retail establishments benefit from sales of recovery equipment, clothing, and other goods (Butler and Fennell, 1994).
- Commercial fishermen and other individuals unemployed due to the spill can benefit from recovery jobs provided in the interim. Vessels of Opportunity programs generally hire boats to lay boom around slicks, catch tar mats with nets, or simply sit idle as a supplementary form of compensation (Cheong, 2011; Rodin et al., 2011; Palinkas et al., 2011; Clark et al., 1997; Hall et al., 2011; IEM and Stone, 2010).

- Local firms can benefit from contracting opportunities during disaster recovery (Stone, forthcoming 2013b). Also, price gouging, though potentially illegal and deleterious in some contexts, has been shown to increase revenues to local firms as well (Barker, 2011).
- Port traffic can also see increases with recovery-related ship and boat traffic (Rodin et al., 1992).

However, it should be mentioned that the impact of these initiatives could be curtailed by competition from outside firms and labour. Hiring itinerant labourers has dampened income transfers in several spill recoveries (US Department of Commerce, 1983; Cooper and Kinniburgh, 1993; Hill and Bryan, 1997). Similarly, the high levels of government procurement through out-of-state firms along the US Gulf Coast consistently deprives local businesses from earning incomes when they need cash flow the most (Stone, forthcoming 2013b).

Also, regional businesses that may be affected by the oil spill but are out of the range of the short-term income opportunities tend to be further negatively affected (McDowell Group, 1990).

### 6.4.3 Expense savings

Although firms may lose revenue during fisheries closures and other downtime following an oil spill, they are typically spending less on variable costs of production or operation. Reduced use of diesel, bait, ice, and labour all reflect cost savings for fisheries and aquaculture business owners (US Department of Commerce, 1983; Garza-Gil et al., 2006). Following the *Prestige* disaster, cost savings related to fisheries inputs and labour were calculated to be over €8.7 million Euro (Loureiro et al., 2002). Although this may be little consolation to a business owner dependent on revenue, it still mitigates the total business loss.

Additionally, the use of volunteers in the response reduces social costs exponentially. Calculations of costs savings by use of volunteers after the *Prestige* disaster were estimated to be €4.858 million Euro (Loureiro et al., 2005).

### 6.4.4 Regulatory relaxation

Another mitigating factor can be the relaxation of regulations after an oil spill. In the *Aegean Sea* spill, the local fisheries council lifted quotas of species in as yet unaffected areas. This allowed fishermen to fish as much as possible to offset their expected losses (Moller et al., 1999)

### 6.4.5 Compensation payments

Subsidies to affected parties not only have a direct effect of supplementing lost incomes, but they also temper the induced losses to the broader economy. The phenomenon of "spillionaires", people who collect large sums of compensation money after an oil spill, were significant fixtures after *Valdez* and Deepwater Horizon (Ritchie et, al, 2011; Barker 2011). In Louisiana, sales at a local Chevrolet car dealership rose 41% (Barker, 2011).

Besides consumer spending, these short-term injections of cash into the economy can also result in reinvestment into businesses, equipment, and property (Barker, 2011; Stone, forthcoming 2013a; Punzon et al., 2009). After the *Braer* spill, the tourism industry also benefitted from income transfers:

> Indirectly, the increased wealth, which has accrued to local Shetlanders, has also allowed many of the small guesthouses and bed-and- breakfast operators to improve their facilities from the late 1970s onwards. Some of the self-catering establishments, which were established initially for the oil-related workers, have since been given over to tourist accommodation. Thus the overall accommodation stock is larger and of a much higher quality than would otherwise have been the case (Butler and Fennell, 1994).

### 6.4.6 Taxes

With increased recovery spending, or spending associated with compensation payments, there are usually increases in tax revenues as well (US Department of Commerce, 1983). Sales tax receipts in the six months following the Deepwater Horizon rose significantly for 8 of 24 affected communities Gulf-wide, and remained on par with pre-spill receipts in 15 of the remaining 16 (Barker, 2011). Receipts increased by 71% for one Louisiana parish, and almost 100% for another parish nearby (Barker, 2011). It is unknown to what extent these figures dropped once recovery activities ended.

### 6.4.7 Conservation benefits

Areas that initiate fisheries closures typically experience conservation benefits from reduced commercial fishing (Moller et al., 1999). Improved lobster catches were reported after the *Sea Empress* fishing ban in Wales was lifted, larger shellfish species were reportedly caught after the *Aegean Sea* ban was lifted, and monthly catch increases were noted after the removal of the *Prestige* fishery closure (Moller et al.,1999; Punzon et al., 2009; Loureiro et al., 2005).

An indirect conservation benefit is in the empowering effects of fisheries associations that develop in response to oil spills (Hill and Bryan, 1997). They have the potential to represent commercial fishing interests, but also be at the forefront of leading change within the fisheries. Moreover, the increased awareness of seafood provenance after oil spills could potentially lead to greater emphasis on traceability systems (Danielson, 2011).

### 6.4.8 Diversity of industries

A final mitigating factor worth mentioning is the notion that a diversity of industries helps reduce impacts both to the direct victims and the broader economy. Following both the *Braer* and the *Sea Empress* spills, the lack of diversified opportunities resulted in little to no alternatives for people who were unemployed from the fishing industry (Goodlad, 1996; Hill and Bryan, 1997). Similarly, tax revenue shortfalls were compounded by a lack of broad revenue streams (Moncrieff and Simpson, 1993). The following quote is from a study of the *Sea Empress* spill:

> As the input from the oil industry into the Shetland economy declines, there is no alternative resource, other than the sea, from which that input can be replaced. The resource base of Shetland is as narrow and as sensitive now as it was in 1493. (Moncrieff and Simpson, 1993).

Therefore, a good diversity of industries can reduce income sensitivities for governments, and provide alternative opportunities for firms and individuals.

## 6.5 *Sources of compensation*

There are several sources from which affected parties may receive compensation. These include private insurance, the tanker owner's insurance and assets, national and international compensation regimes, and affected area governments

### 6.5.1 Private insurance (first-party)

When an individual or business has been affected by an oil spill, their first route of compensation is generally from their own private "first-party" insurance policies. However, most standard form insurance policies fail to cover basic damages caused by oil spills (Abraham, 2011):

- Homeowners and commercial insurance policies generally exclude pollution losses unless caused by "explosion". Also, damages to the land itself (in addition to the structures on it) are generally excluded.
- Some commercial policies provide add-on clauses for pollution clean-up, but set very low limits for compensation (e.g. $10,000 USD).
- Business interruption insurance generally only covers economic losses caused by property damage. If there is no direct damage to an owned asset, losses are not covered.
- Contingent business insurance, which covers economic losses when there has been damage to the property of a third-party such as a customer or supplier, is only valid if that third-party's losses are due to non-excludable damages.
- Some business interruption and contingent business insurance covers losses due to lack of ingress or egress to property by civil order, but this may not extend to waterways or public areas that are not "property".

### 6.5.2 Tanker owner's assets

If an affected party cannot make a claim through their own insurance, they can pursue the liable party, which is usually the tanker owner. However, since the Exxon *Valdez* spill, oil companies have outsourced tanker operations to independent firms that place the individual tanker's assets into "ship-only" corporations (Billah, 2011). In case of an accident, the only value left is the wreckage of the tanker. Moreover, many of them register under Flags of Convenience and different jurisdictions in a manner that makes it difficult to pursue legal action. For example, the *Prestige* was built in Japan, flying the Bahamas flag, under Liberian ownership, and under the control of a Greek shipping company. It was insured in Great Britain and had American certification (Minder, 2012). Criminal and civil trials are still ongoing, over ten years since the disaster.

Most importantly, if the accident happens within a country that has ratified the Civil Liability Convention of 1992 (such as Canada), then the tanker owner's liability is limited, and no assets can be seized (Kiran, 2010). Recompense must solely be drawn from the ship owner's insurance or other established compensation funds without recourse to the company's assets.

### 6.5.3 Private (third-party) insurance and international compensation funds

A network of two conventions, as well as three funds, provides the regulatory and compensatory framework for most international tanker spills (Schoenbaum, 2012). These include the 1969 and the 1992 International Conventions on Civil Liability (CLC) for Oil Pollution Damage, the 1971 and 1992 conventions on the Establishment of an International Fund for Compensation (IOPC) for Oil Pollution Damage, and the 2005 convention for the International Oil Pollution Compensation Supplementary Fund (Schoenbaum, 2012; Kiran, 2010). Most international importers of oil, 130 countries including Canada, are parties to these conventions, although the United States has established its own funds and protocols through the Oil Pollution Act (OPA) (Schoenbaum, 2012; Mason, 2003).

#### *6.5.3.1 Liability and Admissible Claims Under the CLC and IOPC*

These international conventions have established a strict, yet limited, liability system for tanker spills (Røsæg, 2000; Mason, 2002). This means that the ship owner must pay for damages regardless of a finding of negligence – they are strictly liable for the oil spill. Moreover, additional parties cannot be held liable for an oil spill, such as the charterer of the ship (i.e. the oil company that has retained the services of the tanker to ship their oil).[6] However, the ship owner's liability is limited, so they do not have to pay above statutory thresholds, nor do they have to pay for damages that are not recognized under the relevant CLCs (Billah, 2011; Schoenbaum, 2012). The only exceptions to either the "strict" or "limited" clauses fall under very extreme situations of wilful misconduct that is "intended" to bring about harm, or where there was "knowledge that such damage would probably result" (Jacobsson, 2007).

Thus "admissible claims" becomes the central evaluative construct in understanding a ship owner's liability. Fortunately, the IOPC has published a "Claims Manual" that explains in great detail the types of claims that are admissible or inadmissible after an oil spill. There is not room here to discuss all of the various rules, but the following is an overview of how the socioeconomic costs described throughout the study might be compensated (IOPC, 2008):

- Clean-up and preventive measures – "Reasonable" measures taken to prevent, minimize, or clean-up oil are admissible. This covers both the cleaning of facilities and the environment, as well as the restoration of animals and wildlife. It also covers reasonable costs associated with housing and feeding animal rehabilitation volunteers, storing and disposing of debris, and portions of readiness costs taken before a spill. Fixed overhead and scale-up costs for public agencies are covered if these are proven to be additional to normal operations. Damages related to the clean-up itself (such as to roads, piers, etc.) are also admissible. Excessive cleaning beyond the bulk removal of oil is not admissible (especially if natural processes like wave action would have sufficed), unless it is necessary for a public amenity like a beach during the holiday season.

- Damages to property – The cleaning and repairing of damaged private and public property is admissible. However, replacement claims are only paid on the remaining portion of the item's "useful life".

- Economic loss in the fisheries, mariculture, and processing sector – Both consequential

[6] This is a critical difference from the United States' Oil Pollution Act (OPA). OPA imposes strict liability on all "responsible parties" including the owners, operators, and charterers of the ship. Liability is joint and several, which explains why the Federal government can seek damages from a range of parties beyond the tanker owner (Schoenbaum, 2012).

loss and pure economic loss for primary fisheries and mariculture businesses (e.g. commercial fishermen, etc.) are admissible. Losses due to fisheries bans or other preventative measures are admissible. However, losses to supply chain businesses (e.g. of fuel and ice businesses, fish porters, fish wholesalers and retailers) are only admissible if their loss is due to direct contamination, and not simply because the pollution event has occurred. Moreover, pure economic loss can only be accepted if there is sufficient geographic proximity and economic dependency on the lost resource. Subsistence losses are admissible under specific guidelines (IOPC, 2007).).

- Economic loss in the tourism sector – Tourism businesses must prove sufficient causation to files claims for lost earning. There must be close geographic proximity to the polluted amenity and economic dependency. There is a differentiation made between businesses that provide goods or services directly to tourists (e.g. hotels, restaurants, bars, etc.) and supply businesses that provide wholesale goods and service to primary tourism businesses. Claims from the latter group are generally inadmissible.

- Prevention of pure economic loss – Reasonable claims for marketing and branding campaigns for fisheries and tourism are admissible.

- Environmental damage and post-spill studies – Compensation for environmental damage is limited to loss of profits related to the environment and the cost of basic reinstatement. Because it is impossible to bring the environment back completely to its pre-spill character, and because natural processes have great potential for recovery of natural systems, there are limits to admissible claims in this area. Compensation is not paid for claims of environmental damage based on abstract quantification from theoretical models (e.g. passive use valuation). Punitive damages are not admissible. Environmental impact studies are admissible in limited circumstances.

- Use of advisers – The costs of claims preparers are admissible on a case-by-case basis.

In comparison to the costs listed above, there are many areas where the CLC and IOPC regulations are silent, or are deemed inadmissible. In the case of an oil spill, various firms within the fisheries and tourism industries will not be covered. Broader economic losses,

losses in passive use and recreation, and losses in government revenues will not be compensated (Schoenbaum, 2012; Garza-Gil et al., 2006). Damages to the environment will only be partially remediated (Mason, 2002; Mason, 2003). Although the Funds discretionarily pay economic loss claims to other affected businesses outside of the fisheries and tourism, these payments are limited and inconsistently applied (Jacobsson, 2007).

Intangible losses like real estate value, shareholder value, regional brand value, and cultural values are outside of the scope of the CLC/IOPC framework.

#### *6.5.3.2 CLC/IOPC Compensation Tiers*

The payment of claims is channelled through a number of tiers, beginning with the ship owner's insurance policy, and then through the relevant CLC/IOPC funds.

- Tier 1 – 1992 CLC: The Civil Liability Convention mandates ship owner liability up to a maximum of $140 million CAD based on the gross tonnage of the ship (Schoenbaum, 2012; Boulton, 2010). This level of liability is insured by compulsory third-party liability insurance for damages to victims of pollution events (Epstein and Keyes, 20102010; Goodstein, 19921992; Palmer, 2011; Røsæg, 2001; Billah, 2011). Moreover, it is supported by a "direct action" clause that allows victims to claim damages from the insurer directly, rather than going through the ship owner (Billah, 2011; Kiran, 2010).

- Tier 2 –1992 Fund: If the ship owner's insurance fund does not cover the costs of the damages from the spill, the International Oil Pollution Compensation Fund will pay an additional $178 million CAD (or in the case that ship owner does not have liability or cannot pay, the 1992 Fund will pay the entire $318 million CAD) (Kiran, 2010; Boulton, 2010).

- Tier 3 – Supplementary Fund: If total damages exceed the 1992 CLC and fund amounts, then the supplementary fund provides another $862 million CAD, for a maximum total of $1.18 billion CAD per incident (Billah, 20112011; Boulton, 2010).

The rules for determining claims under each tier is the same, both for private insurance (which must conform to CLC guidelines) and for the additional funds themselves (Billah, 2011). One additional point to keep in mind is that according to the CLC rules, all claimants are equal under the law. Therefore every claimant gets an equal chance for compensation (Jacobsson, 2007). The practical result of this is that if claims exceed the total available compensation from all three funds, then all claims are prorated accordingly. In other words, if the total amount of claims is 200% of available funds, then claimants would only get ½ of their requested claim.

Within the context of the current regime, this is very unlikely to occur. Under the 1992 CLC and Fund, 95% of oil spill claims outside of the United States during the 1990s would have been covered (White and Molloy, 2003). With the Supplementary Fund of today, virtually all oil spill claims would be covered in their entirety (Billah, 2011; Jacobsson, 2007). The *Prestige* spill in 2003, however, went far beyond these levels. In fact, a study of the total social and environmental costs of the *Prestige* disaster estimates the final tally to be between €2.25 billion Euro in the short term, and €8.50 billion Euro in the long term (Liu & Wirtz, 2006). Similarly, clean-up and economic injury claims in the *Valdez* spill alone exceeded the current maximum CLC/IOPC amounts (Martin, 1999).).

The conclusion here is that the current international compensatory regime will adequately compensate admissible claims from nearly every oil tanker spill in the contemporary era. However, on occasion there are anomalously large spills that the Funds are ill-equipped to handle. More importantly, the definition of "admissible claims" under CLC/IOPC guidelines may never capture the true costs of an oil spill in the first place.

### 6.5.4 Affected Area Governments

Finally, if all funds are exceeded, the costs must be absorbed by affected area governments or by society at large. Some nations establish their own oil spill pollution funds for this purpose. In Canada, the Ship-source Oil Pollution Fund (SOPF), is a "fund of last resort", and allocates $159 million CAD to oil spill recoveries in Canada (SOPF Administrator, 2012). This brings the total amount of funds available for any oil spill in Canada to $1.34 billion CAD. While this is only marginally higher than what is available from the CLC/IOPC, its true usefulness is in paying for oil spill recoveries when there are no liable parties (i.e. mystery spills) and other similar situations where CLC/IOPC funds are not available

(Boulton, 2010). A weakness in the SOPF system, however, is that the fund was created with a one-time payment and only grows due to interest (EnviroEmerg Consulting, 2012). This is very different from the US fund which charges an 8-cent/barrel levy that is forecast to grow from $1.5 billion in 2009 to just less than $4 billion in 2016 (BC Government, 2012).

Beyond the scope of these figures, there are no institutional forms of compensation. Expenses will either be met by taxpayer funds, or will go unpaid.

#### 6.5.5 Problems with compensation processes

In practice, there are numerous problems with compensation processes that prevent adequate response and recoveries.

As has been mentioned, the primary issue is related to admissible claims and the lack of their total coverage of losses. Even conceptually related claims are sometimes not allowed. Following the *Sea Empress* spill, 25% of lost fishing gear, and 25% of lost market opportunities for fishermen were uncompensated (Moore et al., 1998).

Similarly, at the heart of compensation processes is the notion of "proof"; to have a claim an individual must prove it, generally through documentation (Cheong, 2011). However, literacy, cultural issues, and the stress of the situation may preclude individuals from being able to file claims. Similarly, cash-based economies like small-scale fisheries generally do not have adequate paper trails to prove loss (Moore et al., 1998; Hill and Bryan, 1997, Cheong, 2011). The resources it takes to prepare claims may overwhelm small businesses, and further affect their ability to operate (Moore et al., 1998). It is therefore not surprising that there are low claims submission rates after some spills, sometimes as low as 30% of those affected (Moore et al., 1998; Loureiro et al, 2005). To this extent, NGOs and other support organizations have been critical in representing small businesses throughout the process, and in assisting their claims filing (Cheong, 2011; Cooper and Kinniburgh, 1993).

There are also timing issues that impact response and recovery. Claims under the CLC must be filed by six years at the latest, but long-term damages may not yet be apparent. In these cases they may not be compensated (Mason, 2003; Loureiro et al, 2005). Preparing claims may take a considerable amount of time, and compensation funds may take a year or more to be disbursed. During this time businesses can suffer and fail while they wait (Choeng, 2011; Hill and Bryan, 1997). In these situations, external emergency loan funds and other supports are necessary to help individuals and businesses weather the bad times (Cho, 2010; Hill and Bryan, 1997).

Finally, there is generally an inequality of impact and compensation, which leads to people slipping through the cracks. Due to social patterns within a society, sometimes the elderly, the poor, or indigenous and immigrant groups will not get access to the resources they need to survive a large-scale disaster (Rodin et al., 1992; Palinkas et al, 1993; Cheong, 2011). For one reason or another, some businesses fall just outside of the requirements for post-spill supports. Usually these are smaller businesses or niche operations (Moore et al, 1998; McDowell Group, 1990; Loureiro, 2005). It is important to keep in mind that no single recovery approach will serve all constituencies. Additional approaches, and their attendant costs, may need to be borne by society.

## *6.6 Implications for Vancouver*

The study thus far has reviewed relevant literature concerning a broad array of socioeconomic issues following oil spills. The following section refers to Vancouver in particular, and how these issues are relevant to an oil spill in Burrard Inlet.

In recent years, there have been a number of academic and advocacy studies that suggest the potential impact of an oil tanker spill in British Columbia. Some have predicted clean-up costs and socioeconomic impacts ranging from $3 billion to over $80 billion, and job losses of over 100,000 (Hotte and Sumaila, 2012; Weyler, 2012; Gunton and Broadbent, 2012; Conversations for Responsible Economic Development, 2013). However, the literature shows that the vast majority of oil spills are much smaller in impact (with a mean of between $100 to $500 million USD) (Alló and Loureiro, 2013). Moreover, it appears that no tanker spill has ever produced the higher end estimates of damage and job loss suggested by some of these reports.

It is should be noted that a comprehensive oil spill impact study has not been performed for Vancouver, so no estimate of impact can be considered precise (if precision is even possible in projected impact studies).). In addition, an oil spill in Burrard Inlet would be near shore and unlike the historical examples included in this review. As such, the following discussion should not be considered predictive of all associated risks and losses.

### *6.7 Risk of tanker spill in Burrard Inlet*

This review was prompted in part by the planned twinning of the Kinder Morgan pipeline that terminates in Burnaby, BC. In this plan, pipeline capacity would increase to 850,000 barrels per day, which would increase oil tanker traffic in Burrard Inlet from five to ten vessels per month, to at least 30 vessels per month (Anderson and Spears, 2012). Currently Vancouver is a "very low volume" tanker port, but even an increase to 400 tankers per years would leave it far short of cities like Rotterdam and Singapore that handle 8,200 and 22,300 tankers per year, respectively (Port Metro Vancouver, 2013a).

Based on the history of safety in Canada, and the broader state of tanker incidents globally, a number of risk assessments have been made concerning the likelihood of a significant oil spill in Canadian waters and in the BC area. A study by Transport Canada of Placentia Bay in Newfoundland (which has greater tanker traffic than Vancouver) has suggested that a spill of approximately 1600 tonnes could happen every 27 to 33 years, and a catastrophic spill of 60,000 tonnes may happen once every 200 to 2000 years (Anderson and Spears, 2012; S.L. Ross Environmental, 1999). However, another study in 1999 predicted a spill of over 10,000 tonnes every seven years, with one in the Juan de Fuca Straits every 16 years (S.L. Ross Environmental, 1999).

Clearly there is variability in the forecasting models. However, in terms of port history, Vancouver has a record of only 13 minor incidents since 2001, with the worst resulting in a 2,300 liter spill of canola oil (Vanderklippe, 2012; Det Norske Veritas, 2012; Hudson, 2008). This may be attributed to the stringent regulations that Canada and Port Metro Vancouver has in place for ships in general, and tankers in particular. All oil tankers are pre-screened by Kinder Morgan, and vetted for admissibility by Transport Canada, in order to meet requirements regarding construction (double hulls) and age of ship (less than 20 years old) (Vanderklippe, 2012; Hudson, 2008). When entering local waters, all tankers must take aboard two trained local pilots who physically steer the ships through the waterways, including the Narrows (Vanderklippe, 2012; Port Metro Vancouver, 2012a, Det Norske Veritas, 2012). Protocol states that pilots should be highly skilled and tested, bring their own state-of-the-art navigational systems on board, and have a 99.9% incident free rate in Pacific waters (Anderson and Spears, 2012). Tankers can only pass through at high tide, in daylight, and are given priority right of way. They must be accompanied by three (3) tugs that are fully tethered to the tanker (Vanderklippe, 2012; Port Metro Vancouver, 2012a; Det Norske Veritas, 2012). In addition to the current system, the Federal government of Canada has recently announced that it plans to increase tanker inspections, add pollution control measures, and conduct the first Federal review of tanker safety since the 1990s (Bailey, 2013).

### 6.7.1 Response capacity and protocol

In Canada, the Federal government has jurisdiction over the entire marine environment, while the Province has jurisdiction over the intertidal zone (all land between the low and high watermark) (BC Government, 2012). Although this means that the Canadian Coast Guard is technically the lead agency following an oil spill, and claims command of an oil spill in its own response literature, the Province also has "lead agency" responsibilities regarding its own interests, and claims to take over underperforming spill responses that are "impacting provincial interests" (BC Government, 2012; Department of Fisheries and Oceans, 2011; Office of the Auditor General of Canada, 2010). The situation is complicated further, by the fact that each level of government has its own response structure. The Coast Guard uses its own "Response Management System", while the BC Government uses the more internationally accepted "Unified Command" (BC Government, 2012; Department of Fisheries and Oceans, 2011).[7]

[7] The primary difference between the two is that the Response Management System is a top-down approach composed of only Coast Guard staff, while Unified Command is an integrated approach including local municipalities, First Nations, and other stakeholders.

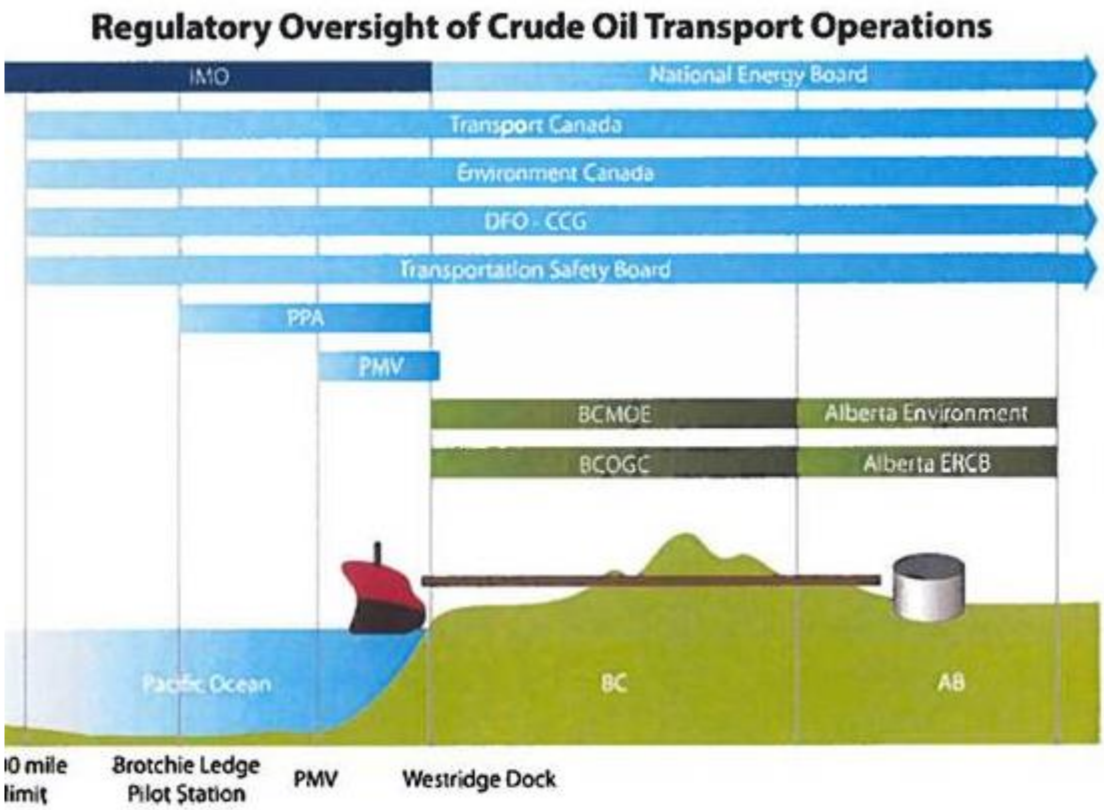


**Figure 6.Regulatory Oversight (Kinder Morgan, 2012)**

Another layer of control is attributed to the tanker owner itself. Technically, the polluter is responsible for oil spill response and must take on the role as “On-Scene Commander” (Department of Fisheries and Oceans, 2011; BC Ministry of Environment, 2007). By law, all vessels calling at a Canadian port must have a contract with an approved oil spill response organization, which will be called upon to take over as “On-Scene Commander” once the response has begun (Port Metro Vancouver, 2013a; Department of Fisheries and Oceans, 2011). If the polluter is unable or unwilling to respond, the Canadian Coast Guard takes over command (Office of the Auditor General of Canada, 2010; Department of Fisheries and Oceans, 2011). Since the liability of the polluter is limited to $140 million CAD, the tanker owner has no obligation to further manage the response when that limit is reached (EnviroEmerg Consulting, 2008)

It is important to note, however, that the oil spill response organization will not immediately begin a response to an oil spill. It must be directed to do so by either the responsible party or the government (Western Canada Marine Response Corporation, 2012). Moreover, there is no formal authority assigned to the City of Vancouver or other municipalities in terms of oil spill management, although they may be called upon to meet the needs of evacuees and responders (BC Government, 2012).

In terms of capacity, oil spill response organizations are required to maintain resources to respond to a maximum quantity of 10,000 tonnes of oil. They must also be able to respond between 6 and 72 hours after notification from the responsible party, and be able to treat a minimum of 500 metres of shoreline per day (BC Government, 2012; Western Canada Marine Response Corporation, 2012).

Western Canada Marine Response Corporation (aka WCMRC or "Burrard Clean"), the only recognized oil spill response organization on the West Coast, claims to have oil spill response capacity up to 25,000 tonnes (Port Metro Vanouver, 2013; Western Canada Marine Response Corporation, 2012). Additionally, WCMRC has 31 full and part-time staff, as well as 130 contractors, of which a large number are members of their Fishers Oil Spill Emergency Team (FOSET). These are commercial fishermen who, when available, can provide on-water operations support including boom deployment, recovery, surveillance and assessment (Western Canada Marine Response Corporation, 2012; Vanderklippe, 2012). Capacity is theoretically augmented by mutual aid agreements with oil spill response organizations in Washington and Alaska. WCMRC also has 30,000 metres of containment boom and other equipment, but these are spread between their three provincial locations. In addition to their equipment, there are also Coast Guard equipment caches and depots along the coast (Western Canada Marine Response Corporation, 2012). In-situ burning and dispersants are not pre-approved for use in Canada, but may be allowed on a case-by-case basis. WCMRC claims to have capacity to clean up to 1500 metre of coastline per day (Western Canada Marine Response Corporation, 2012).

In the Metro Vancouver area, additional local agencies that have responded to clean-up efforts after oil spills includes Oiled Wildlife Society of BC, Oiled Wildlife Trust of BC, BC SPCA, Wildlife Rehabilitator's Network of BC, Vancouver Aquarium Marine Mammal Rescue, Wildlife Rescue Association of BC, BC Society for the Prevention of Cruelty to Animals, and Focus Wildlife Canada.

However, even with stated capacity, there have been some questions about the area's ability to respond to an oil spill. The Office of the Auditor General, the BC Provincial Government, and consulting studies have provided a number of critical points including:

- The recent closure of the search-and-rescue station in Kitsilano, and Environment Canada's oil spill response regional office in Vancouver, has called into question the ability of the Federal government to intervene in a timely manner. However, this station was never intended to be directly involved in oil spill response activities);

- Many of the Coast Guard's vessels are not equipped with spill gear, or the equipment they have is old or outdated (although the Coast Guard is in the process of replacing that equipment);

- For liability reasons, Canada does not allow the participation of volunteers in a response. However, the available staff committed to a response is far short of what is necessary for a major oil spill;

- Moreover, the mutual aid agreements with US response organizations are non-functional because those organizations are not recognized in Canada. Therefore, they lack immunity and will not serve cross-border in case of an oil spill;

- In an Exxon *Valdez*-type spill, capacity for only 10,000 tonnes would be completely overwhelmed. Also, cleaning up to 500 metres a day would take 10 years to clean the 2000km that were impacted in Alaska;

- Several critics, including the Auditor General, have pointed out the dysfunctional management issues between the Coast Guard and the Province, and the risks that the separate command systems create;

- Also, the Coast Guard and Environment Canada lack capacity to assess impacts of contaminants on fish or marine mammals. (Office of the Auditor General of Canada, 2010; BC Government, 2012; B.C. Ministry of Environment, 2007; Vanderklippe, 2012; EnviroEmerg Consulting, 2008; Pacific States/British Columbia Oil Spill Task Force, 2011; CBC News, 2012; Galloway, 2012; The Canadian Press; 2013; Hume, 2011)

Recently, however, the Federal government provided a multipoint plan purported to improve tanker spill safety and response. Some of the announced activities include (Transport Canada, 2013):

- A study of the current regulated response capacity volume of 10,000 tonnes, as well as the outsourcing of spill response, and the placement of response assets;
- A study of oil pollution liability and compensation, specifically focusing on the adequacy of the Ship-source Oil Pollution Fund;
- Research on the specific effects of diluted bitumen;
- The establishment of immunity for foreign oil response organizations;
- Changing the Coast Guard’s oil spill management to an inclusive “Incident Command System” model (similar to the Unified Command System);
- Updating the Coast Guards' navigation systems.

## *6.8 Socioeconomic risks of an oil spill*

The following analysis was limited to published research concerning Metro Vancouver, and consequently it offers no assessment or prediction of possible impacts. In order to better understand the potential effects of a tanker spill, a full economic impact study based on deeper data sets would be required.

### 6.8.1 Commercial fisheries and aquaculture

Commercial fisheries and aquaculture play a relatively limited role in Vancouver’s economy. Income dependencies on fishing for the Greater Vancouver region are less than 0.5%, and are responsible for approximately 500 to 1500 jobs (MMK Consulting, 2007; Vancouver Economic Development, personal communication). There are no aquaculture farms in the Vancouver area, and commercial fishing in Burrard Inlet is highly regulated (MMK Consulting, 2007; Levings and Samis, 2001). However, the Fraser River sockeye run is an important niche fishery commercially, while also providing recreational and First Nations’ uses as well.

The larger risk of an oil spill would be to Vancouver's role as a landing and processing destination. Steveston is one of the largest fishing ports in Canada, with 1,200 boats landing annually (Port Metro Vancouver, 2012b). Additionally, processing companies like Canfisco deal with both wild caught and farmed fish and hire hundreds of processing workers (MMK Consulting, 2007). Vancouver gains half of the economic benefit of the groundfish fishery (GSGislason & Associates, 2010).

### 6.8.2 Tourism

In contrast to commercial fisheries, tourism has a significant impact on the Vancouver economy. Annually there are over 8 million overnight visitors to Metro Vancouver (PKF Consulting Inc.). This level of activity supports over 10,000 local tourism businesses, and employs over 80,000 people (Ministry of Jobs, Tourism and Innovation, 2012). Room revenue alone generates over $1 billion CAD annually (Ministry of Jobs, Tourism and Innovation, 2012).

Additionally, tourism segments have their own individual impact on the economy. The cruise ship industry delivers over 600,000 visitors to Vancouver each year, with direct spending in the Province of over $790 million CAD (Business Research & Economic Advisors, 2013). A smaller but important tourism industry is recreational fisheries. Anglers spend over 750,000 fishing days in the Lower Mainland each year (Freshwater Fisheries Society of BC, 2013). They spend over $95 million locally, and are responsible for 600 FTE of employment each year (Freshwater Fisheries Society of BC, 2005, 2009).

### 6.8.3 Port and other marine based industries

The Port of Metro Vancouver is one of the central economic generators not only for the city, but also for the Province and Western Canada. It handles over 120 million tonnes of cargo annually, employs over 44,000 people, and generates $3.5 billion in GDP for Metro Vancouver (Intervistas, 2009). In the City of Vancouver alone, the Port sustains over 18,000 full and part-time jobs, and is responsible for $870 million in wages.

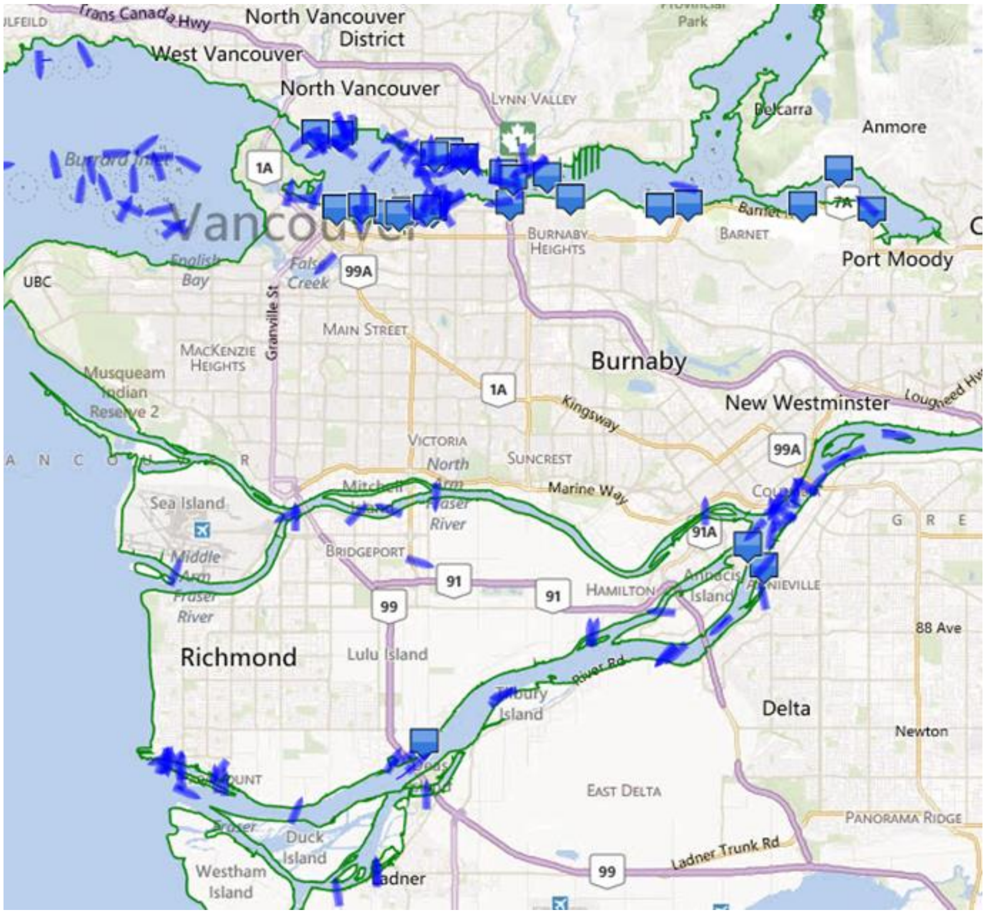


**Figure 7.Ship and terminal locations in PMV – March 25. 2013 (live website capture)**

Within the Port area, there are 28 terminals supporting a broad array of industries (Figure 7). In Burrard Inlet alone there are several petro-chemical plants, a sugar refinery, and multiple bulk container operations, including several of the largest grain handlers in Canada. (Port Metro Vancouver, 2013b; Intervistas, 2011).). There is also a bulk log shipping facility connected to the BC forestry industry, which could be impacted if oil made contact with log floats. (Port Metro Vancouver, 2013; Worley Parsons Canada Ltd, 2011).

Clearly the primary port concern with an oil spill is the possibility of a port closure. While the literature indicates that this is a relatively rare occurrence, an accident within either of the Narrows could potentially strand ships on either side. Also, port industries that use water could be impacted. Obviously this could be a problem for the log handlers, especially if there are log floats in the water.

There are also multiple businesses that use cooling water or other intakes from Burrard Inlet. Several studies have been done of water use by the more than 35 effluent permit holders in Burrard Inlet. Although many of them use storm water, some (including the Burrard Generating Station and the Vancouver Aquarium) draw water in directly (Balanced Environmental Services, Inc., BIEAP, 2010; Jiang and Fissel, 2003). It is unclear what the economic ramifications would be for these businesses.

One last consideration is the area of other marine transportation impacts of an oil spill. Recreational boating is a part of the culture and economy of Burrard Inlet with thousands of personal watercraft slips at local marinas and elsewhere (BC Marine Trades Association, 2013). There is also a vibrant floatplane industry that services 300,000 people annually (McDougal et al., 2011). BC Ferries transports 9 to 12 million passengers in and out of Tsawassen and Horseshoe Bay annually (BC Ferries, 2013). Also, there are numerous commuter water taxis like the Aquabus, False Creek Ferries, and TransLink's Seabus (which itself transports 5 to 6 million passengers per year) (Grant, 2012; Translink, 2011). One would expect an oil spill in Burrard Inlet to cause a short-term port closure, which would likely generate economic impacts for these businesses and their clients.

#### 6.8.4 Agriculture

Although agriculture accounts for a few percent of employment and GDP in Metro Vancouver, it is unlikely that an oil spill in Burrard Inlet would have much direct impact on food production locally. Out of 40,000 hectares of farmland in Metro Vancouver, there are only 547 hectares of farmland in the City of Vancouver and Burnaby (Metro Vancouver, 2012a). This land accounts for 78 total farms, producing approximately $22 million CAD in GDP.

#### 6.8.5 Real estate

Real estate plays a complex but significant role in Vancouver's economy, and has become a key element of economic growth (Barnes et al, 2010). Moreover, real estate has become a significant investment vehicle for international investors, and part-time residents from other provinces like Alberta. Housing starts have been linked directly to economic trends in China, suggesting that real estate is not a locally driven market (Wiebe, 2013). While it is difficult to link oil spill impacts with real estate value, it is important to consider how a spill would shape perception of value and livability here. These perceptions could potentially have an impact on real estate investment, which could affect the $5 billion/year construction industry, and the primarily property tax driven revenue base for the City of Vancouver (Metro Vancouver, 2012b; City of Vancouver, 2013).

### 6.8.6 Pure economic losses to the economy and tax revenues

In a recent report, it was suggested that jobs in clean tech, film, digital media, and other industries could be at risk from an oil spill (Conversations for Responsible Economic Development, 2013). While it is unclear how many jobs would be at risk in which sectors, it is clear that there could be ripple effects throughout the local economy. Retail sales account for $27 billion annually (Metro Vancouver, 2012b). A drop of a percentage point alone could be devastating to the broader economy.

It should also be noted that if Vancouver were to implement a municipal sales tax in future (such as one to fund Translink), the City would suffer a loss in tax revenues from sales in the event of an oil spill. However, current tax losses would mostly accrue to the Province and Federal governments.

### 6.8.7 Vancouver's brand damage

Vancouver's brand is a prized commodity. "Vancouverism" itself is widely held as a paragon of urban planning, and, due to its setting and competitive amenities, the city attracts residents and businesses from all over the world. However, perception is central to brand, and that perception is not always controllable from the inside. Vancouver's "Most Livable City" status is a good example of that. In 2011 the Economist magazine dropped Vancouver from its consistent top spot as Most Livable City, primarily because of traffic construction on the Malahat highway. However, the Malahat is 90 kilometres away on Vancouver Island, and the "Economist Intelligence Unit" did not perceive the difference (Dhillon, 2011).

Vancouver's "Greenest City" goal is a similarly important distinction for attracting residents and businesses. However, an oil spill in Burrard Inlet could seriously challenge the "green" message that city leaders are communicating to the global community. Even an oil spill on Vancouver Island could have cascading impacts simply due to "brand confusion".

Some have argued, however, that the "green" reputation is threatened not just by a potential oil spill, but also by ongoing economic involvement in the fossil fuel trade (Conversations for Responsible Economic Development, 2013). The National Round Table on the Environment and the Economy released a report on the low-carbon economy, and Canada's leadership role within it. While enumerating various opportunities, the report also suggested that contradictory participation in oil production and sales can put our leadership opportunities at risk.

The combination of a perceived image of Canada lagging on climate policy and promotion of labeling schemes that help consumers manage embodied emissions associated with their consumption is particularly powerful. Such an image may also leave Canadian products exposed to consumer actions like boycotts. Modern campaigners are sophisticated enough to try, for example, to track Canadian oil sands products through the supply chain to the retail level, and to urge consumers not to buy. In a sector with such homogeneous products as retail-level gasoline, such actions might be significant. (National Round Table on the Environment and the Economy, 2012)

### 6.8.8 First Nations in Metro Vancouver

There are 17 First Nations that either live in Metro Vancouver, or have direct interests in the region (Metro Vancouver, 2012c). They represent thousands of indigenous peoples upon whose unceded territory Vancouver and its suburbs now reside. First Nations in Metro Vancouver have significant economic interests, as well as social and ceremonial interests, in the land, fisheries, and other natural resources of the area. Sixty-one First Nations from around BC have signed the Save the Fraser Declaration opposing pipeline development around the waterways connected to the Fraser River (Gathering of Nations, 2010). Similarly, the Squamish and Tsleil-Waututh have led the signing of the Save the Salish Declaration, and have vocalized their opposition to the Kinder Morgan pipeline (Canada NewsWire, 2012).

Food, social, and ceremonial fisheries play a central part in First Nations culture, and have special exemptions under DFO licensing schemes (Department of Fisheries and Oceans, 2011). Musqueam, Tsawwassen, Tsleil-Waututh and New Westminster First Nations fish the Fraser with drift nets downstream of the Port Mann Bridge and into the Strait of Georgia, and many nations fish waterways throughout the area. (Department of Fisheries and Oceans, 2013).

While it is impossible to quantify the impact of an oil spill on local First Nations, an economic impact study for Coastal First Nations near the Enbridge pipeline estimated subsistence losses at between $13.2 and $42.5 million CAD, with cultural and heritage impacts of another $1.4 million CAD (Gunton and Broadbent, 2012). Upper bound economic and non-use value losses were estimated in the multiple billions.

### *6.9 A note regarding liability insurance*

From an analysis of the 1992 CLC and available literature, it is unclear whether a municipality like Vancouver could independently require unlimited liability insurance for oil tankers. On the one hand, there is a jurisdictional issue. Canada has ratified the CLC and is bound by its prescriptions under international law. It is not clear that Vancouver would have the legal standing to contravene the limited liability clause of the CLC and subject ship owners to unlimited liability. On the other hand, there is a practical issue of international insurance markets. There is currently no insurance product that would cover unlimited liability, and the risks for insurance companies preclude them from offering one (Abraham, 2011). Moreover, it is not apparent that insurance companies could supply a product that would cover $10 to $20 billion CAD (Abraham, 2011). British Petroleum acted as a self-insurer under OPA, so their own enormous balance sheet was used to cover the majority of spill-related costs. As was described above, tanker owners probably could not do the same.

# 7 DISCUSSION

As revealed in the review above, assessing the potential economic and biophysical impacts of an oil spill poses a tremendously complex challenge, which is further complicated by limitations on available knowledge and data. This section summarizes major findings of the paper, reviews current limitations and identifies future work required.

## *7.1 Key Findings*

- Small oil spills happen routinely, but the risks of a major tanker spill are decreasing internationally. Due to the Port Metro Vancouver's strict regulations regarding tanker traffic, there has been a history of tanker safety in Burrard Inlet. However, there is no way to bring oil spill risk to zero, so continued focus on oil spill prevention is necessary.

- A quick response time and multilayered response methodology are both critical to minimizing the impacts of an oil spill. However, there appear to be challenges in the structure and workings of the current response framework in British Columbia. Proposed new developments by the Federal government may mitigate these issues, but improving local response capacity for any municipality should continue to be a goal.

- National and international compensation regimes limit liability of tanker owners, and provide a maximum of $1.34 billion in total compensation. This amount can cover admissible claims resulting from the vast majority of oil spills, but would potentially fall short in the case of a catastrophic tanker spill. It is unclear if local municipalities could institute insurance requirements in addition to or instead of these international treaties.

- In the event of an oil spill, commercial fisheries and tourism businesses that are adjacent to the spill are most likely to be compensated. Other marine-based businesses with direct damages could be eligible for compensation, as well as a small number of businesses that are directly impacted by oil pollution. Some subsistence claims for First Nations could be compensated. The environment could be cleaned, but would not required to be brought back to pre-spill levels.

- The majority of businesses that experience pure economic loss (i.e. loss with no apparent oil pollution damage) would not be compensated. Losses in retail revenues, real estate value, the financial sector, work stoppages from health-related problems, and sales taxes would not be compensated. Intangible losses like cultural value, recreation, passive use, and opportunity costs would not be captured.

- Some mitigating factors like a clean-up "boom", compensation payments, conservation benefits, and others could reduce the impact of an oil spill.

- An oil spill in Burrard Inlet would have immediate negative impacts on local marine ecosystems. Though the severity of impacts would vary among species and habitats, a species level extinction from an oil spill is not likely. Recovery of populations would depend upon the degree of impact by spill, habitat type, and species in question and could range from weeks to decades. Clean-up measures increase the immediate severity of impact to populations and can substantially delay recovery rates.

## *7.2 Limitations of Study*

As this study was initiated to address current concerns regarding the impact of a potential increase in oil tanker traffic in Burrard Inlet, the research team did not review literature in depth on a number of relevant issues. These include potential impacts from a pipeline spill, as well as the effects of the tanker traffic itself, with respect to waves, noise and operational pollution. The team also did not do any predictions nor modelling of a spill, as significantly more data and research would be required to inform such an exercise; see below for Future Work. Finally, the team did not have the mandate to pursue a full review of current legislation at various regulatory levels to determine actual risk and liability to the City of Vancouver.

As much as possible, the review does attempt to identify potential impacts of a spill on the Vancouver economy and ecosystems; however, the lack of precedent of a major oil spill in an environment that shares the City's geography, biology and socioeconomic circumstances limited the conclusions that could be drawn.

## *7.3 Future work*

Given current gaps in knowledge and data that would be required for predicting and modeling the economic and biophysical impacts of an oil spill from a tanker in or around Burrard Inlet, the literature review suggests several research needs that would inform the City's planning, policy development and decision-making around this issue.

- Perform baseline assessments of natural resources and economic entities to inform economic impact studies and recovery plans, and to ensure accurate monitoring after a spill has occurred.

- Conduct further research to better understand the toxic effects of components of bitumen and crude oil on local marine species in Burrard Inlet and the surrounding region, as information required to manage operational and accidental exposure of flora and fauna. This could take the form of a quantitative meta-analysis of effects of oil spill events on marine species. This could also include laboratory experiments measuring threshold values for bitumen toxicity of local species. This would allow scientists to better predict species level impacts in modelled oil spill scenarios and determine at what point normal operational spillage will impact local marine species.

- Conduct research to better understand the impact of increased vessel traffic and anthropogenic underwater noise on local marine species.

- Develop a model of proposed increases in tanker and industrial traffic in Burrard Inlet to assess the risk of an incident and inform proposed mitigation strategies.

- Develop a dynamic model of a spill in key areas of Burrard Inlet to determine dispersal rates and pathways. This would include further research into the differences in behaviour of light crude, bitumen and dilbit when spilled.

- Perform an audit of actual spill response capacity on the West Coast of Canada to identify potential gaps.

- Conduct qualitative analysis of local expertise through interviews, to inform preparedness for a potential spill.

- Review procedures and management of a spill response at the municipal, metropolitan area, and provincial levels within BC to generate clarity for responsibility and resources required.

- Develop a socioeconomic recovery plan using the assesments recommended above, to address existing inequalities in impact and compensation. Such a plan would focus on involving NGOs and diverse revenue streams to provide a comprehensive recovery program for those who do not benefit from the standard recovery mechanisms.

- Investigate legal limitations for municipalities regarding liability coverage, requirements, responsibility, and clean-up governance. How much can the City of Vancouver do legally to mitigate economic risk?

Addressing these key knowledge gaps is important for anticipating potential oil spill consequences in the Vancouver region and – as crucially – for developing strategies to reduce this risk.

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# 9 APPENDICES

## *9.1 APPENDIX 1: Research Team*

Professor Stephanie E. Chang joined UBC in January 2004 and has a joint appointment in the School of Community and Regional Planning (SCARP) and the Institute for Resources, Environment, and Sustainability (IRES). She holds a Canada Research Chair position (Tier 2) in Disaster Management and Urban Sustainability. Much of Dr. Chang's work aims to bridge the gap between engineering, natural sciences, and social sciences in addressing the complex issues of natural disasters. Her research has ranged from empirical investigation of major urban disasters to computer modeling and analysis of risk reduction strategies. Dr. Chang is particularly interested in issues of disaster recovery and resilience, urban infrastructure systems, and cities of the Pacific Rim. Prior to joining UBC, she was a research assistant professor in the Department of Geography at the University of Washington. She has also worked as a researcher/consultant with EQE International in Los Angeles and Seattle. Dr. Chang was awarded the 2001 Shah Family Innovation Prize by the Earthquake Engineering Research Institute (EERI) and is EERI's 2011 Distinguished Lecturer. She has served on the editorial board of *Earthquake Spectra* and on the U.S. National Research Council's committee on Disaster Research in the Social Sciences.

Kyle Demes recently completed his PhD. in Zoology at UBC. He has an extensive publication record and deep expertise in marine ecosystems. Demes couples laboratory and field research to investigate how physiological, biomechanical, and ecological trade-offs regulate individual, community, and evolutionary level responses to natural and anthropogenic changes in abiotic and biotic factors. Although much of his research uses kelps as model organisms, he is broadly interested in marine and freshwater organisms. He is an active and respected academic researcher, who speaks frequently at international conferences. (Co-author for section on Biological Impacts).

Marina Piscitelli is currently a PhD student at UBC in the Department of Zoology and has a strong interest in the marine environment. With a graduate degree in biology and strong publishing credentials, she also has excellent first-hand experience, having worked on several wildlife rehabilitation projects, including the BP Deepwater Horizon oil spill. (Co-author for section on Biological Impacts and primary author for section on Human Health Impacts.).

A Professor at UBC's Sauder School of Business, Dr. Moura Quayle's interests lie in rethinking, refining and rebuilding collaborative spaces at the intersections of academia, government and business. Now looking at business decision-making in the UBC Sauder School of Business in Vancouver, Canada, Quayle's experience includes leadership of the B.C. Pacific Coast Collaborative Commission, an initiative of five coastal states and one province. As Deputy Minister of the B.C. Ministry of Advanced Education, Research and Innovation, she was responsible for twenty-five public post-secondary institutions. Earlier academic transformation service included terms as Dean of UBC's Faculty of Land and Food Systems, and later as the Associate VP, Programs for a new satellite campus, UBC Okanagan. International work includes CIDA program evaluation in Brazil, community development in the Eastern Caribbean, urban design juries in Japan, and economic task-force membership for trips to India and China. She is a well-respected author, blogger and speaker on the principles and practices of creative thinking in Canada, the US, the UK and the EU, for application from community architecture studios to business school programs. In community service, Quayle chaired Vancouver's Urban Landscape Task Force, which resulted in the birth of the city's Greenways program. She has been recognized by the YMCA as a Woman of Distinction and received an honorary Doctor of Science from her alma mater.

Jeremy Stone is currently a PhD student at UBC in the School of Community and Regional Planning. He is also founder and director of Recovery and Relief Services, a niche consultancy providing economic recovery and disaster planning services. Previously he managed a $20MM grant and loan program following Hurricane Katrina, and designed economic recovery programs with several organizations after the Deepwater Horizon oil spill. Stone has worked extensively throughout the coast of British Columbia with Ecotrust Canada, where he provided business and economic development planning for First Nation governments. His other areas of experience include commercial fishing economies, microfinance, and urban economic development. Stone is a former Peace Corps volunteer (Mongolia), and received his MPA in International Economic Development from New York

University, and his BA in Anthropology from Reed College. (Primary author for section on Economic Impacts).

Denise Withers MSc. is a senior strategic consultant who uses qualitative tools to develop organizational opportunities, capacity and leadership. A co-founder of the Sauder d.studio at UBC, she blends thirty years of practical experience as an award-winning communicator, researcher and international filmmaker with graduate studies in design for engagement and technology-mediated learning. Withers has managed budgets over a million dollars, led teams of eighty, delivered projects on four continents, won eight international broadcasting awards, and written/directed over 150 programs. Her work has been published in national newspapers, aired on major TV networks and praised in boardrooms. Her client list includes all levels of government, high tech, not-for-profits, academia and small business. Recent projects focus on developing shared value for enterprise and entrepreneurs.

## *9.2 APPENDIX 2: Table of Chemical Effects of Bitumen, Benzene and Toluene*

Please note some of these cases represent worst-case scenarios and severe conditions.

| Chemical Name | Skin contact | Inhalation | Eyes | Aspiration | Ingestion | Long-term Exposure | LD 50 Toxicity | LC50 Toxicity | Chronic | Comment | Citation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **BENZENE (common diluent)** | | | | | | | | | | | |
| | cause eye, skin, mucous membrane irritation | anesthetic effects, dizziness, nausea, headache, intoxication; Excessive exposure cause irritation to nose, throat, lungs and respiratory tract; CNS brain effects i.e. - headaches, dizziness, loss of balance and coordination, unconsciousness, coma, respiratory failure, and death; blood - decreased platelet and white blood cell counts; cardiovascular , nervous system, retina, lungs, GI system, spleen and kidneys have been reported from large acute and repeated or prolong exposures | Moderate - Severe irritant | aspiration of liquid results in chemical pneumonia, severe lung damage, respiratory failure and even death; | GI disturbance, irritation, nausea, vomiting, diarrhea, brain effects similar to alcohol intoxication; severe cases - tremors, convulsions, loss of consciousness, coma, respiratory arrest and death | blood disease, anemia, leukemia | Acute dermal (rabbits) > 9.4 mL/kg; Acute oral (mouse) 4.7 g/kg | Acute inhalation (rat; 7 hrs) 10,000 ppm; eye irritation (rabbit) mild to moderate; primary dermal irritation (rabbits) mild to moderate | considered a regulated human carcinogen; potential to cause bone marrow depression, aplastic anemia (low RBC count) and other blood diseases including leukemia after repeated and prolonged exposure; can cause liver and kidney toxicity; irritation from skin exposure may aggravate open wounds, skin disorders and dermatitis (rash); pre-existing chronic respiratory disease, liver or kidney dysfunction or blood, cardiovascular and CNS disorders may be aggravated | Numerous epidemiological (human) and animal studies have reported an increased incidence or a casual relationship between leukemia and benzene exposure; mutagenic | Hovensa, 2006 |
| | irritant | | irritant | fatal if swallowed; aspiration hazard | | repeated exposure cause inhalation, oral, dermal, blood toxicity | acute oral female rat > 2,000 mg/kg; acute inhalation rat 4hr exposure 44.5 mg/l; acute dermal rabbit >8,260 mg/kg; skin, eye, and respiratory irritant; moderate eye in female rat; daily exposure to rats for 52 wks resulted in zymbal gland carcinomas, mammary gland carcinomas and leukemia at doses of 50 and 250 mg/kg; rats exposed for 5d/week for 103 weeks resulted in zymbal gland carcinomas, squamous cell papillomas (pre-cursor to cancer) | Fish 5.3 mg/L exposed for 96hr rainbow trout; water flea and invertebrates EC50 (effective concentration) = 50 mg/L for 48hr exposure; Algae ErC50 = 100mg/L exposed for 72 hr green algea | | carcinogenic to mammals; not considered to be persistent nor bioaccumulating; toxic to aquatic life; carcinogenic; mutagenic - in vivo tests showed mutagenic effects; germ cell mutagenicity, | Chevron Phillips Chemical Company, 2011 |

| Chemical Name | Skin contact | Inhalation | Eyes | Aspiration | Ingestion | Long-term Exposure | LD 50 Toxicity | LC50 Toxicity | Chronic | Comment | Citation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | irritation; if absorbed can affect liver, blood, metabolism, and urinary system | respiratory tract and mucous membrane irritation; absorbed through lungs - may affect behavior / CNS and peripheral NS (somnolence, muscle weakness, general anesthetic; GI tract nausea, blood metabolism, urinary system; may be toxic to liver, kidney, bone marrow | irritant, redness, watering and itching, inflammati on | | GI irritation, vomiting; affect CNS and PNS (convulsions, seizures, tremors, irritability, initial CNS stimulation followed by depression, loss of coordination, dizziness, headache, weakness, pallor, flushing), respiration (breathlessness and chest constriction), cardiovascular (shallow / rapid pulse), and blood | produce target organ damage | Oral acute rat = 930 mg/kg; mouse 4700mg/kg; dermal acute rabbit > 9400mg/kg; (all 4 hr exposure) | Vapor acute rat exposed for 7hrs 10,000ppm (all 4 hr exposure) | human carcinogenic chronic effects possible; possible mutagenic effects; adverse reproductive effects (female fertility, embryotoxic and /or fetotoxic in animals), birth defects; may mutate genetic material (mutagenic); may cause cancer (tumorigenic, leukemia); for human passes the placental barrier and can be detected in maternal milk | human carcinogenic; possible mutagenic; mutagenic for mammalian somatic cells; mutagenic for bacteria and yeast; possible female reproductive toxin | Science, 2012b |
| **TOLUENE (common diluent)** | | | | | | | | | | | |
| | irritant; can be absorbed; reddening of skin or dermatitis resulting from defatting action of tissue | irritant of mucous membranes; serious damage to health if prolong exposure through inhalation; vapors cause drowsiness, dizziness; high vapor concentration causes CNS depression and narcosis; headache, nausea, lack of coordination, anesthesia; Severe exposure may cause respiratory depression, unconsciousness, convulsions, death | irritant; may cause damage to cornea | | harmful if swallowed; GI disturbance, CNS headache, sleepiness, dizziness, slurred speech, blurred vision | Severe exposure cause respiratory depression, unconsciousne ss, convulsions and death | inhalation rat 12.5 mg/L/4hrs; oral 636 mg/kg; rabbit dermal 8390 mg/kg | 96hr 1-day old fathead minnow = 25mg/L; 96Hr rainbow trout = 24 mg/L; 96Hr bluegill fish = 24 mg/L; 96Hr fathead minnow = 31.7 mg/L; 30 min EC50 Photovacterium phosphoreum 19.7 mg/L; 48Hr EC50 water flea = 11.3 - 310mg/L; | Delayed effects and repeated prolong exposure may cause brain and nervous system damage, liver and kidney damage; possible risk of harm to fetus; Inhalation of rats 2500ppm/6.5hrs/day for 15 weeks produced heart, liver, kidney, urethra and bladder changes; pre-existing respiratory, liver or kidney diseases/dysfunction or blood, cardiovascular or CNS disorders may be aggravated | not know to be mutagenic or carcinogenic; harmful to aquatic organisms; accumulation in terrestrial organisms and bioaccumulation is unlikely | BDH, 2005 |

| Chemical Name | Skin contact | Inhalation | Eyes | Aspiration | Ingestion | Long-term Exposure | LD 50 Toxicity | LC50 Toxicity | Chronic | Comment | Citation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | mild to moderate irritant; permeable | Vapor - respiratory tract irritation, coughing and wheezing, nasal discharge. High concentrations affect behavior and affect CNS nausea, headache, dizziness, tremors, restlessness, lightheadedness, exhilaration, memory loss, insomnia, impaired reaction time, drowsiness, ataxia, hallucinations, somnolence, muscle contraction or spasticity, unconsciousness and coma. Cardiovascular system (rapid heart beat, heart palpitations, increased or decreased blood pressure, dysrhythmia), respiration (acute pulmonary edema, respiratory depression, apnea, asphyxia), cause vision disturbances and dilated pupils, and cause loss of appetite. Ingestion: Aspiration hazard, chemical pneumonitis. Irritation of GI tract, nausea, vomiting, pain. | mild to moderate irritant with burning sensation; conjunctivitis, blepharospasm, corneal edema, corneal abrasions that resolves in 2 days | | | | Oral acute rat = 636 mg/kg; dermal acute rabbit = 14100mg/kg; vapor acute rat = 49,000 mg/L / 4hrs; mouse = 440ppm / 24hrs; Lowest published lethal dosage human oral 50mg/kg; rabbit inhaled 55,000ppm/40min | water flea = 313 mg/L/48hrs; blue gill fish = 17 mg/L/24hr; 13 mg/L/96hr; fathead minnow = 56 mg/L/24hr; fathead minnow = 34 mg/L/96hr; goldfish = 56.8ppm / any hour | not known carcinogenic or mutagenic; repeated or prolong exposure can produce target organ damage; may cause damage to blood, kidneys, CNS, liver; Inhalation and Ingestion: Prolonged or repeated exposure via inhalation may cause central nervous system and cardiovascular symptoms similar to that of acute inhalation and ingestion as well liver damage/failure, kidney damage/failure (with hematuria, proteinuria, oliguria, renal tubular acidosis), brain damage, weight loss, blood (pigmented or nucleated red blood cells, changes in white blood cell count), bone marrow changes, electrolyte imbalances (Hypokalemia, Hypophostatemia), severe, muscle weakness and Rhabdomyolysis. Skin: Repeated or prolonged skin contact may cause defatting dermatitis. | may be toxic to blood, kidneys, liver, CNS; detected in maternal milk of humans and can pass through human placental barrier; embryotoxic and / or foetotoxic in animals; may cause reproductive and birth defects (teratogenic); may affect DNA (mutagenic) | Science, 2012a |
| **BITUMEN** | | | | | | | | | | | |
| | | irritation of nose and throat, coughing; inhalation of hydrogen sulfide CNS depression, coma, death, irritant to respiratory tract, chemical pneumonitis, pulmonary edema (may be delayed 24 to 48hrs) | irritant at high vapor concentrations | | nausea, diarrhea | | | | Vapor fumes may give rise to dermatitis, other skin conditions or serious or irreversible nature | National Exposure Standards 8hr time average of 10ppm for hydrogen sulfide and 5mg/m3 for bitumen fumes; short-term exposure limit for hydrogen sulfide is 15ppm; Bitumen is NOT biodegradable and spillages are unlikely to penetrate soil | BPAUST, 2005 |

| Chemical Name | Skin contact | Inhalation | Eyes | Aspiration | Ingestion | Long-term Exposure | LD 50 Toxicity | LC50 Toxicity | Chronic | Comment | Citation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | irritant; vapors/fumes generated by heating this product may cause respiratory irritation with throat discomfort, coughing or difficulty breathing, shortness of breath, headache, dizziness, tiredness, nausea, and vomiting; sensation of dryness an pain of the nose, loss of consciousness | irritant | | | | Acute Dermal LD50 Rabbit: >= 2000 mg/kg ; Acute Oral LD50 Rat: >= 5000 mg/kg | Hydrogen sulfide (7783-06-4) Acute Inhalation LC50 Mouse: > 0.024 mg/l 960 Minutes Acute Inhalation LC50 Rat: > 0.38 mg/l 960 Minutes ; LC50 Lake whitefish (Coregonus clupeaformis): 0.002 mg/l 96 hours Hydrogen sulfide | Exposure to Asphalt fumes can cause severe irritation of the skin and may cause dermatitis and acne-like lesions. Prolonged contact may cause skin pigment change which may be aggravated by sunlight exposure. Further information Asphalt has low systemic toxicity when ingested. However, chewing asphalt has caused gastrointestinal effects. Gastric masses (Bezoars) and stomach (pyloric) obstructions have been reported in individuals who have chewed and swallowed asphalt. Effects on the tracheobronchial tree and lungs of mice inhaling an aerosol of petroleum asphalt & another group inhaling smoke from heated petroleum asphalt incl. congestion, acute bronchitis, pneumonitis, bronchial dilation, some perbronchiolar round cell infiltration, abscess formation, loss of cilia, epithelial atrophy & necrosis. | in vapor form hydrogen sulfide a highly toxic gas is present; overexposure to hydrogen sulfide include respiratory and eye irritation, dizziness, nausea, coughing, a sensation of dryness and pain in the nose, and loss of consciousness; insoluble in water. | Devon, 2010 |
| | irritant; sensitisation; allergic skin reaction | respiratory tract irritation, CNS depression, weakness, dizziness, slurred speech, drowsiness, unconsciousness, and coma and death in severe cases; 10ppm of hydrogen sulfide respiratory tract irritation, respiratory failure, coma and death, pulmonary edema up to 24hrs later; vapors/fumes generated by heating this product may cause respiratory irritation with throat discomfort, coughing or difficulty breathing. Dust from grinding of asphalt or fumes from the heating of this material caused transitory inflammation and irritation of the surface of the eyes and of the respiratory passages, as well as limbal pigmentation of cornea. | irritant | | narcosis | | | Inhalation of hydrogen sulfide gas Rat 444 ppm 4 hours | allergic reaction; repeated skin exposure can produce skin destruction or dermatitis; pre-existing skin disorders may aggravated by over-exposure | | Petro-Canada, 2012 |

| Chemical Name | Skin contact | Inhalation | Eyes | Aspiration | Ingestion | Long-term Exposure | LD 50 Toxicity | LC50 Toxicity | Chronic | Comment | Citation |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | irritant; redness and occasional drying and peeling | moderate to severe irritation of the nose, throat and respiratory tract. May cause headache, nausea, sore throat, nasal congestion, dizziness and nervousness. Confined spaces may accumulate hydrogen sulfide gas. Hydrogen sulfide may cause respiratory tract irritation, nausea, headache, dizziness, pulmonary edema, loss of consciousness, brain damage and death | irritant; dust may cause irritation characterized by burning, redness, swelling and watering. | fatal chemical pneumonitis. | irritant; vomiting and a danger of aspiration. | | 5 to 15 g/kg (oral), >5 g/kg (oral) - mice, rats; 3-8 g/kg (rat-intragastric), >3.16 g/kg (dermal) - rabbits | | Repeated exposure to hot bitumen or bitumen fumes may cause inflammation of the skin, acne like lesions, development of horny growths on the skin, darkening of the skin and sensitization of the skin to light. Bitumen may cause hair loss, dryness, scaling, and dermatitis. May aggravate existing skin conditions. Bitumen contains chemicals that may have a carcinogenic potential. Prolonged exposure to bitumen fumes may cause inflammation of the lungs and mucous membranes of the nose and throat. May cause chronic bronchitis, pulmonary congestion, laryngitis, hoarseness, coughing, fatigue and atrophy and/or death of the epithelium. May aggravate existing respiratory conditions. | | Syncrude Canada, 2006 |

(BDH, 2005; BPAUST, 2005; Chevron Phillips Chemical Company, 2011; Devon, 2010; Hovensa, 2006; Petro-Canada, 2012; Science, 2012a, 2012b; Syncrude Canada, 2006)