# Fate and Effect of Oil Spills from the Trans Mountain Expansion Project in the Gulf Islands, Strait of Juan de Fuca and the Fraser River, British Columbia

Prepared
for

**Living Oceans Society**

Prepared
by


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May 26, 2015
Dated

# 1.0 Introduction

## 1.1 Scope of Work

1. I have been retained by the Living Oceans Society to assess the fate and effects of oil spills that might result from the Trans Mountain expansion project in the Salish Sea, including the Gulf Islands, Strait of Juan de Fuca and the west coast of Vancouver Island and adjacent waters.

2. In particular, I have been asked to: (1) Review the application of Kinder Morgan for its Trans Mountain Expansion Pipeline; and review such other documents as the applicant or the NEB might issue from time to time that are relevant to the further work described in this contract; (2) provide an opinion as to the extent to which the Bunker C oil spilled by the Nestucca might serve as a proxy for diluted bitumen; and (3) prepare an expert report of my opinion regarding, and a critical analysis of the applicant's proposal in respect of its claims regarding (a) the fate and behaviour of diluted bitumen if spilled in the marine environment, (b) impacts to species inhabiting the intertidal zone, shellfish species, forage fish spawning beaches, eelgrass and kelp beds, (c) impacts to species utilizing the ocean's surface, including marine mammals and sea-birds, (d) impacts to species inhabiting the water column at the depths to which you anticipate diluted bitumen to continue to have impacts, (e) the fate and behaviour of diluted bitumen if spilled in the Fraser River, with particular attention to impacts likely to occur to salmon at all of their life stages, (f) the efficacy of chemical dispersants for treating a spill of diluted bitumen in either a marine or fresh water environment, and (g) the impacts of chemical dispersant and dispersant/oil mixtures on species referred to above.

## 1.2 Statement of Qualifications

3. I hold a Bachelor of Science degree in biochemistry and philosophy from the University of California at Riverside, a Master of Science degree in physical chemistry from the University of California at Santa Cruz, and a Doctor of Philosophy degree in fisheries from the University of Alaska at Fairbanks.

4. I was employed as a Research Chemist at the US National Oceanic and Atmospheric Administration, National Marine Fisheries Service for 31 years. Following the 1989 *Exxon Valdez* oil spill, I: (1) led numerous projects to evaluate the distribution, persistence, fate and biological effects of the spilled oil in the marine environment, reporting results in the peer-reviewed scientific literature; (2) established and managed a hydrocarbon analysis facility that analyzed biological and geological samples for oil contamination; (3) established and managed the chemistry data archive for the subsequent studies of the short- and long-term effects of the oil spill; (4) led the

chemistry data quality evaluation and interpretation for both the US Federal government and the State of Alaska; and (5) led the scientific support team for the US Department of Justice to present the scientific basis for a $100M claim against ExxonMobil Corp. for un-anticipated long-term environmental damages caused by the oil spill. Since my retirement in 2008 I have primarily performed or provided support services for research projects and programs on the effects of oil pollution on marine ecosystems.

5. I have published 68 professional scientific papers on oil pollution fate and effects in the peer-reviewed scientific literature, contributed chapters to three books on the same subjects, and have presented written and oral testimony before the United States House of Representatives, the United States Senate, and the Alaska State Legislature on oil spill fate, effects and responses. These studies and presentations focussed primarily on the mechanisms of oil dispersal in the environment following accidental discharges, retention of oil on shorelines and the factors modulating oil persistence, and mechanisms through which oil exposure harms fish and birds.

6. As an employee of the US government, I have advised government agencies of foreign countries on technical matters regarding oil pollution, including Canada, Norway, the Peoples Republic of China, the Russian Federation, and the Republic of Korea. I served under an inter-governmental scientific expert exchange program between the US and Canada to provide expert witness testimony on behalf of the Canadian government during the prosecution of Canadian National Railway for the consequences of the train derailment and subsequent oil spill into Lake Wabamun, Alberta in 2005.

7. I am currently retained (since 2010) to organize and oversee scientific support for the Plaintiff's Steering Committee in the multi-district litigation of lawsuits against British Petroleum PLC and other companies for their roles in causing the 2010 Deepwater Horizon blowout in the northern Gulf of Mexico, and by the Republic of Ecuador in Bilateral Investment Treaty arbitration with Chevron Corporation stemming from oil pollution caused by Texaco (now a subsidiary of Chevron) in the Amazonian rainforest of Ecuador. I have also been retained by the Gitxa'ala First Nation to evaluate environmental risks associated with the proposed Northern Gateway Pipeline Project.

8. A copy of my curriculum vitae is attached as **Appendix 1**.

# 2.0 Executive Summary

## 2.1 Project Background

9. Trans Mountain Pipeline ULC (hereafter, Trans Mountain) has applied for a Certificate of Public Convenience and Necessity to construct and operate (i) 987 km of new pipeline from Edmonton, Alberta to Burnaby, British Columbia; (ii) an expanded petroleum storage facility in Burnaby; (iii) a new and expanded dock complex at the Westridge Marine Terminal; and (iv) two new pipelines from the storage facility to the Terminal (hereafter, Project).

10. The Project would increase pipeline transport capacity from about 47,700 $m^3/d$ to 141,500 $m^3/d$ (i.e., 300,000 bbl/d to 890,000 bbl/d), with a concomitant increase of Aframax-class tanker traffic from five to as many as 34 vessels per month. Three new berths for the Aframax tankers would be constructed at the Westridge Marine Terminal as well. Beginning at the Burnaby terminal, the tanker route would pass through Burrard Inlet, across the mouths of the Fraser River delta in Georgia Strait, through the Gulf Island passages and Haro Strait off the southeastern coast of Vancouver Island, and then through the Strait of Juan de Fuca, remaining in Canadian territorial waters to the North Pacific Ocean (Figure 1). Tanker traffic would remain within about 10 km of shorelines along nearly this entire route to the open ocean. Along the way, tanker traffic passes through some of the most biologically productive and ecologically important marine waters in Canada.

11. The petroleum products shipped by the Project will consist almost entirely of Alberta oil sands bitumen diluted with either gas condensate (i.e., "dilbit") or synthetic crude oil ("synbit"). Gas condensate, sometimes referred to as "natural gasoline", consists mostly of hydrocarbons that condense from natural gas wells at atmospheric pressure and room temperatures. Most of these gas condensate hydrocarbons range from pentane ($C_5H_{12}$) through dodecane ($C_{12}H_{26}$). Synthetic crude oil is produced by refining oil-sands bitumen. Sometimes a mixture of gas condensate and synthetic crude oil is used as the diluent, denoted as "dilsynbit". Dilution lowers the density and the viscosity of the resulting fluid so that it can be shipped through pipelines.

12. If the Project is approved, the increased shipment of diluted bitumen through the expanded pipeline and by tankers brings increased risk of oil spills. Spills may occur because of leaks or ruptures of pipelines or storage tanks, during transfer to tankers at the Westridge Marine Terminal, or during transit of loaded tankers through Burrard Inlet, the Strait of Georgia and the Strait of Juan de Fuca.

## 2.2 Critique of the Trans Mountain Environmental Risk Assessment

13. The Trans Mountain environmental risk assessment (ERA) is fundamentally flawed because:

    (a) it fails to integrate oil exposure risk based on multiple locations within ecologically distinct sub-regions along the marine shipping routes, including at or near ecologically-sensitive areas;

    (b) it fails to assess hazard independently of exposure. Trans Mountain concludes that hazard is minimal whenever their estimate of oiling probability is low. However, Trans Mountain should have assessed hazard based on species sensitivity to oiling independently of oiling probability;

    (c) it fails to assess the possibility of organisms being exposed to submerged oil; and

    (d) it fails to consider all the ways that oil can harm organisms.

14. In addition, the Trans Mountain ERA relies almost exclusively on findings from the 1989 *Exxon Valdez* oil spill in Alaska as the basis for evaluating likely effects of an oil spill in the Salish Sea. However, findings from the 1970 *Arrow* and 1988 *Nestucca* spills of Bunker C oils are in many respects even more relevant, yet ignored by the Trans Mountain ERA.

15. The Trans Mountain ERA obscures the magnitude of shoreline oiling impacts estimated by the oil spill models used. While model-based estimates of total oiled shoreline lengths are presented, comparable estimates for specific shoreline types are not. Instead, these modeled impacts for specific shoreline types are presented in terms of proportions of comparable shoreline types within the regional study area (RSA), and in terms of "...maximum spatial extent of affected shorelines with a high to very high probability of oiling...". Whereas the missing estimates of the total length of oiled shoreline for each shoreline type has a direct bearing on likely oil persistence and remediation costs, the provided estimates expressed as proportions of the RSA depend on the somewhat arbitrary choice of the size of the RSA, are confounded with probability of oiling, and hence furnish only indirect guidance on oil persistence and remediation costs for specific shoreline types. These details are crucial because oil persistence and remediation costs vary greatly depending on shoreline type.

16. The Trans Mountain ERA makes overly simplistic assumptions regarding oil retention on shorelines that lead to overly optimistic speculation regarding

recovery. In the Summary of Potential Ecological Effects and Recovery (section 5.6.2.5), the application states that:

"Very little of the potentially affected shoreline habitat is of a type that would tend to sequester spilled oil (e.g., deep gravel or cobble-boulder substrates that are not underlain by fine substrates that will remain saturated at low tide)."

This statement is inaccurate, because oil may be retained for years to decades or more on other shoreline types including saltwater marshes and mudflats. Moreover, this statement presumes that even on cobble/boulder substrates that are underlain by fine substrates, the finer substrates will remain saturated at low tide, which is another over-simplification. Expectations regarding the rate of shoreline recovery in the Trans Mountain ERA are also speculative and optimistic. The Summary of Potential Ecological Effects and Recovery (section 5.6.2.5) also states that:

"...it is expected that shoreline clean-up and assessment techniques (SCAT) would be applied to the spilled oil that reached the shore, and that most of this oil would be recovered."

Experience with other major oil spills indicates otherwise. For example, following the 1989 *Exxon Valdez* oil spill, only about 15% of the oil that stranded on beaches was recovered by these techniques, despite intensive effort and great expense (>US$ 1 billion) over more than two years.

17. The Trans Mountain ERA summary of ecological effects claims further that:

"Biological recovery from spilled oil, where shoreline communities were contacted by and harmed by the oil or by subsequent clean-up efforts, would be expected to lead to recovery of the affected habitat within two to five years. By comparison, whether cleaned or not, intertidal communities had recovered within five years after the EVOS."

This conclusion is contradicted by the Trans Mountain application itself in Table 5.6.2.1 of section 5.6.2.1, where intertidal communities are listed as "recovering" (but not as "recovered") on the basis of the 2010 Recovery Status from the Exxon Valdez Oil Spill Trustee Council. Furthermore, the Trans Mountain ERA does not provide a clear definition of what is meant by "recovery", without which statements regarding recovery status or prospects are vague and possibly meaningless.

18. Finally, the Trans Mountain ERA fails to provide quantitative estimates of injuries to ecological receptors even when there is a straightforward basis for doing so. The most obvious example is mortality estimates for seabirds,

for which estimates derived from the 1988 *Nestucca* spill are especially relevant.

## 2.3 Lessons from the 1970 *Arrow* and the 1988 *Nestucca* Oil Spills

19. Results from environmental assessments of ecological injury inflicted by the 1970 *Arrow* and the 1988 *Nestucca* oil spills provide especially relevant guidance for anticipating effects from a major spill of diluted bitumen along the tanker transport route in the Salish Sea. Both spills involved Bunker C (i.e. #6) fuel oil, a heavy refined oil that is similar in many important respects to bitumen extracted from the Alberta oil sands. The *Arrow* spill involved discharge of about 10,000 $m^3$ of oil into Chedabucto Bay, Nova Scotia, and the long-term effects of the spill have been documented over decades following the incident. The *Nestucca* spill involved discharge of about 875 $m^3$ of oil off Gray's Harbour, Washington, and led to substantial oiling of Canadian shorelines on Vancouver Island. The *Arrow* spill is thus directly relevant to the long-term effects of a heavy oil spilled into temperate waters, while the much smaller *Nestucca* spill is directly relevant to the Strait of Juan de Fuca.

20. The physical properties and chemical composition of bitumen mined from the Alberta oil sands are closely comparable with those of Bunker C oils. Alberta oil sands bitumen *in situ* is essentially a highly weathered crude oil, having lost the volatile components to evaporation and the most readily biodegradable components to microbial decomposition over geologic time spans. Consequently Bunker C oils may serve as a close proxy for Alberta oil sands bitumen.

21. The *Arrow* spill released Bunker C oil about 6.5 km from shore, oiling more than 305 km of shoreline to varying degrees, with only about 48 km treated or cleaned during the spill response effort. The spill occurred during winter at a comparable latitude (45° N) as the southern Strait of Georgia (~48° N). Although the high-viscosity Bunker C oil released during the *Arrow* spill could not have penetrated into any but the coarsest sediments (i.e. gravel to boulder) along shorelines, pockets of oil remained on impacted beaches for more than 22 years after the incident. These results strongly imply that even superficial surface oiling from a credible worst-case (i.e. 16,000 $m^3$) spill of diluted bitumen near the Gulf Islands or the Strait of Juan de Fuca might result in lingering contamination on a decadal time scale.

22. The *Nestucca* spill released about 875 $m^3$ of Bunker C oil near Grays Harbour, Washington, about 175 km south of the Canadian border, in December 1988. Perhaps 50 – 100 $m^3$ of this oil was transported by the Davidson Current northward and eventually oiled shorelines along the west coast of Vancouver Island, as far north as Goose Island, BC, nearly 600 km from the spill origin. The near neutral buoyancy of the oil resulted in it submerging, which made

the oil much more difficult to track, because submerged oil is much less visible from above the sea surface. Some of the oil eventually sank to the seafloor, exposing benthic organisms to oil contamination.

23. Based on recovery of oiled seabird carcasses, the *Nestucca* spill killed more than 12,000 seabirds, and the estimated total seabird mortality was 56,000. The large estimated seabird mortality in comparison to the relatively modest spill size is likely the result of the oil slick sweeping across a large swath of sea surface as the oil moved north.

24. The *Nestucca* spill killed at least one sea otter (*Enhydra lutris*), and probably oiled 8 harbour seals (*Phoca vitulina*), 18 sea lions (*Eumetopias jubatus*) and 2 elephant seals (*Mirounga angustirostris*). The oiling may have killed at least one of the harbour seals.

25. At least at three locations, oil from the *Nestucca* spill sank and contaminated Dungeness crabs (*Cancer magister*). Contamination of other organisms dwelling on the seafloor at these locations is all but certain.

26. *Nestucca* oiling resulted in mortality to intertidal rockweed (*Fucus sp.*), which provides cover for numerous other intertidal organisms. At one location the oil caused extensive contamination of a salt marsh habitat, which is one of the most productive and sensitive marine habitat types in the region. Oil can persist in salt marshes for decades, and can contaminate a host of resident and migratory species including shorebirds and terrestrial mammals that utilize these habitats. Also, the *Nestucca* spill oiled at least one spawning site for Pacific herring (*Clupea pallasi*). Herring did not spawn at this site after it was oiled for the first time in many years, although it is not clear whether this was related to the oil contamination.

## 2.4 Fate and Effects of an Oil Spill in the Gulf Islands and Strait of Juan de Fuca

27. A credible worst-case spill of 16,000 $m^3$ of diluted bitumen would almost certainly lead to all of the oil contamination effects noted after the *Nestucca* spill, but would be more intensive, more extensive, affect more species and habitats and would last much longer. A spill would likely cause heavy shoreline oiling on tens of kilometers of beaches, and less severe but still substantial oiling on hundreds of kilometers. Entrainment into the Davidson Current would transport diluted bitumen along the west coast of Vancouver Island northward and beyond to the Queen Charlotte Islands and southern southeast Alaska, depositing oil intermittently on shorelines *en route*. The higher sea states typical of the more exposed waters along the Strait of Juan de Fuca and the west coast of Vancouver Island would promote entrainment of diluted bitumen into the water column, making the oil difficult to track. The resulting uncertainty of shoreline oil deposition would likely never be

fully resolved owing to the expense involved in surveying the thousands of kilometers of potentially oiled shorelines.

28. In comparison with the 56,000 seabirds estimated to have died from the Bunker C slick generated by the 875 $m^3$ discharged during the *Nestucca* spill, a large discharge of diluted bitumen could kill seabirds in the hundreds of thousands no matter where the spill origin is located within the Salish Sea.

29. A large diluted bitumen spill anywhere along the tanker route through the Gulf Islands and the Strait of Juan de Fuca would almost certainly kill substantial numbers of marine mammals, especially harbour seals and harbour porpoises because of their relative abundance in the Salish Sea. Exposure of individual killer whales, however, could have adverse population-level consequences for this already endangered stock, where premature loss of just one individual could significantly contribute to the jeopardy of this stock.

30. Spilled diluted bitumen can affect intertidal biota through three different modes of exposure: physical smothering, ingestion of dispersed oil droplets, and absorption of toxic compounds dissolved from oil into the water column. Absorption of toxic compounds dissolved from oil into the water column can cause death from narcosis, embryotoxicity to early life stages of fish, and photo-enhanced toxicity to translucent organisms. Accumulation of oil-derived compounds by organisms can taint tissues at very low concentrations (parts per trillion or less), rendering plants and animals collected during subsistence harvests unpalatable.

31. Early life stages of fish, especially of fish that spawn and pass through their initial developmental stages in the intertidal, are also vulnerable to embryotoxicity. Embryotoxicity involves disruption of the normal sequence of embryological development after egg fertilization, and is caused by polycyclic aromatic hydrocarbons (PAC). Fish embryos are most vulnerable immediately after hatching, and the threshold for onset of these effects is in the mid-parts per trillion (i.e., ng/L).

32. Translucent organisms are vulnerable to photo-enhanced toxicity. Photo-enhanced toxicity occurs when organisms accumulate certain PAC in their tissues and are then exposed to direct sunlight. Certain PAC, when incorporated within translucent cells, can channel the energy in the ultraviolet (UV) component of sunlight into molecular oxygen. These "hot" oxygen molecules can then oxidize proteins, DNA, and other subcellular components, thereby causing extensive damage within cells.

33. The sediment structure of armoured beaches is especially conducive to trapping and retaining diluted bitumen and other spilled petroleum

products. The finer-grained sediments beneath the armour layer usually provide habitat for often rich and diverse communities of infauna, which include burrowing clams (many of which are harvested for subsistence, such as butter, littleneck, razor, horse and softshelled clams, and geoducks), marine worms, and small crabs. This shoreline type is important for subsistence harvesting by First Nations peoples such as the Pacheedaht who inhabit the Strait of Juan de Fuca, where armoured beaches account for about 14% of the shoreline and would retain oil for prolonged periods of decades or longer.

34. The persistence of spilled oil products on sand or mudflat beaches is typically low because the sediment particle sizes are small enough that wave action can churn the upper sediment layer. Depending on the degree of exposure to wave action, oil may be largely removed from sand or gravel beaches within 2–3 years. Although the surfaces of mudflats may be inhabited by relatively low densities of mussels, clams, snails, and algal films, most of the animal biomass lives beneath the surface in burrows. These burrows provide conduits for oil penetration deeper beneath the surface of these beaches. This habitat can be deceptively productive, and may be especially important as foraging habitat for resident and migratory shorebirds that feed on surface algal films or prey on inhabitants of the subsurface animal community.

35. The dense vegetation characteristic of saltwater marshes in the upper intertidal provides another matrix that can trap diluted bitumen for prolonged periods. Spilled diluted bitumen driven ashore by wind into these marshes could associate with the vegetative matrix, both alive and dead. So could oil from a pipeline rupture that discharges diluted bitumen into the Fraser River upstream of the Fraser River estuary. Decaying vegetative mats often have high biological oxygen demands that lead to hypoxic conditions near the interface of the vegetation and the underlying soils. Diluted bitumen that percolates downward into hypoxic zones can persist for years to decades as a result of the slow rate of microbial degradation which occurs there. This shoreline type is also especially important for subsistence harvesting by First Nations peoples such as the Pacheedaht who inhabit the Strait of Juan de Fuca, where estuary, marsh or lagoon shorelines account for about 17% of the shoreline and would retain oil for prolonged periods of decades or longer.

36. Because of the susceptibility of diluted bitumen to submerge or sink, tracking the oil to shorelines would be especially problematic, creating persistent uncertainty regarding the extent and duration of oil contamination on shorelines. If oil penetrates beneath the surface of beaches, especially at undocumented locations as is very likely should a large spill occur along the

tanker route through the Gulf Islands or the Strait of Juan de Fuca, persistent retention of the oil may lead to unanticipated encounters by the public over the course of decades. Such encounters degrade tourism values, especially in national parks such as the Gulf Islands and Pacific Rim National Parks, and threaten subsistence harvest traditions of First Nation peoples, who may feel justifiably uncomfortable consuming plants and animals collected from shorelines where oil contamination persists.

37. The susceptibility of diluted bitumen to sink could temporarily suspend harvests of species such as Dungeness crabs, halibut, other groundfish and other species that support commercial and subsistence harvests. Seafloor oiling may further jeopardize subsistence harvests and commercial markets over longer terms if public perceptions and concerns regarding contamination become entrenched and widespread.

38. Fish, gelatinous zooplankton and other suspension feeding organisms are especially likely to accumulate submerged diluted bitumen droplets, leading to adverse effects on these organisms directly, or to their predators if they ingest these oil-contaminated organisms as prey. Although the direct effects of ingested oil on these organisms are poorly understood, they serve as important prey for some fish species including pink salmon.

39. Submerged diluted bitumen that is naturally dispersed in the upper water column presents a contamination hazard to fish, especially salmon, that are important for subsistence and commercial fishery harvests. In addition to ingestion of submerged diluted bitumen droplets by out-migrating juvenile salmon from the Fraser River or released from salmon hatcheries in Burrard Inlet during spring, diluted bitumen may be ingested by adult and sub-adult life stages of salmon. Adult and sub-adult sockeye salmon are suspension feeders that filter small particulate matter such as phytoplankton and zooplankton from the water column, and would ingest small droplets of diluted bitumen that fall within their filtration size range. Pink and chum salmon ingest gelatinous zooplankton, which provide a means for tainting if their prey is contaminated by oil.

## 2.5 Considerations Regarding Potential Use of Oil Spill Dispersants

40. Although oil spill dispersants are routinely considered as a response method for ordinary oil spills, dispersants are especially unsuitable for diluted bitumen spills and should not be considered as viable response options under any circumstances. The time window for even marginally successful application of dispersant to a surface slick of diluted bitumen would be on the order of about an hour or two after release of the diluted bitumen to receiving waters. It is thus highly unlikely that dispersant could be mobilized, transported and applied rapidly enough to be even marginally effective

during a real spill. Because of the very low likelihood that diluted bitumen would be successfully dispersed under field conditions anywhere along the tanker route in Canadian waters, permission for dispersant use as a countermeasure should be categorically denied for spills involving diluted bitumen.

41. Despite the demonstrated inadequacy of dispersants as a response countermeasure for surface slicks of diluted bitumen spills, dispersants or related products are sometimes promoted for use as shoreline cleaning agents. However, use of these products has not been shown to result in anything more than cosmetic reduction of surface oiling on treated shorelines at best, and their application may inflict additional harm to biota inhabiting these shorelines. Consequently, use of dispersant or other products as shoreline oil cleaning agents should be permitted only if their use is clearly demonstrated to be effective, and not unacceptably harmful to the plants and animals that inhabit the shorelines considered for treatment.

## 2.6 Lessons from the 2010 Kalamazoo Pipeline Spill

42. A pipeline rupture released an estimated 3,200 $m^3$ of diluted bitumen into the Talmadge Creek in July 2010, and flowed into the Kalamazoo River, contaminating it downstream over a length of more than 60 km. Turbulent mixing promoted evaporation of the most volatile components of the diluted bitumen, and also promoted incorporation of riparian sediments into the oil, both of which processes caused the oil to sink in the fresh water of the river. Extensive studies of fish from oiled and un-oiled locations following the discharge indicated consistently poorer health of fish inhabiting oiled habitats. Remediation involved extensive and on-going dredging to remove the sunken oil.

## 2.7 Fate and Effects of an Oil Spill in the Fraser River

43. A pipeline rupture that discharged diluted bitumen into the Fraser River would likely harm fish species that inhabit the river, especially salmonids. Outmigrating juvenile salmonids may ingest small oil droplets, and returning adults may absorb toxic PAC dissolved from the diluted bitumen through their gills, or suffer gill fouling by small oil droplets. Depending on the location and volume of diluted bitumen released, the river could transport bitumen and bitumen-contaminated sediments to marshes near the mouth of the Fraser River and to the Fraser River estuary, where a host of resident and migratory shorebirds could be exposed to oil, along with terrestrial mammals and other animals that inhabit these marshes.

## 3.0 Background on the Proposed Trans Mountain Pipeline and Port Expansion Project

44. Trans Mountain Pipeline ULC (hereafter, Trans Mountain) has applied for a Certificate of Public Convenience and Necessity to construct and operate (i) 987 km of new pipeline from Edmonton to Burnaby; (ii) an expanded petroleum storage facility in Burnaby; (iii) a new and expanded dock complex at the Westridge Marine Terminal; and (iv) two new pipelines from the storage facility to the Terminal (hereafter, Project).

45. The Project would increase pipeline transport capacity from about 47,700 $m^3$/d to 141,500 $m^3$/d (i.e., 300,000 bbl/d to 890,000 bbl/d), with a concomitant increase of Aframax-class tanker traffic from five to as many as 34 vessels per month. Three new berths for the Aframax tankers would be constructed at the Westridge Marine Terminal as well. Beginning at the Burnaby terminal, the tanker route would pass through Burrard Inlet, across the mouths of the Fraser River delta in Georgia Strait, through the Gulf Island passages and Haro Strait off the southeastern coast of Vancouver Island, and then through the Strait of Juan de Fuca, remaining in Canadian territorial waters to the North Pacific Ocean (Figure 1). Tanker traffic would remain within about 10 km of shorelines along nearly this entire route to the open ocean. Along the way, tanker traffic passes through some of the most biologically productive and ecologically important marine waters in Canada.

46. The petroleum products shipped by the Project will consist almost entirely of Alberta oil sands bitumen diluted with either gas condensate (i.e., “dilbit”) or synthetic crude oil (“synbit”). Gas condensate, sometimes referred to as “natural gasoline”, consists mostly of hydrocarbons that condense from natural gas wells at atmospheric pressure and room temperatures. Most of these gas condensate hydrocarbons range from pentane ($C_5H_{12}$) through dodecane ($C_{12}H_{26}$). Synthetic crude oil is produced by refining oil-sands bitumen. Sometimes a mixture of gas condensate and synthetic crude oil is used as the diluent, denoted as “dilsynbit”. Dilution lowers the density and the viscosity of the resulting fluid so that it can be shipped through pipelines.

47. If the Project is approved, the increased shipment of diluted bitumen through the expanded pipeline and by tankers brings increased risk of oil spills. Spills may occur because of leaks or ruptures of pipelines or storage tanks, during transfer to tankers at the Westridge Marine Terminal, or during transit of loaded tankers through Burrard Inlet, the Strait of Georgia and the Strait of Juan de Fuca.

## 4.0 Structure of this Report

48. In this report, I evaluate the fate and effects of a pipeline rupture upstream of the Fraser River delta, and of a marine oil spill along the tanker route through the Gulf Islands or in the Strait of Juan de Fuca, including likely effects of dispersant application. I have considered the fate and effects of a marine oil spill in Burrard Inlet or the Strait of Georgia near the Fraser River estuary in a separate report.[1]

49. My report begins with a critique of the Trans Mountain ecological risk assessment (ERA), followed by a summary of the effects of the 1988 Nestucca oil spill on coastal British Columbia. These sections are followed by independent assessment of the fate and effects of a major oil spill from the Project along the tanker route through the Gulf Islands and the Strait of Juan de Fuca. Finally, I assess the likely utility of dispersant application to diluted bitumen spills and to shorelines contaminated by diluted bitumen, and the likely behaviour and effects of oil released into the Fraser River from a pipeline rupture, informed by the 2010 Enbridge pipeline spill of diluted bitumen into the Kalamazoo River in Michigan, USA.

[1] Short JW (2015) Fate and effect of oil spills from the Trans Mountain expansion project in Burrard Inlet and the Fraser River estuary. JWS Consulting LLC, 19315 Glacier Highway, Juneau, Alaska 99801 USA


**Figure 1.** Salish Sea, including Burrard Inlet, the Westridge Marine Terminal, Sturgeon Bank, South Arm marshes, Robert's Bank, Boundary Bay, the tanker route, Haro Strait, and the oil spill origin locations selected for the oil spill trajectory models presented in the Trans Mountain ERA.

## 5.0 Critique of the Trans Mountain Environmental Risk Assessment

50. In my prior report on the fate and effects of a marine oil spill in Burrard Inlet or the Strait of Georgia near the Fraser River estuary,[2] I noted four fundamental deficiencies of the Trans Mountain environmental risk assessment (ERA):

(a) it fails to integrate oil exposure risk based on multiple locations within ecologically distinct sub-regions along the marine shipping routes, including at or near ecologically-sensitive areas;

(b) it fails to assess hazard independently of exposure. Trans Mountain concludes that hazard is minimal whenever their estimate of oiling probability is low. However, Trans Mountain should have assessed hazard based on species sensitivity to oiling independently of oiling probability;

(c) it fails to assess the possibility of organisms being exposed to submerged oil; and

(d) it fails to consider all the ways that oil can harm organisms.

My comments on these deficiencies apply equally to the portions of the Trans Mountain ERA that pertain specifically to ecological receptors within or near the Gulf Islands, the Strait of Juan de Fuca or the outside coast of Vancouver Island.

51. In addition to the deficiencies noted above, the Trans Mountain ERA relies almost exclusively on findings from the 1989 *Exxon Valdez* oil spill in Alaska as the basis for evaluating likely effects of an oil spill in the Salish Sea. However, findings from the 1970 *Arrow* and 1988 *Nestucca* spills of Bunker C oils are in many respects even more relevant, yet ignored by the Trans Mountain ERA.

52. The Trans Mountain ERA obscures the magnitude of shoreline oiling impacts estimated by the oil spill models used. While model-based estimates of total oiled shoreline lengths are presented,[3] comparable estimates for specific shoreline types are not. Instead, these modeled impacts for specific shoreline types are presented in terms of proportions of comparable shoreline types within the regional study area (RSA), and in terms of "...maximum spatial extent of affected shorelines with a high to very high

[2] *Ibid.*

[3] Trans Mountain application, Table 5.6.2.33

probability of oiling...".[4] Whereas the missing estimates of the total length of oiled shoreline for each shoreline type has a direct bearing on likely oil persistence and remediation costs, the provided estimates expressed as proportions of the RSA depend on the somewhat arbitrary choice of the size of the RSA, are confounded with probability of oiling, and hence furnish only indirect guidance on oil persistence and remediation costs for specific shoreline types. These details are crucial because oil persistence and remediation costs vary greatly depending on shoreline type. For example, on bedrock shorelines oil persistence is relatively low and natural remediation is relatively rapid in comparison with armoured beaches underlain by finer-grained sediments, but the total lengths of these two shoreline types is not clear in the application.

53. The Trans Mountain ERA makes overly simplistic assumptions regarding oil retention on shorelines that lead to overly optimistic speculation regarding recovery. In the Summary of Potential Ecological Effects and Recovery (section 5.6.2.5), the application states that:

"Very little of the potentially affected shoreline habitat is of a type that would tend to sequester spilled oil (e.g., deep gravel or cobble-boulder substrates that are not underlain by fine substrates that will remain saturated at low tide)."

This statement is inaccurate, because oil may be retained for years to decades or more on other shoreline types including saltwater marshes and mudflats. Moreover, this statement presumes that even on cobble/boulder substrates that are underlain by fine substrates, the finer substrates will remain saturated at low tide, which is another over-simplification. Finer sediments located beneath a cobble or boulder surface layer are precisely the conditions that can lead to long-term retention of oil on shorelines. While saturation with water would prevent oil penetration into these sediments, water saturation through the low-tide exposure period depends on the gradient of the shoreline and the hydraulic conductivity of the sediments. Moreover, finer sediments beneath a cobble or boulder surface layer are typically riddled with channels created by intertidal clams, worms and other inhabitants of these sediments, and these channels both increase the hydraulic conductivity of the sediments and hence promote their dehydration during low tide exposure, and provide pathways for oil stranded on the surface of these shorelines to penetrate into the deeper sediments. The Trans Mountain application provides no evidence that all or even most of the cobble or boulder shorelines underlain by finer sediments have such low

[4] *Ibid.*, section 5.6.2.5

hydraulic conductivities that dehydration and oil penetration are precluded during low tides in the field.

54. Expectations regarding the rate of shoreline recovery in the Trans Mountain ERA are also speculative and optimistic. The Summary of Potential Ecological Effects and Recovery (section 5.6.2.5) states that:

"...it is expected that shoreline clean-up and assessment techniques (SCAT) would be applied to the spilled oil that reached the shore, and that most of this oil would be recovered."

Experience with major oil spills indicates otherwise. For example, following the 1989 *Exxon Valdez* oil spill, only about 15% of the oil that stranded on beaches was recovered by these techniques, despite intensive effort and great expense (>US$ 1 billion) over more than two years.[5]

55. The Trans Mountain ERA summary of ecological effects claims further that:

"Biological recovery from spilled oil, where shoreline communities were contacted by and harmed by the oil or by subsequent clean-up efforts, would be expected to lead to recovery of the affected habitat within two to five years. By comparison, whether cleaned or not, intertidal communities had recovered within five years after the EVOS."

This conclusion is contradicted by the Trans Mountain application itself in Table 5.6.2.1 of section 5.6.2.1, where intertidal communities are listed as "recovering" (but not as "recovered") on the basis of the 2010 Recovery Status from the Exxon Valdez Oil Spill Trustee Council. Furthermore, the Trans Mountain ERA does not provide a clear definition of what is meant by "recovery", without which statements regarding recovery status or prospects are vague and possibly meaningless.

56. Finally, the Trans Mountain ERA fails to provide quantitative estimates of injuries to ecological receptors even when there is a straightforward basis for doing so. The most obvious example is mortality estimates for seabirds, for which estimates derived from the 1988 *Nestucca* spill are especially relevant, as discussed below.

[5] Wolfe et al. (1994)

## 6.0 Lessons from the 1970 *Arrow* and the 1988 *Nestucca* Oil Spills

57. Results from environmental assessments of ecological injury inflicted by the 1970 *Arrow* and the 1988 *Nestucca* oil spills provide especially relevant guidance for anticipating effects from a major spill of diluted bitumen along the tanker transport route in the Salish Sea. Both spills involved Bunker C (i.e. #6) fuel oil, a heavy refined oil that is similar in many important respects to bitumen extracted from the Alberta oil sands. The *Arrow* spill involved discharge of about 10,000 $m^3$ of oil into Chedabucto Bay, Nova Scotia, and the long-term effects of the spill have been documented over decades following the incident. The *Nestucca* spill involved discharge of about 875 $m^3$ of oil off Grays Harbour, Washington,[6] and led to substantial oiling of Canadian shorelines on Vancouver Island. The *Arrow* spill is thus directly relevant to the long-term effects of a heavy oil spilled into temperate waters, while the much smaller *Nestucca* spill is directly relevant to the Strait of Juan de Fuca.

58. Bunker C fuel oil is a heavy, viscous refined product that consists of residuum remaining after removal of volatile petroleum components by distillation. The petroleum components lost through distillation generally correspond to components lost by weathering processes acting on spilled crude oil. Most components of petroleum that have boiling points below about 300 °C are lost from Bunker C oils,[7] corresponding to losses of normal alkanes containing less than 16 carbon atoms (i.e. hexadecane, $C_{16}H_{34}$) and of aromatic hydrocarbons containing one or two rings (i.e. benzene, toluene, ethylbenzene and xylene or BTEX compounds, and naphthalenes including naphthalene containing up to four alkyl carbon atoms; see Fig. 2). Removal of the volatile compounds from Bunker C oils increases their density to 940 – 1,040 kg/$m^3$, and viscosity to 10,000 – 50,000 mPa-s (at 15°C; from Table 5.4.3 in the Trans Mountain application). The higher-density Bunker C oils are thus prone to submergence in water as their densities approach or exceed the density of fresh water (1,000 kg/$m^3$).

59. The physical properties and chemical composition of bitumen mined from the Alberta oil sands are closely comparable with those of Bunker C oils. Alberta oil sands bitumen *in situ* is essentially a highly weathered crude oil, having lost the volatile components to evaporation and the most readily biodegradable components to microbial decomposition over geologic time

[6] Duval W, Hopkinson S, Olmsted R, Kashino R (1989) The Nestucca oil spill: Preliminary evaluation of impacts on the west coast of Vancouver Island. ESL Environmental Sciences Ltd, Vancouver, B.C.

[7] Environment Canada, 2006. Oil Properties Database. www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html.

spans.[8] As with Bunker C oils, most (> ~85%) of the components of Alberta oil sands bitumen have boiling points above 300 °C,[9] and consequently have viscosities of 100,000 or more,[10] and densities that may reach 1,041 kg/m$^3$, which is sufficiently great to sink in full-strength seawater (density ≈ 1,025 kg/m$^3$). While concentrations of total polycyclic aromatic compounds (PAC) is typically less in Alberta oil sands bitumen than in Bunker C oils, this is mainly because of greater concentrations of 2-ring naphthalenes in Bunker C oils (Fig. 2). Concentrations of 3-ring PAC are more comparable in Alberta oil sands bitumen and Bunker C oils (Fig. 2). Consequently Bunker C oils may serve as a close proxy for Alberta oil sands bitumen.

[8] National Energy Board (2000) Canada's oil sands: A supply and market outlook to 2015. National Energy Board, Calgary, AB.

[9] Environment Canada, 2006. Oil Properties Database. www.etc-cte.ec.gc.ca/databases/OilProperties/oil_prop_e.html; Yang C, Wang Z, Yang Z, Hollebone B, Brown CE, Landriault M, Fieldhouse B (2011) Chemical fingerprints of Alberta oil sands and related petroleum products. Environmental Forensics 12:173-188.

[10] Meyer RF, Attanasi E (2004) Natural bitumen and extra-heavy oil. Ch. 4 in 2004 Survey of Energy Resources, World Energy Council, Elsevier.

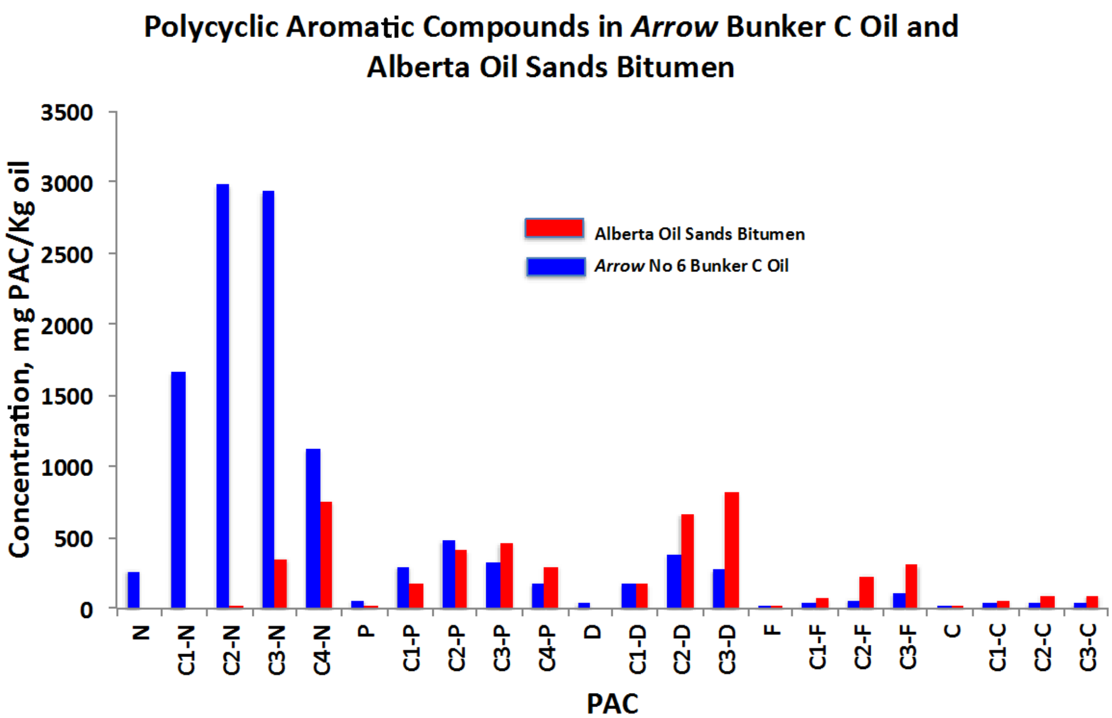


Figure 2. Concentrations of the most abundant polycyclic aromatic compounds (PAC) in Bunker C oil from the T/V *Arrow* (blue bars)[11] and in bitumen from the Alberta oil sands (red bars)[12]. The letter suffixes on the horizontal axis denote naphthalenes (N), phenanthrenes & anthracenes (P), dibenzothiophenes (D) and chrysenes (C). The prefixes "CX-" (X = 1,2,3, or 4) denote the number of alkyl carbon atoms of alkane substituents on the PAC (e.g. "C1-" = methyl, "C2-" = ethyl or two methyl's, "C3-" = propyl, isopropyl or methyl + ethyl, etc.)

60. As noted above,[13] the products that would be shipped over the life of the Project include bitumen diluted with gas condensate or by synthetic crude oil to meet the viscosity required for transport through the Project pipelines.

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[11] Concentrations estimated from Figure 3A in Wang Z, Fingas M and Sergy G (1994) Study of 22-year-old Arrow oil samples using biomarker compounds by GC/MS. Environmental Science and Technology 28:1733-1746

[12] Concentrations for sample AOS #2 in table 2 of Yang C, Wang Z, Yang Z, Hollebone B, Brown CE, Landriault M, Fieldhouse B (2011) Chemical fingerprints of Alberta oil sands and related petroleum products. Environmental Forensics 12:173-188

[13] See paragraph 46

Dilution of the bitumen alters its initial behaviour if spilled into receiving waters in comparison with a Bunker C oil spill. Compared with Bunker C oil, the relatively low (<350 mPa-s) viscosity of the diluted bitumen would allow it to spread much more quickly to form a thin (~0.4 mm thick) slick,[14] while the lower density (~940 kg/m$^3$) would insure that the diluted bitumen would remain afloat initially. However, careful comparison of evaporation rates of diluted bitumen measured in laboratory experiments with results from an experimental oil spill in the field suggest that nearly all of the low-density gas condensate diluent would volatilize within about a day following discharge.[15] Once most of the diluent is lost, the remaining bitumen may become susceptible to submergence or sinking, and more generally its behaviour in the environment would become very similar to that of Bunker C oil.

61. The *Arrow* spill released about 10,000 m$^3$ of Bunker C oil about 6.5 km from shore, oiling more than 305 km of shoreline to varying degrees, with only about 48 km treated or cleaned during the spill response effort.[16] The spill occurred during winter at a comparable latitude (45° N) as the southern Strait of Georgia (~48° N). The extent of shoreline oiling in comparison with the amount of oil spilled is broadly consistent with the modeling results presented in the Trans Mountain application,[17] suggesting that the modeling results are generally reasonable as estimates of likely oiled shoreline extent. Although the high-viscosity Bunker C oil released during the *Arrow* spill could not have penetrated into any but the coarsest sediments (i.e. gravel to boulder) along shorelines, pockets of oil remained on impacted beaches for more than 22 years after the incident.[18] However, most of the oil-affected shorelines self-cleaned after 22 years, with only a few localized exceptions.[19] These results strongly imply that even superficial surface oiling from a credible worst-case (i.e. 16,000 m$^3$) spill of diluted bitumen near the Gulf Islands or the Strait of Juan de Fuca might result in lingering contamination on a decadal time scale. Moreover, more persistent oiling would likely result from a spill of diluted bitumen because the initial viscosity of the diluted bitumen would be much lower than the Bunker C oil released during the

[14] Stronach J, Hospital A (2013) Technical memo to Trans Mountain dated 4 July 2013 re: Spreading of Diluted Bitumen.

[15] Short (2015)

[16] Wang Z, Fingas M, Sergy G (1994) Study of 22-year-old Arro oil samples using biomarker compounds by GC/MS. Environmental Science and Technology 28:1733-1746.

[17] See Trans Mountain application section 5.4.4.7

[18] Wang (1994)

[19] *Ibid.*

*Arrow* spill, so diluted bitumen would more readily penetrate into porous shorelines.

62. The *Nestucca* spill released about 875 $m^3$ of Bunker C oil near Grays Harbour, Washington, about 175 km south of the Canadian border, in December 1988.[20] Perhaps 50 – 100 $m^3$ of this oil was transported by the Davidson Current northward and eventually oiled shorelines along the west coast of Vancouver Island, as well as several locations along both Canadian and United States shorelines within the Strait of Juan de Fuca, after spending 1 – 3 weeks at sea.[21] Oil from the *Nestucca* spill was confirmed as far north as Goose Island, BC, nearly 600 km from the spill origin. The density of one sample of floating oil was measured as 1,018.6 $kg/m^3$, only slightly less dense than the seawater collected with it (1,022.9 $kg/m^3$ at 5°C, implying a surface seawater salinity of 29‰).[22] The near neutral buoyancy of the oil with respect to the underlying seawater allowed ready entrainment of oil beneath the sea surface under breaking wave conditions, and association of the oil with even small quantities of inorganic suspended solids allowed some of the oil to reach neutral buoyancy, resulting in it submerging. These conditions made the oil much more difficult to track, because submerged oil is much less visible from above the sea surface. Oil that contacted shorelines often acquired a burden of sediments that increased the oil-sediment density, resulting in oil that could move back to the water column beneath the sea surface and hence be transported to other beaches. This resulted in persistent shoreline re-oiling that frustrated shoreline clean-up efforts.[23] Some of the oil eventually sank to the seafloor, exposing benthic organisms to oil contamination.[24]

63. Based on recovery of oiled seabird carcasses, the *Nestucca* spill killed more than 12,000 seabirds, and the estimated total seabird mortality was 56,000.[25] The large estimated seabird mortality in comparison to the relatively modest spill size is likely the result of the oil slick sweeping across a large swath of sea surface as the oil moved north.

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[20] Duval (1989)

[21] *Ibid.*; Harding LE, Englar JR (1989) The Nestucca oil spill: Fate and effects to May 31, 1989. Environmental Protection, Conservation and Protection, Environment Canada Regional Program Report 89-01.

[22] Harding (1989)

[23] Harding (1989)

[24] *Ibid.*

[25] Ford RG, Casey JL, Hewitt DB, Varoujean DH, Warrick DR, Williams WA (1991) Seabird mortality resulting from the Nestucca oil spill incident, winter 1988-89. Report for Washington Department of Wildlife. Ecological Consulting, Inc., Portland, OR

64. The *Nestucca* spill killed at least one sea otter (*Enhydra lutris*), and probably oiled 8 harbour seals (*Phoca vitulina*), 18 sea lions (*Eumetopias jubatus*) and 2 elephant seals (*Mirounga angustirostris*). The oiling may have killed at least one of the harbour seals.[26]

65. At least at three locations, oil from the *Nestucca* spill sank and contaminated Dungeness crabs (*Cancer magister*).[27] This was considered significant oiling because nearly all of the crabs recovered in traps were oiled. Crabs contaminated by *Nestucca* oil were detected at least 3 months after the spill incident.[28] Contamination of other organisms dwelling on the seafloor at these locations is all but certain. Oil adhered to eelgrass and at one location the oil-contaminated eelgrass was removed to prevent consumption by geese.[29]

66. *Nestucca* oiling resulted in mortality to intertidal rockweed (*Fucus sp.*),[30] which provides cover for numerous other intertidal organisms. At one location the oil caused extensive contamination of a salt marsh habitat, which is one of the most productive and sensitive marine habitat types in the region. Oil can persist in salt marshes for decades, and can contaminate a host of resident and migratory species including shorebirds and terrestrial mammals that utilize these habitats.

67. Oil from the *Nestucca* spill oiled at least one spawning site for Pacific herring (*Clupea pallasi*). Herring did not spawn at this site after it was oiled for the first time in many years, although it is not clear whether this was related to the oil contamination.[31]

## 7.0 Fate and Effects of an Oil Spill in the Gulf Islands and Strait of Juan de Fuca

68. A credible worst-case spill of 16,000 $m^3$ of diluted bitumen would almost certainly lead to all of the oil contamination effects noted after the *Nestucca* spill, but would be more intensive, more extensive, affect more species and habitats and would last longer. A spill in the Canadian waters of the Strait of

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[26] Duval (1989); Harding (1989)

[27] *Ibid.*

[28] *Ibid.*

[29] Duval (1989)

[30] Duval (1989); Harding (1989)

[31] Duval (1989)

Juan de Fuca would likely cause heavy shoreline oiling on tens of kilometers of beaches, and less severe but still substantial oiling on hundreds of kilometers. Entrainment into the Davidson Current would transport diluted bitumen along the west coast of Vancouver Island northward and beyond to the Queen Charlotte Islands and southern southeast Alaska,[32] depositing oil intermittently on shorelines *en route*. The higher sea states typical of the more exposed waters along the Strait of Juan de Fuca and the west coast of Vancouver Island would promote entrainment of diluted bitumen into the water column, making the oil difficult to track. The resulting uncertainty of shoreline oil deposition would likely never be fully resolved owing to the expense involved in surveying the thousands of kilometers of potentially oiled shorelines.

69. In comparison with the 56,000 seabirds estimated to have died from the Bunker C slick generated by the 875 $m^3$ discharged during the *Nestucca* spill,[33] a large (8,000–16,000 $m^3$) discharge of diluted bitumen could kill seabirds in the hundreds of thousands no matter where the spill origin is located within the Salish Sea.

70. Like seabirds, marine mammals spend part of their lives in contact with the sea surface, making them vulnerable to direct contact with oil. Marine mammals are especially vulnerable to narcosis following inhalation of hydrocarbon vapours, and narcosis may lead to drowning.[34] Marine mammals are vulnerable to adverse effects from ingestion of oil, through ingestion of oiled prey or through preening of oiled fur. Exposure to oil may also irritate the eyes and skin of marine mammals. Unlike other marine mammals, sea otters rely on their fur instead of a layer of blubber for their insulation, so contact with oil reduces their ability to conserve heat.

71. Oil spills are capable of causing extensive mortalities of marine mammals when present in large numbers. For example, the 1989 *Exxon Valdez* oil spill killed an estimated 300 harbour seals (or ~13% of the resident population)[35]

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[32] Thomson (1991)

[33] Ford RG, Casey JL, Hewitt DB, Varoujean DH, Warrick DR, Williams WA (1991) Seabird mortality resulting from the Nestucca oil spill incident, winter 1988-89. Report for Washington Department of Wildlife. Ecological Consulting, Inc., Portland, OR

[34] Engelhardt FR (1987) Assessment of the vulnerability of marine mammals to oil pollution. Pp 101-115 *in* J Kiuper and WJ Van Den Brink (eds.), Fate and Effects of Oil in Marine Ecosystems. Martinus Nijhoff Publishing, Boston, Massachusetts.

[35] Frost KJ, Lowry LF, Sinclair EH, Ver Hoef J, McAllister DC (1994) Impacts on distribution, abundance and productivity of harbor seals. Pages 331-358 *in* TR Loughlin (ed.), Marine Mammals and the *Exxon Valdez*. Academic Press, New York.

and 2,800 sea otters (~28%).[36] Two pods of killer whales that were observed to come into contact with floating oil from the *Exxon Valdez* spill had unprecedented mortalities within the next year, and one of the pods has yet to recover.[37]

72. In the Salish Sea, there are 29 species of marine mammals that are both highly dependent on intertidal or marine habitat as well as on marine derived food. The most abundant of these species include harbour seals, river otters, harbour porpoise, and Dall's porpoise.[38] Less abundant, occasional or rare species include Northern fur seal; Steller's and California sea lions; Northern elephant seal; Minke, Bryde's, Grey, Fin, Short-finned pilot, Northern Right, Pygmy sperm, Killer, False-killer and four species of beaked whales; and Long-beaked, Short-beaked, Risso's and Pacific white-sided dolphins and sea otters.

73. Based on stock assessments conducted for the waters within the United States, harbour seals are perhaps the most abundant marine mammal in the Salish Sea. The stock assessments suggest that comparable numbers (~10,000) of harbour seals may inhabit Canadian waters in the Georgia Strait.[39] The Harbour porpoise population of the inside waters of southern British Columbia and the State of Washington is around 10,000, with perhaps half that number in southern British Columbia.[40] Except for killer whales, population estimates for the other species are either unavailable or are not specific to the Salish Sea.[41]

74. The population of the southern resident stock of killer whales that mainly inhabit the Salish Sea and Puget Sound was estimated at 87 individuals in 2007, and the stock is listed as endangered under the U.S. Endangered

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[36] Garrott RA, Eberhardt LL, Burn DM (1993) Mortality of sea otters in Prince William Sound following the *Exxon Valdez* oil spill. Marine Mammal Science 9:343-359.

[37] Matkin CO, Saulitis EL, Ellis GM, Olesiuk P, Rice SD (2008) Ongoing population-level impacts on killer whales Orcinus orca following the '*Exxon Valdez*' oil spill in Prince William Sound, Alaska. Marine Ecology Progress Series 356:269-281.

[38] Gaydos 2011.

[39] Carretta JV, Forney KA, Lowry MS, Barlow J, Baker J, Johnston D, Hanson B, Muto MM, Lynch D, Carswell L (2009) U.S. Pacific marine mammal stock assessments: 2008. NOAA Technical Memorandum NMFS # NOAA-TM-NMFS-SWFSC-434. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center.

[40] *Ibid*.

[41] *Ibid.*

Species Act and by the Canadian Species at Risk Act.[42] This population of killer whales is currently suffering from high body burdens of persistent organic pollutants such as flame retardants,[43] making them especially vulnerable to adverse effects from other contaminants such as oil pollution.

75. A large (e.g. 8,000–16,000 $m^3$) diluted bitumen spill anywhere along the tanker route through the Gulf Islands and the Strait of Juan de Fuca would almost certainly kill substantial numbers of marine mammals, especially harbour seals and harbour porpoises because of their relative abundance in the Salish Sea. Other marine mammals may also be adversely affected by diluted bitumen from a spill, although detecting adverse impacts to these species remains problematic. These marine mammals are vulnerable to direct contact with diluted bitumen floating on the sea surface, and also indirectly through ingestion of oil-contaminated fish or other prey. Exposure of individual killer whales, however, could have adverse population-level consequences for this already endangered stock, where premature loss of just one individual could significantly contribute to the jeopardy of this stock.

76. Shoreline oiling following a major oil spill would inflict serious injuries to biological communities inhabiting them in the short term, and lingering effects could persist for decades to a century on porous beaches (gravel, sand and mud) and in intertidal marshes if oil becomes associated with hypoxic sediments or accumulations of organic matter. These lingering reservoirs of oil pose long-term threats to intertidal organisms, predators that consume them, and to marsh-dwelling birds and mammals.

77. Spilled diluted bitumen can affect intertidal biota through three different modes of exposure: physical smothering, ingestion of dispersed oil droplets, and absorption of toxic compounds dissolved from oil into the water column. Physical smothering can lead to suffocation or starvation. Ingestion of oil droplets by intertidal suspension-feeding organisms including clams, mussels, barnacles as well as by fish and other species can reduce growth or in severe cases cause death. Absorption of toxic compounds dissolved from oil into the water column can cause death from narcosis, embryotoxicity to early life stages of fish, and photo-enhanced toxicity to translucent organisms (which may include early life stages of fish and other organisms). Accumulation of oil-derived compounds by organisms, whether through

[42] *Ibid.*; Gaydos JK, Brown NA (2009) Species of concern within the Salish Sea marine ecosystem: changes from 2002 to 2008. Proceedings of the 2009 Puget Sound Georgia Basin Ecosystem Conference, Seattle, Washington.

[43] Krahn MM, Hanson MB, Baird RW, Boyer RH, Burrows DG, Emmons CK, J. Ford KB, Jones LL, Noren DP, Ross PS, Schorr GS, Collier TK (2007) Persistent organic pollutants and stable isotopes in biopsy samples (2004/2006) from Southern Resident killer whales. Marine Pollution Bulletin 54:1903–1911.

physical contact, ingestion of oil or absorption of compounds that dissolve into the water column can taint tissues at very low concentrations (parts per trillion or less), rendering plants and animals collected during subsistence harvests unpalatable. Effects from these modes of exposure and toxic action depend on when, where and how diluted bitumen impinges on shorelines, the type of shoreline oiled, and the biota inhabiting the shoreline.

78. Bedrock and other hardened shorelines provide space for diverse biological communities. Since both diluted bitumen and biota are limited to the surface of hardened substrates, diluted bitumen penetration and effects on animals and plants are limited to the substrate surface. By the time diluted bitumen impinges on shorelines, its viscosity and adhesion are likely much greater than after initial discharge to receiving waters, making the diluted bitumen very likely to adhere to rock and concrete, and to the plant and animal communities there. Some plants such as rockweeds (*Fucus sp.*) and shellfish such as bay mussels (*Mytilus trossulus*) can form dense, interconnected assemblages that provide cover and surface area for numerous other species such as marine snails and worms. These 3-dimensional structural networks also act as a kind of "sponge" for diluted bitumen, such that viscous diluted bitumen that penetrates into these networks may be very difficult to dislodge just by tidal pumping or moderate wave action. It can persist there for weeks or months.[44]

79. If sensitive species or life stages become associated with these diluted bitumen-contaminated structural networks, the trapped diluted bitumen may provide a persistent source of contamination by slowly releasing PAC to the interstitial water of the networks, exposing eggs, larvae and other translucent species to PAC for protracted periods. This trapped oil can also pose a contact hazard for shorebirds that prey on intertidal snails, worms, and other animals that inhabit the interstices of *Fucus* and mussel beds. Moreover, shoreline remediation efforts to remove diluted bitumen trapped by these biological communities may inflict additional damage to resident plants and animals, which should be included as a toxic effect of a spill.

80. Intertidal plants and animals inhabiting bedrock or artificially hardened shorelines are vulnerable to physical smothering by oil. In extreme cases smothering may prevent respiration of plants and animals causing death. Less severe smothering may still impede or prevent feeding and movement of mobile grazers and predators such as marine snails and intertidal fish that are stranded in oiled rocky habitats such as tide pools during low tides.

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[44] Carls MG, Babcock MM, Harris PM, Irvine GV, Cusick JA, Rice SD (2001) Persistence of oiling in mussel beds after the Exxon Valdez oil spill. Marine Environmental Research 51:167–190.

81. Suspension-feeding intertidal organisms including mussels, barnacles, and many clams often inhabit rocky shorelines and can ingest small diluted bitumen droplets entrained in the water column during tidal submergence. These organisms can also absorb oil-derived compounds that dissolve into the water column. Oil compounds accumulated by these organisms can impair their growth[45] and increase their susceptibility to disease.[46] Also, the accumulated body burden of oil by these organisms can be transferred to their predators, including marine shorebirds. Accumulation of even traces of oil can taint shellfish and other biota harvested for subsistence consumption by humans, rendering them unpalatable.

82. Early life stages of fish, especially of fish that spawn and pass through their initial developmental stages in the intertidal, are also vulnerable to embryotoxicity. Embryotoxicity involves disruption of the normal sequence of embryological development after egg fertilization, and is caused by 3- and 4-ringed PAC,[47] especially alkyl-substituted PAC.[48] Fish embryos are most vulnerable immediately after hatching,[49] and the threshold for onset of these effects is in the mid-parts per trillion (i.e., ng/L).[50]

83. Translucent organisms are vulnerable to photo-enhanced toxicity. Photo-enhanced toxicity occurs when organisms accumulate certain PAC in their tissues, either by direct absorption from contaminated water or by ingestion of oil, and are then exposed to direct sunlight. Certain PAC, when incorporated within translucent cells, can channel the energy in the ultraviolet (UV) component of sunlight into molecular oxygen. This makes

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[45] Widdows J, Donkin P, Brinsley MD, Evans SV, Salkeld PN, Franklin A, Law RJ, Waldock MJ (1995) Scope for growth and contaminant levels in North Sea mussels *Mytilus edulis*. Marine Ecology Progress Series 127:131-148; Luquet P, Cravedi JP, Tulliez J, Bories G (1984) Growth reduction in trout induced by naphthenic and isoprenoid hydrocarbons (dodecycyclohexane and pristane). Ecotoxicology and Environmental Safety 8:219-226.

[46] Kennedy CJ, Farrell AP (2008) Immunological alterations in juvenile Pacific herring, Clupea pallasi, exposed to aqueous hydrocarbons derived from crude oil. Environmental Pollution 153:638–648.

[47] Incardona JP, Collier TK, Scholz NL (2004) Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. Toxicology and applied pharmacology 196:191-2005.

[48] Lin H, Morandi GD, Brown RS, Snieckus V, Tantanen T, Jorgensen KB, Hodson PV (2015) Quantitative structure-activity relationships for chronic toxicity of alkyl-chrysenes and alkyl-benz[a]anthracenes to Japanese medaka embryos (*Oryzias latipes*). Aquatic Toxicology 150:109-118.

[49] Brinkworth L, Hodson P, Tabash S, Lee P (2003) CYP1A induction and blue sac disease in early developmental stages of rainbow trout (*Oncorhynchus mykiss*) exposed to retene. Journal of Toxicology and Environmental Health, Part A 66:627-646.

[50] Ibid.; Carls MG, Marty GD, Hose JE (2002) Synthesis of the toxicological impacts of the *Exxon Valdez* oil spill on Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska, USA. Canadian Journal of Fisheries and Aquatic Sciences 59:153-172.

the oxygen much more reactive. These "hot" oxygen molecules can then oxidize proteins, DNA, and other subcellular components, thereby causing extensive damage within cells. Meanwhile the PAC that channels the UV energy usually remains unaltered, capable of channelling more energy to more oxygen molecules. This causes cells to burn from the inside out. This effect also occurs at very low PAC thresholds, on the order of one part per billion (ug/L) or less,[51] and played a major part in damaging Pacific herring eggs and larvae developing on or near oiled beaches following the *Cosco Busan* oil spill in San Francisco Bay, California.[52]

84. The sediment structure of armoured beaches is especially conducive to trapping and retaining diluted bitumen and other spilled petroleum products. Armoured beaches consist of a surface layer of cobbles to boulders that protect finer-grained sediments beneath them from erosion. Underlying sediments usually consist of an assortment of smaller grain size particles, ranging from mud-sized particles through pebbles, embedded cobbles, and boulders. Underlying sediments have relatively high hydraulic conductivity, meaning water can flow through them relatively easily. During falling tides the interstices of these sediments lose water relatively quickly, especially as the steepness of the beach increases. These conditions set the stage for trapping diluted bitumen that initially strands on the beach surface during an out-going tide, where it could remain for decades.[53]

85. Diluted bitumen coating the surface of armoured beaches would have the same effects on surface biota as it does on biota inhabiting bedrock and hardened shorelines. In addition, the finer-grained sediments beneath the armour layer usually provide habitat for often rich and diverse communities of infauna, which include burrowing clams (many of which are harvested for subsistence, such as butter, Pacific, littleneck, razor, and horse clams, and

[51] Duesterloh S, Short J, Barron MG (2002) Photoenhanced toxicity of weathered Alaska North Slope crude oil to two species of marine calanoid zooplankton. Environmental Science and Technology 36:3953-3959; Newsted JL, Geisy JP (1987) Predictive models for photoinduced acute toxicity of polycyclic aromatic hydrocarbons to *Daphnia magna*, strauss (cladocera, crustacea). Environmental Toxicology and Chemistry 6:445-461.

[52] Incardona JP, Ylitalo G, Myers M, Scholz N, Collier T, Vines C, Griffin F, Smith E, Cherr G (2011) The 2007 *Cosco Busan* oil spill: Field and laboratory assessment of toxic injury to Pacific herring embryos and larvae in the San Francisco estuary. *Cosco Busan* oil spill Final Report, September 2011. Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, Washington 98112.

[53] Li H, Boufadel MC (2009) Long-term persistence of oil from the *Exxon Valdez* spill in two-layer beaches. Nature Geoscience 3:96-99.

geoducks),[54] marine worms, and small crabs. This shoreline type is important for subsistence harvesting by First Nations peoples such as the Pacheedaht who inhabit the Strait of Juan de Fuca, where armoured beaches account for about 14% of the shoreline and would retain oil for prolonged periods of decades or longer.[55] They also shelter the larval and juvenile life stages of a host of developing animals including many fish species. Diluted bitumen sequestered in the rocky interstices in sediment layers beneath the armouring layer therefore provide a long-term source of exposure to toxic PAC that slowly dissolve from the trapped diluted bitumen. Accumulation of these dissolved compounds may cause embryotoxic effects, while ingestion of diluted bitumen may impair growth[56] and possibly cause death, and physical contact with the diluted bitumen may impair mobility.

86. The persistence of spilled oil products on sand beaches is typically low because the sediment particle sizes are small enough that wave action can churn the upper sediment layer. This churning action serves to re-expose oil sub-surface oil where abrasion can scour oil films from the sediments. As with armoured beaches, initial penetration of diluted bitumen into sand or gravel beaches depends mainly on the interaction of diluted bitumen viscosity and the hydraulic conductivity of the substrate. Depending on the degree of exposure to wave action, oil may be largely removed from sand or gravel beaches within 2–3 years.[57]

87. The lower stability of sand and gravel beaches makes them less hospitable for most intertidal dwelling organisms. These substrates may contain diverse communities of meiofauna, which are barely visible invertebrates that live within the sand and gravel and feed on micro-organisms there. Larger and more mobile burrowing predators that prey on the meiofauna and also on plankton during higher tide levels, such as clams, crabs, and worms may inhabit these substrates and can accumulate oil by ingestion or physical contact. Macroscopic plants are usually rare or absent, although surface films of algae may contribute to supporting meiofauna and other grazing animals such as worms. The resident biota is adapted to the dynamic nature of these

[54] Pacheedaht First Nation (2014) Pacheedaht First Nation traditional marine use and occupancy study (TMUOS). Pacheedaht Heritage Project, Pacheedaht First Nation Treaty Department, and Tradition Consulting Services, Inc.

[55] Beckmann L., Hammond M, Morris M (2015) Adequacy of the TMEP application for determining potential adverse effects on Pacheedaht territory and interests from shipping accidents resulting in the release of diluted bitumen. Pottinger Gaherty Environmental Consultants Ltd. #1200-1185 West Georgia Street, Vancouver, British Columbia V6E 4E6.

[56] Luquet (1984).

[57] Yim 2012.

habitats, and hence usually recovers quickly to disturbances including ephemeral oil contamination.

88. Mudflats are composed of very small sediment grain sizes, most of which typically range from less than 1 µm to 200 µm. Compared with sand or gravel beaches, these small grain sizes make for greater beach stability, with less interstitial space among the sediment grains. Although the surfaces of mudflats may be inhabited by relatively low densities of mussels, clams, snails, and algal films, most of the animal biomass lives beneath the surface in burrows. These burrows provide conduits for oil penetration deeper beneath the surface.[58] This habitat can be deceptively productive, and may be especially important as foraging habitat for resident and migratory shorebirds that feed on surface algal films or prey on inhabitants of the subsurface animal community.

89. The dense vegetation characteristic of saltwater marshes in the upper intertidal provide another matrix that can trap diluted bitumen for prolonged periods.[59] Spilled diluted bitumen driven ashore by wind into these marshes could associate with the vegetative matrix, both alive and dead. So could oil from a pipeline rupture that discharges diluted bitumen into the Fraser River upstream of the Fraser River estuary. Decaying vegetative mats often have high biological oxygen demands that lead to hypoxic conditions near the interface of the vegetation and the underlying soils. Diluted bitumen that percolates downward into hypoxic zones can persist for years to decades as a result of the slow rate of microbial degradation. As with armoured beaches, this shoreline type is important for subsistence harvesting by First Nation peoples who inhabit the Strait of Juan de Fuca, where estuary, marsh or lagoon shorelines account for about 17% of the shoreline and could retain oil for prolonged periods of decades or longer.[60]

90. Oil-contaminated salt marshes create potentially long-term sources of oil contact hazard to birds, mammals, and invertebrates that inhabit, traverse or otherwise depend on this habitat. Any contact with oil by birds or mammals can have serious and often lethal results. Marsh oiling may also deplete the insect and spider communities, reducing prey available for insectivorous birds.[61] Heavy marsh oiling may kill the marsh vegetation, exposing the

[58] Peacock 2006, Burns 1994.

[59] Yim 2012, Peacock 2006, Burns 1994.

[60] Beckmann (2015)

[61] Pennings SC, McCall BD, Hooper-Bui L (2014) Effects of oil spills on terrestrial arthropods in coastal wetlands. Bioscience 64:789-795.

underlying sediments to accelerating erosion leading to potentially permanent loss of marsh land.

91. Because of the susceptibility of diluted bitumen to submerge or sink, tracking the oil to shorelines would be especially problematic, creating persistent uncertainty regarding the extent and duration of oil contamination. If oil penetrates beneath the surface of beaches, especially at undocumented locations as is very likely should a large spill occur, persistent retention of the oil may lead to unanticipated encounters by the public over the course of decades. Such encounters degrade tourism values, especially in national parks such as the Gulf Islands and Pacific Rim National Parks, and threaten subsistence harvest traditions of First Nation peoples, who may feel justifiably uncomfortable consuming plants and animals collected from shorelines where oil contamination persists.

92. The susceptibility of diluted bitumen to sink raises the possibility, observed in fact following the *Nestucca* spill,[62] of significant oil contamination of the sea floor. This could temporarily suspend harvests of species such as Dungeness crabs, halibut, other groundfish and other species that support commercial and subsistence harvests. Seafloor oiling may further jeopardize subsistence harvests and commercial markets over longer terms if public perceptions and concerns regarding contamination become entrenched and widespread.

93. Fish, gelatinous zooplankton and other suspension feeding organisms are especially likely to accumulate submerged diluted bitumen droplets, leading to adverse effects on these organisms directly, or to their predators if they ingest these oil-contaminated organisms as prey.[63] Larval and juvenile life stages of fish often target prey organisms within size ranges that are similar to those of dispersed oil droplets, and hence may ingest these droplets directly.[64] Ingestion of oil impairs growth, prolonging the window of vulnerability of these larval and juvenile stages to their predators.[65]

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[62] Duval (1989); Harding (1989).

[63] Peterson CH, Anderson SS, Cherr GN, Ambrose RF, Anghera S, Bay S, Blum M, Condon R, Dean TA, Graham M, Guzy M, Hampton S, Joye S, Lambrinos J, Mate B, Meffert D, Powers SP, Somasundaran P, Spies RB, Taylor CM, Tjeerdema R, Adams EE (2012) A tale of two spills: Novel science and policy implications of an emerging new oil spill model. Bioscience 62:461–469.

[64] Wertheimer AC, Celewycz AG (1996) Abundance and growth of juvenile pink salmon in oiled and non-oiled locations of western Prince William Sound after the Exxon Valdez oil spill. Pp 518–532 *in* SD Rice, RB Spies, DA Wolfe, BA Wright (eds.) Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society 18.

[65] Luquet 1984; Carls MG, Holland L, Larsen M, Lum JL, Mortensen DG, Wang SY, Wertheimer AC (1996) Growth, feeding and survival of pink salmon fry exposed to food contaminated with crude oil.

Gelatinous zooplankton such as jellyfish, larvaceans,[66] and other organisms that filter zooplankton and other particulate matter may ingest naturally dispersed crude oil products such as diluted bitumen. Although the direct effects of ingested oil on these organisms are poorly understood, they serve as important prey for some fish species including pink salmon.[67]

94. Submerged diluted bitumen that is naturally dispersed in the upper water column presents a contamination hazard to fish, especially salmon, that are important for subsistence and commercial fishery harvests. In addition to ingestion of submerged diluted bitumen droplets by out-migrating juvenile salmon from the Fraser River or released from salmon hatcheries, diluted bitumen may be ingested by adult and sub-adult life stages of salmon. Adult and sub-adult sockeye salmon are suspension feeders that filter small particulate matter such as phytoplankton and zooplankton from the water column, and would ingest small droplets of diluted bitumen that fall within their filtration size range. Pink and chum salmon ingest gelatinous zooplankton, which provide a means for tainting if their prey is contaminated by oil. The mere credible threat of contamination should a large-scale spill occur could have serious adverse consequences for these fisheries stemming from impaired marketability of products suspected of tainting, even when tainting is undetectable.

## 8.0 Considerations Regarding Potential Use of Oil Spill Dispersants

95. Although oil spill dispersants are routinely considered as a response method for ordinary oil spills, dispersants are especially unsuitable for diluted bitumen spills and should not be considered as viable response options under any circumstances. Experiments conducted on behalf of Trans Mountain to evaluate the effectiveness of dispersant applied to diluted bitumen showed that it "...was marginally effective on the relatively fresh oil

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Pp 608-618 *in* SD Rice, RB Spies, DA Wolfe, BA Wright (eds.) Proceedings of the *Exxon Valdez* oil spill symposium. American Fisheries Society 18.

[66] Larvaceans are small (~1 cm) free-swimming tunicates, and pteropods are small (< 1 cm) free-swimming marine snails. Both secrete mucus films that traps particulate matter including microscopic phyto- and zooplanton from the water column, and can also trap small droplets of crude oil.

[67] Cooney RT, Allen JR, Bishop MA, Eslinger DL, Kline T, Norcross BL, McRoy CP, Milton J, Olsen J, Patrick V, Paul AJ, Salmon D, Scheel D, Thomas GL, Vaughan SL, Willette TM (2001) Ecosystem controls of juvenile pink salmon (*Oncorhynchus gorbuscha* and Pacific herring (*Clupea pallasi*) populations in Prince William Sound, Alaska. Fisheries Oceanography 10(s1):1–13.

(CLWB) but not effective on one day weathered CLWB."[68] The unrealistically thick oil slick used in this experiment (13.46 mm) is about 30 times thicker than the thickness of a diluted bitumen slick unconfined by container walls (i.e. ~0.4 mm),[69] and consequently a real diluted bitumen slick would weather about 30 times faster.[70] This implies that the time window for even marginally successful application of dispersant to a surface slick of diluted bitumen would be on the order of about an hour or two after release of the diluted bitumen to receiving waters. It is thus highly unlikely that dispersant could be mobilized, transported and applied rapidly enough to be even marginally effective during a real spill, assuming all the other conditions for successful dispersant application (i.e. attainment of 1:20 dispersant:oil application rate, modest wind speed and sea state to promote mixing but not so high as to interfere with aerial application, high-visibility weather and daylight conditions) were close to ideal. Because of the very low likelihood that diluted bitumen could be successfully dispersed under field conditions anywhere along the tanker route in Canadian waters, permission for dispersant use as a countermeasure should be categorically denied for spills involving diluted bitumen.

96. Despite the demonstrated inadequacy of dispersants as a response countermeasure for surface slicks of diluted bitumen spills, dispersants or related products are sometimes promoted for use as shoreline cleaning agents. However, use of these products has not been shown to result in anything more than cosmetic reduction of surface oiling on treated shorelines at best, and their application may inflict additional harm to biota inhabiting these shorelines. The only quantitative study of chemical shoreline cleaning showed that while the treatment resulted in a statistically significant reduction of oil retained on an armoured beach formerly used for subsistence harvesting prior to oiling by the 1989 *Exxon Valdez* oil spill, it was not efficient.[71] Aggressive application of the shoreline cleaning agent into the subsurface sediments about doubled the rate of oil removal from this

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[68] Witt O'Brien's, Polaris Applied Sciences, Western Canada Marine Response Corporation (2013) A study of fate and behavior of diluted bitumen oils on marine waters, dilbit experiments—Gainford, Alberta; at Trans Mountain application at V8C_TR__S&_01. CLWB: Cold Lake Winter Blend, which is Cold Lake Bitumen diluted with gas condensate to satisfy density and viscosity requirements for transport through Trans Mountain pipelines during winter conditions.

[69] Stronach J, Hospital A (2013) Technical memo to Trans Mountain dated 4 July 2013 re: Spreading of Diluted Bitumen.

[70] Short (2015)

[71] Brodersen C, Short J, Holland L, Carls M, Pella J, Larsen M, Rice S (1999) Evaluation of oil removal from beaches 8 years after the Exxon Valdez oil spill. Proceedings of the Twenty-Second Arctic and Marine Oilspill Program (AMOP) Technical Seminar, June 2-4, Calgary, Alberta Canada. Environment Canada.

beach compared with the natural oil attenuation rate, but only for portions of the beach that were not covered by rocks movable by hand. Consequently, use of dispersant or other products as shoreline oil cleaning agents should be permitted only if their use is clearly demonstrated to be effective, and not unacceptably harmful to the plants and animals that inhabit the shorelines considered for treatment.

## 9.0 Lessons from the 2010 Kalamazoo Pipeline Spill

97. The environmental behaviour of diluted bitumen released into fresh receiving waters is illustrated by the 2010 Kalamazoo pipeline spill. A pipeline rupture released an estimated 3,200 $m^3$ of diluted bitumen into the Talmadge Creek in July 2010, and flowed into the Kalamazoo River, contaminating it downstream over a length of more than 60 km.[72] Turbulent mixing promoted evaporation of the most volatile components of the diluted bitumen, and also promoted incorporation of riparian sediments into the oil, both of which processes caused the oil to sink in the fresh water of the river. Extensive studies of fish from oiled and un-oiled locations following the discharge indicated consistently poorer health of fish inhabiting oiled habitats.[73] Remediation involved extensive and on-going dredging to remove the sunken oil from the river and from the downstream Morrow Lake, which acted as a trap preventing migration of oil and oiled sediments further downstream.

## 10.0 Fate and Effects of an Oil Spill in the Fraser River

98. A pipeline rupture that discharged diluted bitumen into the Fraser River would likely harm fish species that inhabit the river, especially salmonids. Outmigrating juvenile salmonids may ingest small oil droplets, and returning adults may absorb toxic PAC dissolved from the diluted bitumen through their gills, or suffer gill fouling by small oil droplets. Depending on the location and volume of diluted bitumen released, the river could transport bitumen and bitumen-contaminated sediments to marshes near the mouth of the Fraser River and to the Fraser River estuary, where a host of resident and migratory shorebirds could be exposed to oil, along with terrestrial mammals and other animals that inhabit these marshes.

[72] See www.epa.gov/enbridgespill/ and www.darrp.noaa.gov/greatlakes/enbridge/index.html

[73] Papoulias DM, Veléz V, Nicks DK, Tillitt DE (2014) Health assessment and histopathologic analyses of fish collected from the Kalamazoo River, Michigan, following discharges of diluted bitumen crude oil from the Enbridge Line 6B. United States Geological Survey, Administrative Report 2014.

# 11.0 Appendix 1

**Curriculum Vitae**

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## Professional Experience:

**Chevron/TexPet Ecuador Oil Contamination (since January 2013).** Retained by Louis Berger, Inc. on behalf of Winston-Strawn LLP, attorneys representing the Republic of Ecuador in Bilateral Investment Treaty Arbitration in the matter of lingering petroleum contamination in the northern Amazon forest of Ecuador produced during exploration and production operations conducted by Texaco (now Chevron) prior to 1993. Responsibilities include evaluation of analytical chemistry evidence of source, toxicity, and persistence of lingering oil associated with oil production facilities.

**Water Quality Monitoring Review, Lake George, New York (since December 2012).**

Provide expert review of 30-year limnological monitoring program sponsored by The FUND for Lake George, and provide senior scientific guidance for The Jefferson Project, a collaboration of The FUND, Rensselaer Polytechnic University and IBM Corp. to combine advanced environmental sensors and computing power to create the most advanced ecosystem model of a lake anywhere in the world.

**Science Coordinator, BP MDL 2179 PSC (since December 2010).** Retained by the Plaintiff's Steering Committee for the British Petroleum Multi-District Litigation to oversee scientific support for the transport, fate and environmental effects of oil released from the April 2010 *Deepwater Horizon* blowout in the Gulf of Mexico. Responsibilities included formulating the overall science strategy, identifying and recruiting internationally recognized experts to support it, and providing scientific guidance, insight and advice to the PSC attorneys. This case recently settled for ~$7.8B on terms favorable to the PSC, based in part on the strength of the scientific positions established by the expert team I recruited.

**Jet A Fuel Oil Review for the Vancouver Airport Fuel Delivery Project (January–February 2012).** Retained by Coastal & Ocean Resources Inc. to review ecotoxicological risks posed by jet A/A-1 fuels and additives following accidental spills.

**Expert Witness, Northern Gateway Pipeline Proposal (since May 2011).** Retained by Janes Freedman Kyle Law Corporation on behalf of the Gitxa'ala First Nation for a scientific expert panel to review environmental risks presented by the Northern Gateway pipeline project from Edmonton, Alberta to Kitimat, British Columbia proposed by Enbridge Corporation.

**Pacific Science Director, Oceana (November 2008 to December 2010).** My main focus was to foster and coordinate the collaborative development and articulation of the scientific rationale for ocean policy recommendations of the Pacific Team of Oceana. My responsibilities included ensuring that policy recommendations have a firm scientific basis and providing scientific advice regarding advocacy and litigation priorities. As supervisor of the Pacific Team's scientific staff, I was also responsible for the scientific defense of Oceana's advocacy positions at scientific, litigation and policy venues relevant to Pacific and Arctic Ocean issues, including their articulation in media ranging from op/ed articles and news releases to peer-reviewed scientific manuscripts, and for supporting these activities through grant writing. Finally, I promoted our contacts with the scientific community engaged in ocean and climate research, with relevant government agencies and with other environmental organizations, which included organizing the scientific program for the 2009 International Arctic Fisheries Symposium held in Anchorage, Alaska.

**Expert Witness, Cosco Busan Oil Spill (April 2009 to April 2011).** Retained by Cotchett, Pitre & McCarthy LLP to provide advice and testimony on behalf of fishing industry plaintiffs injured by the 2008 Cosco Busan oil spill in San Francisco Bay, California.

**Expert Witness, Lake Wabamun Oil Spill (October 2007 to November 2008).** On loan from the US Government to the Government of Canada, I designed and supervised a study to estimate the amount of oil remaining in Lake Wabamun, Alberta following a Canadian National derailment a year earlier, and wrote an expert opinion on the implications of the results. Case settled out of court in favor of the government.

**Supervisory Research Chemist, Alaska Fisheries Science Center, National Marine Fisheries Service (1982 through November 2008).** My four basic responsibilities include acting as principal investigator (PI) on research projects, managing the Center's marine chemistry laboratory, advising the government's legal team on the long-term fate and effects of the 1989 *Exxon Valdez* oil spill, and reviewing research products that touch on the environmental chemistry of oil for the Center and for numerous peer-reviewed environmental journals.

- **Research Project Principal Investigator.** This includes conceiving, designing, securing funding, executing, analyzing and publishing results for environmental research projects, usually in collaboration with numerous colleagues and support staff. Most of my work has been on the *Exxon Valdez* oil spill. Major projects included: (1) assessment of the initial distribution and persistence of the spilled oil in seawater; (2) discovery and elucidation of a cryptic toxicity mechanism through which oil pollution is nearly 1,000-fold more toxic to fish eggs than previously thought; (3) definitive refutation of alternative hydrocarbon pollution sources advanced by scientists employed by Exxon Corp. as plausible causes of biological effects in the *Exxon Valdez* impact area; (4) discovery of a natural hydrocarbon trophic tracer in the marine food web of the northern Gulf of Alaska; and (5) quantitative measurement of the amount and loss rate of *Exxon Valdez* oil lingering in beaches 12 years or longer after the incident. Each of these was funded at $500K to $5M, and I played the leading role on all but the second. A summary of these projects appeared in *Science* as a review article I co-authored in 2003 (See Peterson, C.H et al.).

- **Manager, AFSC Marine Chemistry Laboratory.** I presided over a major expansion of the AFSC marine chemistry laboratory in the aftermath of the *Exxon Valdez* spill, when the government urgently needed additional capacity capable of meeting the stringent standards imposed by impending litigation. Staff increased nearly tenfold from two, and successfully qualified as one of only three such facilities nationally to participate, generating revenues of $500K - $1M annually. Today the facility is internationally recognized, specializing in the environmental analysis of hydrocarbons, biogenic lipids in support of nutritional ecology studies, and high-precision characterization of the marine carbonate buffer system in support of incipient studies on ocean acidification.

- **Scientific Advisor to the *Exxon Valdez* Legal Team for the Governments of Alaska and the United States.** The civil settlement between Exxon Corp. and the governments of Alaska and the US created a $900M fund administered by the *Exxon Valdez* Trustee Council that supported scientific studies, habitat acquisition, and other impact offsets. I was one of four scientists selected to design the Council's scientific review policy and administrative structure, and I have since provided policy guidance on request on numerous occasions, leading to publication of the 1993 symposium presenting the initial findings of the Exxon Valdez oil spill impacts as a book, establishment of and support for the annual Alaska Marine Science Conference begun in 1993, and leading the team that drafted the scientific support for invoking the $100M "re-opener" clause of the Exxon Valdez settlement on behalf of the US Department of Justice.

- **Reviewer and Advisor for the AFSC on Chemistry Issues.** In addition to providing peer-review of dozens of manuscripts submitted to scientific journals and proposals submitted to various funding agencies, I provided scientific advice to or on behalf of NMFS management. This includes providing occasional invited testimony to the Alaska Legislature and Governor, NOAA management and the Scientific and Statistical Committee of the North Pacific Fisheries Management Council, and advice to government agencies in Canada, China, Norway and Russia.

Education:

- Bachelor of Science, Biochemistry and Philosophy, University of California at Riverside, 1973
- Master of Science, Physical Chemistry, University of California at Santa Cruz, 1982
- Doctor of Philosophy, Fisheries Biology, University of Alaska at Fairbanks, 2005
- Languages: Mandarin Chinese (speak, read and write); Russian (read)

Selected Activities and Honors:

- Bronze Medal, U. S. Department of Commerce, "For scientific research and publications describing the long-term, insidious effects of oil pollution on fish embryos at parts per billion levels”
- Program reviewer for studies conducted by the Korean Ocean Research & Development Institute on the effects of the 2007 Hebei Spirit oil spill in Korea
- Appointment as Visiting Professor for the Key Laboratory of Oil Spill Identification and Damage Assessment Technology, State Oceanic Administration, Qingdao, People’s Republic of China
- Coordinating scientist for an on-going, privately-funded studies of the impacts of polycyclic aromatic hydrocarbons and toxic metals on the Athabasca River system from oil sands mining, in conjunction with the University of Alberta, the University of Saskatchewan and Queen’s University in Canada
- Advisor to the Sakhalin Research Institute for Fisheries & Oceanography for hydrocarbon monitoring and analysis, Yuzhno-Sakhalinsk, Russian Federation

## Publications, Reports and Presentations:

Haney, J.C., Geiger, H.J. and **Short, J.W.** 2014. Bird mortality from the Deepwater Horizon oil spill. I. Exposure probability in the offshore Gulf of Mexico. Mar. Ecol. Prog. Ser. 5113:225-237

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