ATTACHMENT D

To the Written Evidence of

Raincoast Conservation Foundation

The Potential Impacts of Dispersant Use on the Marine Environment

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Introduction

Among the multiple threats to the marine environment if the Trans Mountain Expansion Project (the "Project") proceeds is the potential application of the dispersant Corexit 9500 following a spill of diluted bitumen. Corexit 9500 is a chemical dispersant which is intended to break up surface oil slicks into smaller droplets and disperse them into the water column. It, along with Corexit 9580, a surface-washing agent, was indicated in Trans Mountain's 2015 application to the National Energy Board (NEB) as a potential spill response tool. At that time, neither product was approved for use in Canada. However, in July 2016, both products were approved for use in Canada.

The primary focus of this report is the efficacy and toxicity of Corexit 9500. We focus on this particular formulation for two reasons: 1) the majority of the literature focuses on Corexit 9500 because it was used so extensively during the Deepwater Horizon spill; and 2) this is the formulation that has recently (2016) been approved for use on an oil spill in Canada. Most of the toxicological research on Corexit 9500 has occurred in the years since the 2010 Deepwater Horizon blowout in the Gulf of Mexico, with most prior research focussing on the efficacy, rather than the toxicity, of Corexit. Although there is much research still required in order to understand the behaviour, fate, and toxicity of Corexit in the marine environment, the studies that have been done suggest that Corexit is of questionable effectiveness in breaking up a spill of diluted bitumen, and there is cause for concern with respect to marine organisms in general and critically endangered southern resident killer whales in particular.

The effectiveness of Corexit in dispersing a dilbit spill in the Salish Sea

Past experience on the BC coast has taught us that the rough conditions commonly encountered can render booms and skimmers not just ineffective but unusable. Conventional mechanical oil spill response typically involves the use of booms and skimmers. Booms are floating, physical barriers to oil. Booms can either be 'hard' (used simply as a physical barrier to oil) or 'sorbent' (made of oil absorbent material and used to try to physically remove some of the oil). Skimmers are simply devices that collect and remove oil from the water's surface. They can be towed by boats or can be self-propelled, and are often used once booms have sequestered the oil in one area. However, both of these methods rely on relatively calm seas to be effective, and, even in ideal conditions, only manage to recover an average of 5-15% of spilled oil (Transport Canada 2013).

Complicating the use of mechanical recovery methods, as Trans Mountain noted in their original application to the NEB, diluted bitumen can submerge in the water column and sink, thereby “reducing the effectiveness of a conventional spill response” (TM 2013a). The National Academies of Sciences (NAS) further points out that with respect to dilbit, “in cases where traditional removal or containment techniques are not immediately successful, the possibility of submerged and sunken oil increases” (NAS 2016).

Therefore, in the likely event that booms and skimmers cannot be deployed at an offshore spill due to weather conditions, Trans Mountain indicated that they would consider the use of dispersants such as Corexit 9500. At the time of their original submission, Corexit 9500 was not approved for use in Canada. However, in June 2016 the federal government approved its use (Government of Canada 2016). As described below recent science question the effectiveness of Corexit in cleaning up spilled oil.

The intended purpose of dispersants is to break up oil slicks on the water’s surface by increasing the rate at which oil droplets form and move into the water column. Chemical dispersion does not reduce the amount of oil entering the marine environment; rather, it aims to change where the oil goes and how quickly it gets there. The goal of dispersant use is to turn the oil into small droplets, which are more easily degraded by naturally occurring microbes, but the reality appears to be more complex.

Following the Deepwater Horizon disaster in the Gulf of Mexico, some researchers did find increased numbers of hydrocarbon-degrading microorganisms in water containing chemically dispersed oil (Hazen et al. 2010). However, other studies found that dispersed oil was not degraded faster than undispersed oil (Lindstrom and Braddock 2002, Nyman et al. 2007). Kleindienst et al. (2015a) noted, “of the 23 dispersants currently approved by the US EPA for use in oil spill response [including Corexit 9500], to the best of our knowledge none has been tested thoroughly to evaluate its effect on microbial communities under environmentally relevant conditions”.

Further, “based on currently available information, the utility of the environmental use of dispersants as a stimulant for microbial oil degradation through oil dispersion is questionable” (Kleindienst et al. 2015a). Recent research has discovered that not only is Corexit 9500 toxic to some naturally occurring hydrogen-degrading microbes, but that it can also suppresses their oil-degrading ability. Chemical dispersants applied to both deep water and surface water did not stimulate oil degradation, and actually selected against the most effective hydrocarbon-degrading microorganisms, instead selecting for a microorganism with the potential to degrade dispersant (Kleindienst et al. 2015b). The authors measured the oxidation of hydrocarbons, suggesting that previous studies have generated contradictory results because the metrics they used were nonspecific (e.g. CO_2 production), such that while they may have reflected changes in microbial growth, they did not necessarily reflect hydrocarbon degradation (Kleindienst et al. 2015b).

In general, chemical dispersion is less effective on weathered oils than on fresh oils (e.g. Ward et al. 2018). Because the lighter components of dilbit weather rapidly through processes such as evaporation and photo-oxidation, leaving behind a heavy, viscous substance (bitumen), the window during which chemical dispersion may be effective for dilbit would be expected to be smaller than it would be for conventional crude oils. This was confirmed by the NAS, which stated "the time windows during which dispersants and in situ burning can be used effectively are significantly shorter for diluted bitumen than for other commonly transported crudes" (NAS 2016). Further, the changes in density and viscosity that occur as diluted bitumen weathers are more rapid than those of conventional oil products, such that a spill of diluted bitumen "may require a faster adaptation of routine response options…" (CSAS 2018).

New research has shed light on the importance of photo-oxidation[1] (the degradation of petroleum hydrocarbons by sunlight) in determining dispersant effectiveness (Ward et al. 2018). Previous studies to determine the effectiveness of dispersants used primarily "fresh" oil that had not been altered by sunlight. In the Ward et al. study published in 2018, the researchers conducted extensive lab tests examining the effects of both evaporation and photo-oxidation. While evaporation is frequently considered in the determination of spill response options, it had far less impact on dispersant effectiveness than did photo-oxidation. Evaporation of 8-30% of the initial oil mass resulted in a reduction in dispersant (Corexit 9500) effectiveness of 3-7%. Conversely, an equivalent of 53 hours of natural sunlight decreased dispersant effectiveness by 29-34% (Ward et al. 2018). These results indicate that exposure to sunlight rapidly transformed the oil into residues that were only partially soluble in dispersant, such that the dispersant's ability to break down the oil mass into smaller droplets was limited.

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[1] Photo-oxidation occurs when light energy from the sun begins to break chemical bonds in oil compounds, which creates openings for oxygen to attach. This process, sometimes also called photochemical weathering, is similar to the process that causes paint on cars or colours on clothes to fade if they are left out in the sun for extended periods.

Water temperature also appears to play an important role in dispersant effectiveness. Although Corexit 9500 was somewhat effective on heavy fuel oil under breaking waves at higher temperatures (16°C), dispersion was found to be “ineffective” under breaking waves at lower temperatures (10°C) (Li et al. 2010). Average temperatures in the Salish Sea are typically below 10°C although some higher summer temperatures may be observed.[2]

Both Trans Mountain and Environment Canada have examined the efficacy of dispersants on dilbit. Environment Canada found that under breaking wave conditions, dispersants were able to disperse less than half of the dilbit released into the water. At seawater temperatures of 8.3 ± 1.3°C, the effectiveness of Corexit 9500 ranged from 30% to 45%, depending on the type of diluted bitumen tested, with the rest remaining as a non-dispersed slick on the surface (EC 2013). In non-breaking waves, dilbit was not affected at all by dispersant application, and remained as a non-dispersed slick on the surface. The report concluded that the physical properties of dilbit “limit the effectiveness of currently-available spill treating agents” (EC 2013).

Trans Mountain found that Corexit 9500 was “marginally effective” on 6-hour weathered dilbit and “not particularly effective” on more weathered dilbit (the Gainford study; Witt O’Brien’s 2013). This very short period during which Corexit may be “marginally effective” could pose major challenges given that under Trans Mountain’s “enhanced response regime”, a full spill response could take up to 36 hours to arrive in some locations (TM 2013b). The risk would be magnified in the event that weather conditions prevented the use of booms and skimmers and dispersant was the only feasible option – as discussed above, weathering significantly reduces the effectiveness of chemical dispersants.

In addition to its unproven effectiveness in breaking down spilled oil, researchers found that in the presence of Corexit 9500, polycyclic aromatic hydrocarbons (PAHs; organic compounds which are the primary contributor to the toxicity of oil products) were able to penetrate faster and deeper into permeable saturated sands (Zuijdgeest and Huettel 2012). This is of concern because the absence of oxygen, light, and microbes in sand can slow degradation, creating a reservoir of toxic compounds that may be re-released into coastal waters with continued wave flushing or following a storm or other disturbance.

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[2] https://seatemperature.info/january/canada-water-temperature.html

Dispersant toxicity to wildlife

The majority of research on dispersants that occurred before 2010 was focused on the efficacy, rather than the toxicity, of dispersants in general and Corexit formulations in particular (e.g. Wise and Wise 2011, Place et al. 2010). However, some research was carried out, largely on marine invertebrates and, to a lesser extent, on fish. Then, in 2010, almost 7 million litres of dispersant (Corexit formulations 9500 and 9527) were used in the Gulf of Mexico following the Deepwater Horizon disaster. Chemical dispersants had never before been used on this scale and essentially turned the Gulf into a real-time experiment on the effects of these dispersants on individual animals, populations, and ecosystems. Toxicity research examined lethality, sub-lethal effects, and modes of action on everything from cell lines to whole animals. However, all this research also had the effect of raising even more questions, such that further extensive study is required in order to begin to understand the effects on animals and ecosystems of dispersant alone and dispersant combined with various oil products.

Wildlife toxicity studies before 2010

Before the 2010 Deepwater Horizon disaster in the Gulf of Mexico, in which an estimated 760 million litres of light crude oil were released into the waters of the Gulf, relatively little was known about the fate and effects of dispersants used in marine oil spills (e.g. Place et al. 2010). Most studies on Corexit focussed on its efficacy as a dispersant, rather than on its toxicity (either alone or when combined with oil). According to Wise and Wise (2011), as of February 2011 there were only 38 peer-reviewed articles available on the toxicity of 35 dispersants, with many examining the lethality of dispersants (as opposed to sub-lethal endpoints).

The majority of the studies done before 2010 examined the effects of chemically dispersed oil on marine invertebrates. For example, amphipods (Amphipoda) and snails (Gastropoda) were used to examine the various toxicities of the “water-accommodated fraction” (WAF)[3] of crude oil, Corexit 9527, Corexit 9500, and chemically dispersed crude oil (Gulec et al 1997). “CEWAF”. For both lethal and sub-lethal endpoints (in the case of Gulec et al. the sub-lethal endpoint examined was the suppression of natural behaviours), the authors found that chemically dispersed oil was significantly more toxic to both species than the WAF.

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[3] The water-accommodated fraction (WAF) is the solution of smaller, low molecular weight hydrocarbons that naturally partition (dissolve) from oil into water.

Studies on fish also found increases in toxicity due to the use of Corexit. In trout (Salmonidae), the induction of CYP1A[4] (the enzyme responsible for metabolizing petroleum hydrocarbons) was 6- to 1100-fold higher in the chemically enhanced WAF (CEWAF)[5] of crude oil than in the WAF alone (Ramachandran et al. 2004). Because the metabolic breakdown of some PAHs can create substances that cause toxicity and cancers, researchers measure the induction (i.e. increase in biosynthesis) of the CYP1A enzyme as an indicator of the potential toxicity of the substance(s) they are examining. Corexit 9500 was not found to induce CYP1A on its own, indicating that the observed increase in toxicity was due to increased exposure to the toxic components of oil.

Larval mummichog (*Fundulus heteroclitus*), a small fish that inhabits brackish and coastal waters (e.g. estuaries and salt marshes), experienced higher mortality rates (89%) following exposure to the CEWAF than to the WAF alone (Couillard et al. 2005). The addition of dispersant also caused sublethal effects, including reductions in body length and increased ethoxyresorufin-O-deethylase (EROD activity (a measurement of how hard the body is working to try to detoxify hydrocarbons). The authors attributed these effects to increases (from two- to five-fold) in both the total PAH concentration and in the concentration of toxic, higher molecular weight PAHs (i.e. those with three or more benzene rings[6]) caused by the addition of dispersant (Couillard et al. 2005). This work indicates the use of dispersant causes an increase in the concentration of PAHs, which results in increased exposure for aquatic organisms.

Wildlife toxicity studies since 2010

As noted in the previous section, most studies on Corexit done before 2010 Gulf spill focused on Corexit's effectiveness at dispersing oil, rather than on its toxicity. However, the unprecedented use of dispersants (almost 7 million litres of Corexit 9500 and Corexit 9527 combined) in the wake of the Deepwater Horizon disaster essentially turned the Gulf of

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[4] Cytochrome P4501A, or CYP1A, is an enzyme that metabolizes, among other substances, PAHs. It helps convert the PAH into a more reactive substance that can be excreted by the body.

[5] The addition of dispersant to an oil mass results in chemically enhanced water-accommodated fraction (CEWAF). While the WAF is the solution of smaller, lighter hydrocarbons that naturally dissolve in water, the addition of dispersant facilitates the dissolution of some of the larger, heavier hydrocarbons as well.

[6] Polycyclic aromatic hydrocarbons (PAHs) are, by definition, compounds with 2 or more benzene rings joined together. PAHs composed of between 3 and 5 rings have been found to be highly toxic, particularly to the early life-stages of fish. As noted previously, the addition of dispersant can allow some of these larger compounds, to dissolve in the water column and result in exposure for fish and other aquatic organisms.

Mexico and its inhabitants into a real-time experiment on the short- and long-term impacts of dispersants mixed with oil, prompting a surge of research.

A growing body of evidence shows that exposure to a combination of Corexit and oil can cause greater toxicity than exposure to oil alone. In many cases, this increased toxicity occurs because the dispersant is doing what it was designed to do: increasing the concentration and bioavailability of petroleum hydrocarbons in the water column (e.g. MacInnis et al. 2018). Specifically, dispersants promoted droplet formation and increased concentrations in the water column of the less water-soluble PAHs (particularly those with three to five rings), some of which are highly toxic on their own (e.g. alkyl three-ring PAHs; Hodson et al. 2007), and some of which induce enzymes (e.g. CYP450) that can degrade or break down PAHs into their more toxic metabolites (e.g. Couillard et al. 2005).

Researchers examined the chronic toxicity of four crude oils to the embryos of rainbow trout by exposing them to both the water-accommodated fraction (WAF) and the chemically enhanced WAF (CEWAF). Chemical dispersion caused a dramatic increase in toxicity, from >35 to >300 fold (Wu et al. 2012). The smallest differences were observed in the lightest and least viscous oil, with the largest differences observed in the heaviest, most viscous oil. This result is of concern in the case of a spill of diluted bitumen, which is heavier and more viscous than crude oil. The researchers also compared effects against the measured concentration of oil in each solution and interestingly, found no difference in toxicity between WAF and CEWAF treatments (Wu et al. 2012). This indicates that chemical dispersion resulted in droplet formation and the partitioning of hydrocarbons from oil to water, such that increased toxicity resulted from increased exposure of embryos to oil constituents, rather than from any change in hydrocarbon concentrations.

The possibility of synergistic toxicity[7] of oil combined with dispersant was examined by Adams et al. (2014a), who exposed Atlantic herring (*Clupea harengus*) embryos to WAFs and CEWAFs of crude oil. Based on the nominal loading of test solutions (%v/v), they found that the CEWAF was approximately 100-fold more toxic than the WAF. However, in a result similar to that obtained by Wu et al. (2012), when toxicity was expressed as measured oil concentrations, there was no difference in toxicity, suggesting that the higher toxicity was caused by an increase in hydrocarbon exposure as a result of chemical dispersion (Adams et

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[7] Synergistic toxicity is when exposure to two or more chemicals at a time results in health effects that are greater than the sum of the effects of the individual chemicals.

al. 2014a). A second experiment exposed rainbow trout (*Oncorhynchus mykiss*) embryos to heavy fuel oil (HFO) dispersed with Corexit 9500 and to a chemically dispersed nontoxic mineral oil. While the dispersant alone was toxic, the chemically dispersed mineral oil was nontoxic, suggesting that the dispersant had been sequestered by the oil (Adams et al. 2014a). Conversely, dispersed HFO caused concentration-dependent[8] increases in toxicity. The authors suggest that the results of both studies indicate that chemically dispersed oil is more toxic to fish embryos than mechanically dispersed oil due to increased exposure to petroleum hydrocarbons rather than to any change in toxicity or synergistic toxicity of the oil and dispersant combined (Adams et al. 2014a).

Conversely, an industry-funded study reported that although the use of dispersant significantly increased PAH concentrations in the test solutions, the acute toxicity of the CEWAF was lower to all test organisms than that of either the WAF or mechanically dispersed oil (Gardiner et al. 2013). However, these results were reported in terms of measured total hydrocarbon concentrations, and, as noted by other researchers (e.g. Adams et al. 2014a; Wu et al. 2012), toxicity expressed in this way may appear to be vastly different than toxicity expressed as nominal loadings of test solutions (simply the amount of WAF or CEWAF added to the test solutions). This is because toxicity occurs not as a function of total hydrocarbon concentration, but rather as a function of the increased exposure of organisms to bioavailable hydrocarbons. Further, the findings by Gardiner et al. (2013) (and others) that the CEWAF contains not only substantially higher total petroleum hydrocarbon concentrations (up to 100 fold higher), but also a significantly greater proportion of highly toxic alkylated PAHs[9] (87% of total PAHs) (Gardiner et al. 2012), are of great concern from a chronic toxicological perspective. Alkylated 3- to 5-ring PAHs in particular have been demonstrated to be the main drivers of chronic toxicity in fish (e.g. Hodson et al. 2007; Adams et al. 2014b; Martin et al. 2014).

Similar results have been observed in marine invertebrates. In deep water marine corals, exposure to a mixture of oil and Corexit 9500 resulted in concentration-dependent health

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[8] Concentration-dependent increases in toxicity simply refer to the fact that as exposure concentrations of a substance increase, so too does observed toxicity.

[9] Alkylated PAHs are PAHs with attached alkyl groups. Alkyl groups contain only carbon and hydrogen, and have the formula C_nH_{2n+1}.

declines (fragment mortality[10]) that were 1.1 – 4.4 fold more severe than those resulting from oil exposure alone (DeLeo et al. 2016). The larva of both broadcast spawning and brooding coral experienced either significant reductions in settlement and survival, or complete or near complete (1% survival) mortality, following exposure to the chemically enhanced water accommodated fraction (CEWAF) of BP Horizon source oil (Goodbody-Gringley et al. 2013). In marine plankton, the combination of Corexit and crude oil mixed at ratios recommended by the US Environmental Protection Agency (EPA) caused toxicity up to 52-fold higher than oil alone (Rico-Martinez et al. 2013). This increased toxicity occurred after eight hours of mixing the Corexit and oil by stirring; however, even with no stirring, toxicity increased 27.6 fold (Rico-Martinez et al. 2013).

To differentiate the effects of chemically dispersed oil from those of mechanically dispersed oil, the marine copepod *Calanus finmarchicus* (a tiny aquatic crustacean) was exposed to environmentally realistic concentrations of oil dispersed both ways and then allowed to recover for 25 days (Hansen et al. 2015). This copepod inhabits the upper water masses in the spring and summer, which is where oil would be expected to be present following a spill on the surface. Both dispersal methods resulted in high residues of PAH measured in the body of the copepod relative to controls, and reduced egg and nauplii[11] production during the first 15 days of recovery. However, those animals exposed to mechanically dispersed oil were able to recover and reach control levels of egg and nauplii production by recovery day 25, while those exposed to chemically dispersed oil could not compensate (Hansen et al. 2015).

Recent research also indicates that Corexit 9500 itself is toxic to wildlife. Deep-water corals were susceptible to acute Corexit 9500 toxicity: three different species demonstrated more severe health declines (e.g. fragment mortality) in response to dispersant exposure alone (2.3 – 3.4 fold) than to oil exposure (DeLeo et al. 2016). The response was concentration-dependent, meaning that higher concentrations of dispersant led to more severe health declines. Coral larvae experienced significant reductions in both settlement success and survival following exposure to Corexit 9500, with complete larval mortality occurring at medium (50 ppm) and high (100 ppm) concentrations (Goodbody-Gringley et al. 2013).

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[10] Fragments are the genetically identical pieces of coral used to examine toxicity. Fragment mortality simply refers to the death of these pieces due in this case to exposure to toxic substances.

[11] Nauplii are the first larval stage (first stage of development after leaving the egg) of many crustacean species (including copepods).

In the liver cells of rainbow trout, exposure to Corexit 9500 knocked down the activity of the enzyme CYP1A, which is responsible for metabolizing petroleum hydrocarbons (Dasgupta and Mcelroy 2017). Thus, their ability to metabolize PAHs (and therefore be able to excrete hydrocarbons from their bodies) was compromised due to exposure to Corexit 9500.

Some of the toxic effects of dispersants may be caused by the surfactants they contain. In Corexit 9500, this includes dioctyl sulfosuccinate, or DOSS, which was more toxic to the liver cells of rainbow trout than Corexit 9500 as a whole (Dasgupta and Mcelroy 2017). Short term DOSS exposure at environmentally realistic concentrations also had multiple effects on larval sheepshead minnow (*Cyprinodon variegatus variegatus*), including decreased survival, genotoxicity, oxidative stress, and affected antioxidant response capabilities (Dasgupta 2016, Dasgupta et al. 2018).

DOSS can also persist in marine environments: detectable levels of this surfactant were reported near deep sea coral communities and in tar balls on beaches in the Gulf Coast up to six month and four years, respectively, after the Deepwater Horizon spill (White et al. 2014).

While less toxic than DOSS, other surfactants in Corexit 9500 (e.g. Tween 80 and 85) were also found to exert effects, including a disruption in the ability of rainbow trout liver cells to metabolize petroleum hydrocarbons (Dasgupta and Mcelroy 2017). This indicates that there are different modes and mechanisms of toxicity within Corexit 9500, making it even more difficult to predict the impacts of exposure in a real-world scenario.

Finally, application of dispersants may also affect the transfer of carbon to higher trophic levels, which can be important in shaping food webs and productivity. In a mesocosm[12] experiment, the addition of oil alone to a microbial community resulted in an increase in the biomass of ciliates, grazers that transfer carbon to higher trophic levels (Ortmann et al. 2012). However, the addition of dispersed oil or dispersant alone (Corexit 9500) significantly inhibited the growth of ciliate biomass, suggesting a reduction in grazing and therefore a decrease in the transfer of carbon to higher trophic levels. The authors suggest that the addition of dispersant to the Gulf of Mexico might therefore have led to a decrease in the production of zooplankton and fish due to reduced flow of carbon to higher trophic levels (Ortmann et al. 2012).

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[12] A mesocosm experiment is an outdoor experimental system that examines the natural environment under controlled conditions. In this way, mesocosm studies provide a link between field surveys and highly controlled laboratory experiments.

The existing literature on Corexit 9500, both alone and combined with oil, reports a high level of variation in toxicity, depending on the species tested, the life stage, and the specific exposure conditions. As noted by Rico-Martinez et al. (2013), “rigorous toxicological comparison of untreated and dispersant-treated oil is complicated by the fact that when oil, seawater, and dispersants are mixed, a complex multiphase system results. In this complex system, aquatic organisms can be exposed to many toxicants, in many forms, which can have several modes of action”. Much more research across species and ecosystem types (particularly in the types of conditions encountered in the Salish Sea), as well as on different types of oil, is required in order to begin to understand the impacts of Corexit use on a spill of diluted bitumen.

Human health

There is very little information in the literature on the effects of Corexit on human health, with most of what does exist coming in the wake of the Deepwater Horizon spill. In a survey of almost 5,000 United States Coast Guard (USCG) personnel who responded to that spill, more than half reported being exposed to crude oil, and nearly one quarter (22%) were exposed to dispersants (Alexander et al. 2018). Many reported acute respiratory symptoms, with the most prevalent being coughing, shortness of breath, and wheezing. These symptoms were much more prevalent in those exposed to a combination of oil and dispersant than in those exposed to oil alone (Alexander et al. 2018).

Similar results were obtained in a 2017 study by the National Institutes of Health, which was also able to distinguish between dispersant exposure and exposure to crude oil alone. After adjusting for crude oil exposure, the researchers found that workers exposed to dispersants were 61% more likely than unexposed workers to report burning in the nose, throat, and/or lungs, 58% more likely to report chest tightness, 49% more likely to report eye irritation, and 40% more likely to report coughing and/or wheezing (McGowan et al. 2017). Although direct work with dispersants was more strongly associated with these symptoms, indirect exposure was still significantly associated with symptom presence (McGowan et al. 2017).

Work on human cell lines has shown effects of Corexit 9500 exposure at concentrations of 16 mg/L (reviewed in Dasgupta and Mcelroy 2017). Human cell cultures propagated *in vitro* are used as models for more complex biological systems, and are an integral part of molecular biology and biomedical research. In a study of the cytotoxicity[13] of DOSS and Corexit to human hepatocyte cell lines (liver cell lines used in laboratory research), Corexit and DOSS were equally toxic after 24 hours. However, Corexit become more cytotoxic than DOSS after 72 hours, indicating that DOSS may be primarily responsible for the initial Corexit-induced cytotoxicity, but that other components might play a greater role over time (Bandele et al. 2012).

In human bronchial airway cells, Corexit 9500 resulted in concentration-dependent toxicity, with 50% loss in viability of cells at 200 ppm and a decreased in cell survival to 2% at 300 ppm (Shi et al. 2013). The actual dispersant concentrations to which response workers might be exposed are extremely difficult to predict, and would depend on parameters including the amount of dispersant used, the proximity of workers to the application, wind speed and direction, etc. As Shi et al. (2013) note, "As is was not possible to monitor the concentration of dispersants used in response to the *Deepwater Horizon* disaster, the actual environmental concentrations of dispersant remain nonquantifiable".

In work extending across species, researchers found that Corexit 9500 damaged epithelial cells in human airways, mice lungs, and gills of zebrafish and blue crabs (Li et al. 2015). It caused dispersant-induced cell detachment, edema (swelling), contraction in cell diameter, and increased permeability, all of which point to structural and functional abnormalities in the cells (Li et al. 2015).

Other work on mammals has also indicated adverse effects resulting from Corexit 9500 exposure. Rats (*Rattus norvegicus* sp.) exposed to acute inhalation of Corexit 9500 experienced transient effects (observed on day one post-exposure, but not on day seven) on both their cardiovascular and peripheral vascular functions (Krajnak et al. 2011). Acute inhalation exposure also disrupted olfactory signalling and axonal function – disrupted sense of smell and nerve impulses/transmissions - which may in turn disrupt neurotransmitter signalling (Sriram et al. 2011).

In addition to its own toxicity, Corexit can also increase exposure to the toxic components of oil by breaking the oil down into particulate so fine that it can become airborne and, depending on conditions, can travel up to 80 kilometers (Afshar-Mohajer et al. 2018). The addition of dispersant to an oil slick increased the concentration of airborne oil particulate

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[13] The quality of being toxic to cells.

between one and two orders of magnitude[14] (Afshar-Mohajar et al. 2018). This airborne mixture can enter the lungs, where the dispersant continues to work, facilitating the uptake of toxic oil components into cells (Afshar-Mohajer et al. 2018).

Implications for BC's Southern resident killer whales

To date, both acute and chronic effects of dispersants on the health of cetacean populations and individual animals are unknown.

Although much of the recent research on the effects of oil and dispersant has been conducted on species inhabiting the Gulf of Mexico, it does not preclude the possibility that other species, such as BC's killer whales, may be negatively affected. Following the Deepwater Horizon disaster, 101 cetacean carcasses that washed up on the northern shores of the Gulf of Mexico were associated with spilled oil, although the actual number of mortalities may have been up to 50 times higher (Williams et al. 2011). The role, if any, played by dispersant exposure in these mortalities is unknown.

The literature examining the toxicity of Corexit 9500 to marine mammals is limited to a single study. In what is, to the best of our knowledge, the only available study, the authors examined the cytotoxicity and genotoxicity (toxicity to the genetic material within a cell) of Corexit 9500 and Corexit 9527 to sperm whale skin cells (Wise et al. 2014). They found that while only Corexit 9527 was genotoxic, both dispersants were cytotoxic, with exposure to 250 ppm Corexit 9500 reducing cell survival to 67% (Wise et al. 2014).

Cetaceans breathe at the air-water interface and can therefore be exposed to volatile compounds through inhalation and contact in the course of their normal behaviours (e.g. breathing, feeding, travelling, etc.). Based on existing research documenting the toxic effects of dispersant on human and other mammalian airways (discussed above), the evaporating components of diluted bitumen combined with airborne Corexit 9500 pose a serious risk to these critically endangered animals. This risk is beyond the very real threats posed by inhalation of the evaporating components of crude oil alone (e.g. Matkin et al. 2008, Schwacke et al. 2014). Further, this risk may be magnified by the ability of Corexit to a) increase the concentration of airborne oil particulate by up to two orders of magnitude and b) to allow this airborne mixture to travel up to 80 kilometers (Afshar-Mohajer et al. 2018).

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[14] An order of magnitude is an exponential change of plus or minus 1. For example, going from 10 to 100 would be an increase of one order of magnitude, from 10 to 1000 would be two orders of magnitude, etc.

Beyond the risks posed to the resident killer whales themselves are risks posed to Chinook salmon (*Oncorhynchus tshawytscha*), the primary prey of resident killer whales, including the critically endangered Southern residents. As noted above, researchers have reported toxic effects of dispersant alone and dispersant combined with oil on a variety of fish species, including herring and rainbow trout (a salmonid).

While much more research is required to elucidate the threats posed to BC's killer whales by Corexit itself and Corexit/oil combinations, what we do know is that killer whales are obligate surface breathers, and spend much of their time at or near the surface of the water. They are thus at risk of exposure to both the evaporating components of oil and airborne Corexit, both of which have been shown to be toxic. Corexit may also pose a risk to Southern resident killer whales indirectly through potential harm to Chinook salmon, their primary prey.

Conclusions

Previous experience has taught us that mechanical methods of oil spill clean-up on the BC coast can be ineffective, and often unusable, due to weather conditions. Thus, in their 2015 application to the NEB, Trans Mountain suggested Corexit 9500 as a potential alternative. Though not approved for use at the time, Corexit 9500 was approved as a spill-treating agent by the federal government in July 2016. However, the unique properties of diluted bitumen make the already small window during which dispersant use may be effective even smaller. Further, research has indicated that even under controlled conditions, Corexit is not particularly effective at breaking up slicks of diluted bitumen.

In addition to its unproved effectiveness, toxicological research has shown that the addition of Corexit 9500 to an oil spill can increase toxicity to wildlife by orders of magnitude. This increased toxicity appears to be due in large part to increased exposure of organisms to the more toxic petroleum hydrocarbons (i.e. PAHs). In addition, Corexit itself appears to be toxic to wildlife.

Because of the unprecedented use of Corexit 9500 following the Deepwater Horizon oil spill in 2010, many response workers were exposed. Research indicates that in humans, Corexit causes respiratory toxicity. Corexit can also increase exposure to oil by creating oil particulate that is so fine that it becomes airborne, travelling up to 80 kilometres.

BC’s Southern resident killer whales spend much of their time at the surface, not just for breathing, but also for travelling, feeding, and other natural behaviours. The potential for exposure not just to the evaporating toxic components of dilbit but to airborne Corexit and Corexit/oil mixtures presents a serious threat in the event of a spill of dilbit on the BC coast.

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EDUCATION

University of Victoria, Victoria, BC
M.Sc. in Earth and Ocean Sciences **2010**
Thesis: "Hydrocarbons in sea otters (*Enhydra lutris*) and their habitat in coastal British Columbia, Canada"

University of Victoria, Victoria, BC
B.Sc. in Biology with Distinction **2005**
Areas of Concentration: Marine Biology, Ecology

PROFESSIONAL EXPERIENCE

Independent Consultant, Prince George, BC **January 2015 – present**
Clients include Raincoast Conservation Foundation, Vancouver Aquarium. Project work includes detailed technical review of behaviour, fate, and toxicity to salmon of diluted bitumen spilled in the Lower Fraser River; preparation of report on the same topics for general public; review of proposals for monitoring work and literature review in the wake of the April 2015 oil spill in English Bay; preparation of reports on the use of chemical dispersants (both for regulatory agencies and the media).

Stantec Consulting Ltd., Sidney, BC
Toxicologist/Project Coordinator **January 2012 – January 2015**
Toxicology: Collection and analysis of complex data sets with respect to potential health effects on wildlife species; method development using laser ablation of mammalian hair to monitor temporal changes in metal exposure.

Project Coordination: Worked as part of multi-city teams to coordinate complex projects. Tasks included deployment of dozens of field personnel; logistics planning and authorizations; document compilation and technical editing; discipline liaison and communication. Lead on achieving First Nations participation in, and engagement with, field programs, which required building respectful and effective working relationships with representatives from over two dozen First Nations across BC.

Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC
Contract scientist **January 2011 – December 2012**
Projects included publication of two manuscripts on hydrocarbons in BC sea otter food webs; a critical review of existing sediment quality guidelines on local and global scales; a comprehensive assessment of contaminant inputs into salmon habitat along the Fraser River in BC and potential impacts; and a collaborative assessment of the overall health of the BC sea otter population (e.g. hematology parameters, emerging infectious diseases).

University of Victoria/Institute of Ocean Sciences, Fisheries and Oceans Canada, Victoria/Sidney, BC
M.Sc. Candidate **Sept 2007 – December 2010**
My work focused on the source, transport, and fate of hydrocarbons in the food web of sea otters in British Columbia. The project included written, laboratory, and field components.

Institute of Ocean Sciences, Fisheries and Oceans Canada, Sidney, BC
Contract scientist **January 2006 – August 2007**
Publication of technical reports on marine environmental quality in the Pacific North Coast Integrated Management Area (PNCIMA) and the North Coast and Haida Gwaii, including contaminant sources, types, risks, and recommendations; publication of a manuscript on pesticide residues in Lower Mainland salmon habitat; and extensive literature review on the long-term effects of oil spills, with particular focus on the *Exxon Valdez*.

PUBLICATIONS AND PAPERS

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CONFERENCE PRESENTATIONS

Harris, K.A., Nichol, L.M., Yunker, M.B., Dangerfield, N., Ross, P.S. 2010. Source, transport, and fate of hydrocarbons in British Columbia sea otter (*Enhydra lutris*) habitat. SETAC North America 31st Annual Meeting, 7-11 November 2010, Portland, Oregon (poster).

Harris, K.A., Telmer, K., Ross, P.S. 2010. Source, transport, and fate of hydrocarbons in BC sea otter habitat. University of Victoria School of Earth and Ocean Sciences Graduate Student Workshop, 22 April 2010, Victoria, British Columbia (platform presentation).

Harris, K.A., Nichol, L.M., Yunker, M.B., Dangerfield, N., Ross, P.S. 2009. The FCSAP-SARA link: Hydrocarbons in British Columbia sea otters. FCSAP DFO-NEST Technical Workshop, 20-22 October 2009, Sidney, British Columbia (platform presentation).

Harris, K.A., Nichol, L.M., Yunker, M.B., Dangerfield, N., Ross, P.S. 2009. Source, transport, and fate of hydrocarbons in British Columbia sea otter (*Enhydra lutris*) habitat. 18th Biennial Conference on the Biology of Marine Mammals, 12-16 October 2009, Quebec City, Quebec (poster).

Harris, K.A., Dangerfield, N., Ross, P.S. 2009. Marine mammal toxicology in BC. Meeting of the Fisheries and Oceans Canada Marine Mammal Working Group, 4-5 June 2009, Parksville, British Columbia (platform presentation).

Harris, K.A., Nichol, L.M., Ross, P.S. 2008. The influence of feeding ecology on hydrocarbon patterns in British Columbia sea otters (*Enhydra lutris*). Workshop: Assessing and Addressing Small Scale Maritime Oil Pollution and Ecosystem Impacts in BC, 4-5 December 2008, Vancouver, British Columbia (platform presentation).

Harris, K.A., Nichol, L.M., Ross, P.S. 2008. Does feeding ecology influence hydrocarbon patterns in British Columbia sea otters (*Enhydra lutris*)? 35th Annual Aquatic Toxicity Workshop, 5 – 8 October 2008, Saskatoon, Saskatchewan (platform presentation).

Harris, K.A., Tierney, K., Dangerfield, N., Woudneh, M., Brown, T.G., Kennedy, C.J., Ross, P.S. 2007. Current-use pesticides in British Columbia salmon habitat. 34th Annual Aquatic Toxicity Workshop, 30 September – 3 October 2007, Halifax, Nova Scotia (poster).

Harris, K.A., Tierney, K., Dangerfield, N., Woudneh, M., Brown, T.G., Kennedy, C.J., Ross, P.S. 2007. Current-use pesticides in Fraser River salmon habitat. Department of Fisheries and Oceans Regional Science Symposium, 24-25 May 2007, Sidney, British Columbia (poster).

Harris, K.A., Tierney, K., Dangerfield, N., Woudneh, M., Brown, T.G., Kennedy, C.J., Ross, P.S. 2007. Current-use pesticides in Fraser River salmon habitat. Proceedings of the 2007 Georgia Basin Puget Sound Research Conference, 26-29 March 2007, Vancouver, British Columbia (poster).

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MEMBERSHIPS

College of Applied Biology (Registered Professional Biologist)
Professional Association of Diving Instructors