Short- and long-term health impacts of marine and terrestrial oil spills

A literature review prepared for the Regional Health Protection Program, Office of the Chief Medical Health Officer, Vancouver Coastal Health

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Table of Contents

List of Tables

Abbreviations

bFGF	Basic fibroblast growth factor
EPA	Environmental Protection Agency
$FEF_{25\text{-}75\%}$	Forced expiratory flow
FEV_1	Forced expiratory volume in 1 second
FVC	Forced vital capacity
GAD	Generalized anxiety disorder
MVV	Maximum voluntary ventilation
NIEHS	National Institute of Environmental Health Sciences
NIOSH	National Institute of Occupational Safety and Health
NOAA	National Oceanic and Atmospheric Administration
OSHA	Occupational Safety and Health Administration
PAHs	Polycyclic aromatic hydrocarbons
PPE	Personal protective equipment
PTSD	Post-traumatic stress disorder
SAMHSA	Substance Abuse and Mental Health Services Agency
USCG	United States Coast Guard
VEGF	Vascular endothelial growth factor
VOCs	Volatile organic compounds

Executive Summary

A review of academic literature, government agency reports, and interviews with past agencies responding to oil spills was conducted to both assess the evidence for health impacts due to oil spills and to glean insight for future oil spill response planning.

A growing body of evidence demonstrates the physical, mental, and community health of historical oil spills. The review found evidence of appreciable but reversible short-term impacts for residents living in the impact zone, as well as an extended range of impacts with potentially longer duration for workers (resident and non-resident volunteers and paid professionals) engaged in clean-up. Workers also suffered a number of physical injuries related to the strenuous nature of clean-up activities. Although long-term studies are lacking, there is some evidence of respiratory, endocrine, immunological, and genotoxic effects persisting for years in highly exposed clean-up workers. However, these short- and long-term physical impacts can be mitigated to some extent through the use of appropriate personal protective equipment (PPE) and through effective health and safety orientation prior to participations in clean-up work.

Regarding mental health and community impacts, this review found that mental health impacts were more sensitive indicators of harm than physical impacts. This is because mental health impacts often showed broader geographic extent than physical impacts, impacted the family as well as the individual, and were found to persist or worsen over years. Commonly identified issues included increased anxiety, depression, and post-traumatic stress disorder. Mental health impacts were most often related to income loss or financial uncertainty and, at the community level, cultural losses and deterioration in kin and non-kin relationships and social order. Individuals and communities dependent on natural resources affected by the spill are particularly vulnerable. In contrast, evidence was found suggesting that mental health and community impacts can be mitigated, in some cases, by easing financial uncertainty through timely and satisfactory compensation and through mechanisms that encourage or utilize social support.

The health impact literature and related work on oil spill responses also identified a number of important health considerations when planning for future spills. These included critical research considerations when attempting to study the short- and long-term impacts of future spills. These included identifying and securing funding, making broader use of environmental monitoring and human biomonitoring data, correcting issues in study design, and the preparation of research tools and protocols to facilitate a timely response. Public engagement and risk communication around oil spills generally and food safety in particular were found to be important factors in protecting public health during an oil spill. The review also highlighted a number of organizational considerations when mobilizing a clean-up response, including the need to register, evaluate, train, and follow-up with volunteer and paid clean-up workers. Finally, the review noted several planning considerations when attempting to conduct broad public health surveillance in the event of a spill.

1 Introduction

The petrochemical industry has provoked intense public concern regarding the release of toxic substances into the environment through processes related to the exploration, extraction, transport, refining, and finally consumption of oil products. The human health impacts of exposure to oil spills are of particular interest to public health agencies and the general public. Because these events are difficult to predict, perceived to be harmful to current and future generations, and are highly visible in the media, the perceived risk of harm from these events is greatly elevated (1), which may hamper effective health hazard response and communication.

Oil spills may cause toxic and other physical health, mental health, and community health impacts. Toxic effects may occur when residents are exposed to the complex mixture of hazardous compounds in petroleum, which includes volatile organic compounds (VOCs; *e.g.,* benzene, toluene, ethylbenzene or xylene), polycyclic aromatic hydrocarbons (PAHs), heavy metals and, in the case of controlled or uncontrolled burning of spilled oil, particulate matter and other combustion products. A brief listing of these classes of compounds, potential exposure pathways, and their suspected toxic effects can be found in **Table 1.** Furthermore, beyond these toxic effects, oil spills have the ability to inflict harm on other aspects of human well-being, including mental health and the resilience and cohesiveness of communities.

Table 1. Oil-derived contaminants and human exposure pathways.

For each contaminant, the primary route of exposure *expected during an oil spill* is indicated, along with a brief description of short- and long-term impacts. Exposure pathways were indicated as follows: inhalation (Inh), dermal absorption (Dml), ingestion (Ing). All contaminants have the potential for inhalation exposure due to the potential formation of oil mists or aerosols during a spill. Exposure limits were collected from several sources and were chosen as those most relevant to an oil spill scenario, in which inhalation exposures are initially high and then subside through volatilization.

Compound	***Exposure Pathways***	***Exposure Limits***	***Short-term effects***	***Long-term Effects***
Particulate Matter				
PM$_{2.5}$	Inh	25 μg/m^3 [a]	Respiratory effects (exacerbation of asthma, decreased function, inflammation)	Cardiovascular and respiratory disease, pre-mature death
PM$_{10}$	Inh	50 μg/m^3 [a]		
VOCs				
Benzene	Inh	0.009 ppm [b]	Haematopoetic, nervous and immune effects;	Carcinogenic to humans (IARC Group 1); reproductive and developmental effects in animals
Toluene	Inh	1 ppm [b]	Nervous effects (headaches, nausea, fatigue, drowsiness)	Upper respiratory symptoms; nervous effects; developmental effects
Ethylbenzene	Inh, Dml	5 ppm [b]	Eye and throat irritation, dizziness,	Possible human carcinogen (IARC Group 2B); developmental effects in animals
Xylene	Inh	2 ppm [b]	Nervous effects and nose, eye and throat irritation; skin irritation and vasodilation.	Developmental effects in animals; not classifiable as to its carcinogenicity to humans (IARC Group 3)
PAHs (as mixtures)	Inh, Dml, Ing	NA	Headaches, nausea, vomiting, loss of appetite, skin irritation (itching, burning, oedema), eye irritation,	Liver damage; haematological effects; reproductive and developmental effects in animals; known or suspected carcinogens.
Hydrogen Sulphide	Inh	0.07 [b]	Respiratory effects (sore throat, cough, shortness of breath, and impaired lung function in asthmatics), nervous effects (loss of consciousness) , eye irritation.	Central nervous effects
Dispersant Components [c]				
2-Butoxyethanol	Inh	6 ppm [b]	Headache, irritation of the nose and throat, vomiting, metallic taste	Developmental and reproductive effects in animals; not classifiable as to its carcinogenicity to humans (IARC Group 3)
Heavy Metals				

Cadmium (Cd)	Inh	0.00003 mg/m^3 [b]	Respiratory effects at extremely high exposures	Kidney damage, respiratory disease and decreased lung function, carcinogenic to humans (IARC Group 1)
Mercury (Hg)	Inh	0.0002 mg/m^3 [d]	Various nervous and respiratory effects ranging from low to high exposures.	Nervous and respiratory effects; not classifiable as to its carcinogenicity to humans (IARC Group 3)
Nickel (Ni)	Inh, Ing, Dml	0.0002 mg/m^3 [d]	Respiratory effects (inflammation, atrophy of the nasal epithelium),	Chronic lung inflammation; carcinogenic to humans (IARC Group 1), developmental effects in animals

[a] Twenty-four-hour air quality objectives (AQOs) for the Province of British Columbia: http://www.bcairquality.ca/reports/pdfs/aqotable.pdf

[b] Acute (<14 days) minimum risk levels (MRLs) set out by the Agency for Toxic Substances and Disease Registry (ATSDR), which reflect the level at which appreciable health effects are *not* expected: http://www.atsdr.cdc.gov/mrls/index.asp

[c] Further resources on dispersants and their components can be found at: http://www.epa.gov/bpspill/dispersants.html

[d] Intermediate (14-364 days) minimum risk levels (MRLs) set out by the ATSDR.

In Canada, a number of recent small spills (**Table 2**) have generated a great deal of media attention and aroused public concern regarding oil development in general and more specifically the safety of transport via pipelines, railways, and tankers. For example, in 2011, a pipeline rupture released 3,800 tonnes (28,000 barrels or 4.4 million litres) of light crude into a wetland 12 km from the Lubicon Cree community of Little Buffalo, Alberta (2), in association with which residents reported disturbing odours, headaches, nausea, and lack of appetite. However, for this and many of the other 'small' spills affecting Canadian communities, formal studies to assess and document health impacts, both physical and mental, are lacking.

This lack of data is concerning given the forward momentum on several large-scale infrastructure projects looking to increase the flow of oil into and through Canadian communities. In Metro Vancouver and the Lower Fraser Valley, the proposed 'twinning' of the Kinder Morgan Trans Mountain Pipeline will almost triple the quantity of a variety of petroleum products entering the region. In response to concerns over the increased risk of spills, Kinder Morgan modelled two 'credible worst case' spill scenarios and provided human health risk assessments (HHRAs) for these events. The modelled spills include a marine spill (15,300 tonnes) off the Gulf Islands and smaller loading accident spill (1,450 tonnes) in the tanker terminal. The existing pipeline was also the cause of an actual spill in 2007, when approximately 200 tonnes of oil were released in a residential neighbourhood. A portion of the spilled oil escaped through storm sewers into Burrard Inlet. Accordingly, and in the light of the recent proposal to 'twin' the Trans Mountain Pipeline, Vancouver Coastal Health and Fraser Health have been asked by local municipalities to provide more detailed information on health impacts in the event of another marine or terrestrial spill.

The occurrence of several serious tanker accidents in the previous 25 years (**Table 2**) has created opportunities to observe and document the health impacts of oil spills in other regions of the world. However, although these events have cumulatively affected many thousands of people, assessing the health impact of a given spill and comparing those impacts among spill events remains a challenge. This is because every spill is unique in terms of its severity and human exposure. The severity of a given spill refers to the total amount of non-recoverable oil lost and its persistence in the environment, and is determined by numerous factors, including total volume of the spill, the product spilled (as relates to its biodegradability/persistence/volatilization, toxicological profile, *etc.*), and its movement by wind and water (influencing spatial extent) (3).

In addition to severity, past spill events have differed tremendously in terms of the human population exposed. This is because spills that happen far out to sea may be naturally (biodegradation, volatilization) or artificially remediated to some extent before contaminants reach coastal resources or communities. Similarly, a land-based spill far removed from human settlements and activities may not result in extensive human exposure or subsequent impact, although the environmental damage at the same time may be severe. Furthermore, because of the difficulty in estimating the total number of people affected in a given event (which may not be fully appreciated until years after the fact), studies often cite the distance of the accident to shore or to human communities, or kilometers of coastline oiled, as a way to give context to the risk of human exposure. However, because of these differences in severity and human exposure, simple indicators such as the total amount of oil spilled are not useful indicators of overall human impact.

Despite these difficulties, there remains a great deal to be learned from studies of historical spill events. This review will focus on the documented health impacts associated with marine and terrestrial oil spills and the strength of evidence for this body of work. This review organizes the literature according to *physical impacts* (acute toxic impacts, acute injuries, and long-term impacts), *mental health impacts* (short- and long-term, and differences in their occurrence compared to physical impacts), and impacts on *community health and resilience*. This review relied primarily on peer-reviewed epidemiological studies from the academic literature, as well as government agency reports, to outline oil spill-related health impacts. However, where appropriate, sociological and other studies have been included to give context to the results. In addition, insights from the literature and past spill experiences have been used to specifically highlight some important considerations for planning that could minimize human health impacts when a spill does occur, as well as maximize the ability to monitor health impacts that remain.

Table 2. Major spills and pipeline ruptures with documented human health effects.

Of the numerous oil spills in the previous century, relatively few events have been investigated with respect to health effects. For reference, Kinder Morgan's credible worst case (CWC) scenarios include a marine spill (Gulf Islands, 15,300 tonnes), a loading accident (Westridge Terminal, 1,450 tonnes), and four pipeline ruptures (2,500, 1,300, 1,200, or 1,160 tonnes). All spills involve Cold Lake Winter Blend diluted bitumen (density = 926 kg/m^3). In addition, several Canadian spills are included, although the health impacts of these events have not been addressed in the literature.

Spill	***Year***	***Type***	***Region Impacted***	***Product***	***Spill Volume (tonnes)***	***Human Impact Indicators[a]***	***Health Studies***
Deepwater Horizon	2010	Wellhead blow-out	Gulf of Mexico	Crude oil	650,000	11 fatalities; 170,000 clean-up workers; 1,500 km of shoreline oiled	(4–17)
Odyssey spill	1988	Tanker	Nova Scotia, Canada	Crude oil	132,000	Offshore	None
Exxon Valdez	1989	Tanker	Prince William Sound, AL, USA	Crude oil	104,000	1,900 km of shoreline oiled	(16,18–23)
Braer	1993	Tanker	Shetland, UK	Light crude	85,000	5 km off the coast	(24–26)
Sea Empress	1996	Tanker	Southwest Wales, UK	Light crude	72,000	200 km of shoreline oiled	(27,28)
Prestige	2002	Tanker	Northwestern Spain	Heavy fuel oil	62,000	300,000 clean-up workers 1,000 km of shoreline oiled	(29–44)
Tasman Spirit	2003	Tanker	Karachi, Pakistan	Light crude	36,000	10 km of res. shoreline oiled	(45–48)
Erika	1999	Tanker	Bay of Biscay, France	Fuel oil	25,000	400 km of shoreline oiled	(49)
Hebei Spirit	2007	Tanker	Daesan, South Korea	Crude oil	10,800	8 km from coast	(50–57)
Nakhodka	1997	Tanker	Western Honshu, Japan	Crude oil	6,000	1,200 km of shoreline oiled	(58,59)
Lac-Mégantic	2013	Railcar	Lac-Mégantic, QC, CA	Crude oil	4,830	49 fatalities	None
Little Buffalo spill[b]	2011	Pipeline	Little Buffalo, AB, CA	Sweet crude	3,800	~300 community members	None
Kalamazoo spill	2010	Pipeline	Michigan, USA	Diluted bitumen	2,600	40 km of riverbank oiled	(60)
Pine River[c]	2000	Pipeline	Chetwynd, BC, CA	Light crude	885	Drinking water disrupted	None
Sundre spill[d]	2012	Pipeline	Sundre, AB, CA	Sour crude	410	40 km of riverbank oiled	None
Burnaby spill[e]	2007	Pipeline	Burnaby, BC, CA	Crude oil	201	250 homes evacuated	None

[a] Because the impacts of oil spills are difficult to characterize, factors such as economic losses, distance from shore, kilometres of oiled shoreline, population of oil coastline are often used as impact indictors

[b] ERCB, 2013. ERCB Investigation Report: Plains Midstream Canada ULC, NPS 20 Rainbow Pipeline Failure, April 28, 2011. Calgary, Alberta. Available at: http://www.aer.ca/documents/reports/IR_20130226-PlainsMidstream.pdf

[c] Environment Canada final report: http://www.env.gov.bc.ca/eemp/incidents/earlier/pembina_00.htm

[d] AER, 2014. AER Investigation Report: Plains Midstream Canada ULC, NPS 12 Rangeland South, Pipeline Failure and Release into the Red River, June 7, 2012. Calgary, Alberta. Available at: http://www.aer.ca/documents/reports/IR_20140304-PlainsRangeland.pdf

[e] Transportation Safety Board final report: http://www.tsb.gc.ca/eng/rapports-reports/pipeline/2007/p07h0040/p07h0040.asp

2 Assessing strength of evidence in epidemiological studies

Epidemiological studies seek to assess the excess risk within a population of developing a given condition or disease, and to identify the potential risk factors (or protective factors) associated with the disease. To do this, epidemiologists use a variety of statistical tools to determine whether the risk of developing a certain condition after an exposure is elevated above that of developing the condition by chance (61,62). However, the power of an epidemiological study to quantify excess risk and correctly identify risk factors is dependent on careful study design that identifies and minimizes issues with bias, confounding factors, and the effects of random chance (63,64). At the same time, it may not be possible to carry out an 'ideal' epidemiological study, particularly in observational studies where the work must be carried out under real-world conditions and time and cost constraints. Furthermore, retrospective studies (*i.e.*, conducted "after the fact") may be vulnerable to recall bias, as subjects struggle to remember details of their activities and effects. Such studies should not be disregarded, but rather contextualized through a strength of evidence approach.

The strength of evidence from the collected studies is discussed according to criteria set out by the National Research Council (65), which are used to assess both the merit of individual publications and the strength of the body of evidence as a whole. Briefly, the criteria used to assess individual papers taken into account methodological rigor, exposure characterization, use of objective *vs.* subjective measures, the presence of a dose–response relationship, biological plausibility, and the consistency and specificity of the relationship between exposure and outcome. These criteria are used to assign a category of association for the body of evidence as a whole, as follows: 1) *sufficient evidence of a causal association*, 2) *sufficient evidence of an association*, 3) *limited/suggestive evidence of an association*, 4) *inadequate/insufficient evidence of an association*; or 5) *limited/suggestive evidence of no association*.

3 Human health impact

3.1 Physical health impacts

Numerous previous studies have documented the short-term impacts of exposure to spilled oil products in a variety of contexts and populations. However, not all sectors of the population will be equally affected, which can create challenges in assessing the true prevalence of specific impacts. In the literature, investigators typically distinguish between *residents* of an affected area, who may or may not have direct contact with spilled oil, and *clean-up workers*, who are in direct contact and thus have increased exposure to spilled products as well as to hazards related to clean-up activities. This section will review the range of acute physical health impacts observed among residents and clean-up workers impacted by oil spills, and will examine how these impacts vary with exposure time and type. We will also review the evidence for long-term health impacts due to oil spill exposure and the use and efficacy of personal protective equipment (PPE) and other measures in mitigating these impacts.

3.1.1 Acute toxic impacts among residents

Few studies have examined acute physical impacts in residents, due to the fact that relatively few oil spills have happened near densely populated areas (**Table 2**). In total, three academic studies have been performed examining effects on individuals who resided in the exposure area, but did not participate in clean-up activities. After the *Braer* wreck just off the coast of Scotland in 1993, residents living within 4.5 km of the wreck site experienced a higher incidence of irritated throats and eyes compared to non-exposed residents living farther away (26). Although a brief (1-day) spike in total hydrocarbons (6.3 ppm) and benzene (0.074 ppm) were observed on the day of the accident, no differences were observed between populations in terms of respiratory function (peak expiratory flow,) liver or renal function, or biological indicators of toxicity in urine analysis (*i.e.*, presence of VOC metabolites). Most symptoms (97%) resolved within 1 week. Similarly, Lyons et al. (27) noted a range of acute symptoms after the *Sea Empress* accident in Wales in 1996. In this incident, the authors collected information on both physical symptoms, as well as data on mental health, perceived health, and anxiety. After correcting their data for differences in age, sex, smoking status, and anxiety scores observed between the exposed *vs.* non-exposed populations, the authors observed a statistically significant increase in the prevalence of headaches, nausea, sore eyes, sore throat, cough, itchy skin, rashes, shortness of breath, and general weakness among the exposed. To further refine this data, the authors also corrected for perceived changes in health status, which produced a very conservative estimation of what symptoms were most strongly linked to the spill (headache, sore eyes, and sore throat) (27).

When the *Tasman Spirit* tanker ran aground off the coast of Pakistan in 2003, it directly impacted the densely populated coastal city of Karachi. Within 3–4 weeks of the spill, Janjua et al. (46) surveyed residents living 0, 2, or 20 km from the impacted shoreline regarding a wide range of 48 respiratory, ophthalmic, neurological, dermatological, gastrointestinal, and general ill health effects. After adjusting for demographic factors as well as anxiety over health effects, the authors observed an increased risk of acute symptoms among those living on the shore (sore eyes, dry sore throat, cough, headache, irritability, fever, and fatigue), which decreased among those living > 2 and > 20 km away (46).

These previous tanker spills, although much larger in scale, show similarities in acute impacts compared to two small pipeline ruptures for which some health data are available. In the United States, a pipeline rupture in Calhoun County, Michigan, resulted in the release of roughly 3,300 tonnes of diluted bitumen into a tributary of the Kalamazoo River in 2010. Although this spill was small in magnitude compared to most of the tanker accidents noted in **Table 2**, the spill nevertheless impacted several nearby communities, as well as clean-up workers. To assess acute health impacts, the Michigan Department of Community Health launched a multi-pronged public health surveillance program, described in more detail in **Section 5.4** (60). Overall, only 18% of oil-spill related health incidents (including headaches, nausea, and respiratory symptoms) concerned clean-up workers, suggesting that residents were more frequently impacted. The number of symptoms ranged from 2.4 symptoms in cases with minor effects (45 cases), 3.7 symptoms among those with moderate effects (94), to up to 8 symptoms in a single individual (a clean-up worker) found to be showing major effects. The same study also performed surveys in four communities identified by public health surveillance as having a high incidence of oil-related health complaints. Of the 500 residents represented, approximately 58% reported one or more new or aggravated ill health effect post-spill, compared to only 4% in a distant community used as the control. These symptoms included, again, headaches, respiratory symptoms (cough, breathlessness), and gastrointestinal symptoms (nausea and vomiting). Notably, relatively few of those within the affected communities complained of anxiety (≤ 11%), but a large percentage of households (30%) opted to relocate out of the affected zone, and those who did were more likely to have reported acute symptoms. In contrast, residents evacuated in response to the Burnaby oil spill in 2007 showed very low symptom prevalence data for headaches (15%), nausea (6%), dizziness (3%), upper respiratory tract irritation (8%), and eye irritation (3%) (Fraser Health, Burnaby Environmental Health Office, unpublished data).

3.1.2 Acute toxic impacts and physical injuries among clean-up workers

Numerous studies have focused on the risk of toxic effects in workers participating in clean-up activities, who through the nature of this work have heightened exposure to spilled oil. These clean-up workers may include non-resident volunteers, resident volunteers, paid untrained workers, and paid, trained professionals. Headaches, respiratory effects (cough, wheezing, breathlessness), gastrointestinal symptoms (nausea and vomiting), and sore eyes and throats are among the most common acute symptoms faced by clean-up workers (35,39,45,54,58,66), the risk of which is typically increased by prolonged duration of work. After the *Nakhodka* ran aground off the coast of western Honshu, Japan, residents who volunteered for clean-up work showed acute symptoms including primarily irritated eyes and sore throats, and approximately 57% of men and 78% of women experienced at least one of these symptoms. However, both environmental and personal air quality monitoring revealed that airborne hydrocarbons were well below occupational exposure limits, and hydrocarbon metabolites were not significantly elevated upon urine analysis. In a more detailed analysis, Suárez et al. (35) found that acute symptoms differed markedly amongst clean-up workers (volunteers, salaried workers, bird cleaners and seamen) depending on the type of activities performed, information made available to them, and their degree of contact with the spilled oil. For example, seamen removing oil at sea showed the highest prevalence of headaches (28%), throat and respiratory complaints (30%), and dizziness, nausea and vomiting (15%). Seamen were the most frequent to report distressing odours; they were also largely smokers, often working with damaged or no protective equipment in the most polluted areas for the longest periods, had eaten while in contact with oil, and were the least informed regarding safety (35,39). In contrast, paid workers showed only small increases in the prevalence of acute symptoms, even though they had been involved in clean-up for a much longer duration. However, for all groups, the risk of experiencing acute symptoms increased with having worked for more than 20 days, working in the most polluted areas, and getting oil on the head or neck (35). Working on the water may also entail increased exposure, as VOCs may have had less time to volatilize. In the *Tasman Spirit* spill, cleaning freshly spilled oil from the water was associated with impaired respiratory function (FEV_1, FVC, $FEF_{25\text{-}75\%}$, and MVV) compared to age- and gender matched controls (48).

The *Hebei Spirit* oil spill in South Korea in 2007 offered a unique opportunity to better understand the acute health impacts of oil spills. Because the accident occurred near a densely populated area, several of the studies carried out were able to analyze large study populations. In the immediate aftermath of the accident, a large number of volunteers (~200,000 people) mobilized for the clean-up. Sim et al. (57) reported that, among 846 volunteers surveyed, 30% reported headaches, 18% reported eye symptoms, 28% reported nausea, dizziness or drowsiness, and 41% reported respiratory symptoms after participating in less than 2 weeks of clean up work. The occurrence of headache and respiratory symptoms were related to increased number of days worked and longer working days, respectively (57). Similarly, Korean military personnel (*n* = 3,198) who were involved in clean-up activities for more than 4 weeks showed increased self-reported prevalence of specific acute effects, including neurological (headache, dizziness, nausea, fatigue, and insomnia), respiratory (sore throat, dry mouth, cough, and phlegm production), dermatological (itchy skin), and eye (sensitive, itchy or watery eyes) symptoms compared to individuals who worked for a week or less (54). In the same study, an increase in the prevalence of acute symptoms was also observed for people working in a heavily polluted region compared to those working in less severely impacted regions. These, and other, studies are of note because they suggest a clear dose–response relationship between oil spill exposure and severity of effects.

Three studies also used urine analysis to link VOC, PAH, and heavy metal exposure with specific symptoms. Overall, Cheong et al. (52) found that clean-up workers showed elevated levels of mandelic acid, an indicator of styrene exposure, as well as elevated levels of urinary lead, mercury, and cadmium compared to unexposed residents of an unaffected community. After adjusting for a number of health-related factors and overall degree of health concern, multiple logistic regression showed that urinary levels of hippuric acid and methyl hippuric acid (indicators of toluene and xylene exposure, respectively) were associated with increased risk of nasal irritation, vomiting, and fatigue/fever. Urinary lead, mercury, nickel, and cadmium levels were associated with increased risk of eye irritation, dermal irritation and headache (52). Ha et al. (56) improved on these findings by examining urinary metabolites in student volunteers after a single day of clean-up work, and found elevated levels of *t,t*-muconic acid, mandelic acid, and 1-hydroxypyrene (indicators of benzene, styrene, and PAH exposure, respectively). However, although workers in both of these previous studies showed increased prevalence of acute symptoms (visual disturbance, nasal and bronchial irritation, headache, palpitation, abdominal pain, memory/cognitive disturbance, and fatigue/fever), and the risk of these symptoms increased with the duration of work, these symptoms were for the most part not statistically related to urinary metabolite levels (52,56). Furthermore, although workers showed increases in urinary metabolites relative to their pre-exposure baseline, the absolute and relative increase in VOC metabolites was small compared to occupational exposures in other industries (67).

3.1.3 Potential health effects of dispersants

In addition to the toxic components of spilled oil, additional toxic exposures can be generated through the use of chemical dispersants during clean-up. Although these substances have been in use for decades, the U.S. EPA recently asserted that their use should be minimized due to their demonstrated toxic effects on aquatic species, in which the combination of dispersants with oil was found to be more toxic than either oil or dispersant alone (68). However, during the *Deepwater Horizon* disaster, the scale of the accident demanded a similarly unprecedented degree of dispersant use, with roughly 6.8 million liters applied over the first 3 months of the spill (69).

Unfortunately, very little has been published regarding the human health effects of dispersants. Exposure is thought to occur through inhalation of droplets when the compound is sprayed over water from air planes or boats. In human airway epithelial cells, exposure to the dispersants COREXIT EC9500A and EC9527A caused dose-dependent decreases in cell viability, increased expression of the LC3B protein (a marker of type II cell death), and markers of oxidative stress (70); similar results were also observed in human hepatocytes (71). D'Andrea and Reddy (4) found that workers exposed to a combination of spilled oil and the dispersant COREXIT for more than 3 months during the *Deepwater Horizon* clean-up showed altered haematological profiles (decreased platelet counts and increased haemoglobin and hematocrit), as well as several indicators of liver and renal dysfunction. These changes were associated with the presence of phenol in the urine, an indicator of oil-derived benzene exposure, which highlights the difficulty of separating effects due to oil *vs.* dispersant exposure. These physiological changes were also persistent, in that they were detected from 0–19 months after the accident (4). These indicators signal that further investigation of dispersants is warranted.

3.1.4 Long-term physical impacts

Compared to the documentation of acute physical impacts, relatively little has been published regarding the long-term effects of oil spill exposure, due to the difficulty and expense of following subjects over long periods of time. However, in general, the literature suggests that acute impacts observed in residents and clean-up workers in the months following an oil spill do not persist over the long term (>1 year). For example, although immediate short-term impacts (itchy eyes and sore throats) were reported among local area residents after the MV *Braer* wreck, detailed analysis for toxicological markers and impacted liver, renal, or respiratory function showed no significant differences at the time of the accident or six months later, although exposed individuals did perceive that their general physical health had declined since the spill (non-specific malaise) (25,26). In contrast, residents who were directly involved in clean-up activities, which implies a greater degree of exposure, showed a more complex recovery over the year following the *Hebei Spirit* accident. After a relatively short period of clean-up work (<2 weeks), headaches (37% of workers) persisted for a mean duration of 8.4 months, eye symptoms (20%) for 9.7 months, skin symptoms (7%) for 8.3 months, respiratory symptoms (39%) for 2.1 months, and nausea, dizziness or drowsiness (35%) for 6.9 months (51,57). Within this short period of work (< 2 weeks), the total duration of work (days worked) was not correlated with the duration of symptoms (51), suggesting that exposure incurred during the first two weeks past a threshold pre-disposing the respondents to slightly longer term effects.

It is important to note that, in this previous study, exposure duration (participation in clean-up work) was relatively short (< 2 weeks). In contrast, a much larger cohort study following a group of fishermen involved in the *Prestige* response, the majority of whom had participated in clean-up work for weeks to months, found that respiratory symptoms persisted over much longer periods of time. A year after the accident, Zock et al. (37) found that lower respiratory tract symptoms (persistent coughing, wheeze, breathlessness, and phlegm production) increased significantly with the amount of time spent performing clean-up activities (days worked and hours per day). Two years after the accident, the same cohort of exposed fishermen ($n = 501$) continued to show increased prevalence of lower respiratory tract symptoms compared to those who did not participate in the clean-up ($n = 177$) (30). Although the exposed fishermen showed no difference in lung function (FEV1, FVC), they did identify elevated levels of markers of oxidative stress (8-isoprostane) and elevated growth factors (VEGF and bFGF) in exhaled breath condensate. Although the relevance of these sub-clinical indicators is unclear, the authors attributed their presence to *ongoing or persistent airway injury* in exposed fishermen. Similarly, five years after the spill, self-reported upper and lower respiratory tract symptoms remained elevated among exposed fishermen compared to non-exposed fishermen. However, during the final follow-up performed 6 years after the spill, issues such as loss to follow-up and health variation within the relatively small control group meant that although several objective measures suggested persistent respiratory health effects among the exposed, these effects could not be unequivocally attributed to spill exposure (44).

Similarly, studies on the endocrine impacts over time showed persistent endocrine and immunological change among clean-up workers. Of primary concern are the effects of PAHs, which are known endocrine disruptors (72). In a series of three cross-sectional studies concerning the *Prestige* oil spill, researchers used plasma levels of the hormones prolactin and cortisol as indicators of endocrine disturbance. Roughly six months after the spill, Pérez-Cadahía et al. (40) noted a trend toward elevated prolactin and a significant decrease cortisol levels among clean-up workers *vs.* an unexposed control, indicating that the endocrine status of these individuals had been affected. These changes were furthermore associated with the levels of various heavy metals in the blood of those exposed (41). Notably, exposure-related changes in several hormones were in evidence as late as seven years after the accident; exposed fishermen, not previously examined by the authors, showed increased cortisol levels and decreased natural kills (NK) cells ($CD16^{+}56^{+}$ lymphocytes) (42), which are known for their role in the suppression of tumours (73).

Given the known toxicological characteristics of specific petroleum components (**Table** 1), there is considerable public concern regarding teratogenic, mutagenic, and carcinogenic effects in contaminated communities. To date, there is no literature examining the occurrence of teratogenic effects in humans exposed to oil spills. Furthermore, excess carcinogenesis in response to an environmental exposure is extremely difficult to detect due to the long periods required for cancers to manifest, further confounded by individual susceptibility and migration in and out of the study area during the long lag time (usually decades). To date, there is no definitive or suggestive evidence linking an oil spill (a one-time event) with increased cancer incidence. However, a number of studies have provided evidence of genotoxicity in response to oil spill exposures, which refers to damage to genetic material that may result in mutations and, potentially, cancer. Such studies make use of genotoxic assays that detect DNA damage in exposed *vs.* unexposed groups, which are then used to determine the need for additional long-term follow-up.

After the *Prestige* spill in northern Spain in 2002, a number of cross-sectional studies examined indicators of genotoxicity among residents and clean-up workers for up to 7 years after the accident. Shortly after the spill, Pérez-Cadahía et al. (43) noted increased cytogenetic damage (structural alterations in chromosomes) in clean-up workers using high-pressure spray cleaning equipment, which was associated with low-level chronic exposure to total VOCs and BTEX specifically over the course of three months, as well as elevated blood concentrations of heavy metals. Similarly, Laffon et al. (31) found that young adults involved in bird cleaning and autopsies showed genotoxic effects (DNA damage), which may or may not be repaired, but did not show cytogenetic damage, which implies a higher level of damage; notably, environmental VOC exposures in this study did not exceed levels of concern. Two years after the Prestige spill, Rodríguez-Trigo et al. (30) observed structural chromosomal alterations among fishermen who had participated in spill clean-up. However, after 7 years, Laffon et al. (29) found no evidence of persistent genotoxic effects in a group of similar study subjects. Although genotoxic effects were not observed in this final study, the authors noted that because it had become increasingly difficult to recruit participants after so much time had passed, their small study may have had limited statistical power to detect such changes.

Importantly, polymorphism in genes involved in DNA repair appear to influence susceptibility to these oil-related cytogenetic and genotoxic effects. For example, Laffon et al. (31) found that carrying specific variants of the XRCC1 and APE1 genes increased the risk of oil exposure-induced DNA damage. Pérez-Cadahía et al. (40,43) linked polymorphism in the GSTM1, CYP1A1, EPHX1, and the GSTP1 genes with increased or decreased susceptibility to chromosomal damage. Thus, within groups of exposed individuals, some will be more affected.

3.1.5 Physical injuries associated with clean-up work

In addition to toxic effects due to oil and dispersants, clean-up activities are also associated with increased incidence of physical injuries, primarily lower back pain (35,56–58,66). Although lower back pain was the most prevalent physical injury reported within and among studies, data collected in the year following clean-up activities suggest that this condition resolved itself relatively quickly, with a mean duration of 1.8 months among volunteers participating in the *Hebei Spirit* clean-up (51). Other physical injuries noted in these studies included limb pain, cuts, bruises, blisters, scrapes, and broken bones and teeth, which are in keeping with the strenuous and physically hazardous nature of clean-up work. During the *Deepwater Horizon* clean-up, heat stress was identified as a key risk factor in a variety of activities, which was related to the use of PPE and the fact that the clean-up operations extended throughout the summer months (66). Bird cleaning, in particular, was associated with a higher overall rate of physical injuries (~19% of injured workers in a single study), as might be expected when handling wild animals (35,66). When considering acute toxic effects (above) and injuries together, Suárez et al. (35) found that roughly 44% of workers reported at least one of these adverse outcomes as a result of participating in clean-up activities.

3.1.6 Utility of personal protective equipment (PPE) and safety orientation

Studies focusing on both acute and long-term symptoms of exposure to oil spills have also provided insight into the appropriate and sufficient use of personal protective equipment

(PPE). As described in the following sections, the majority of studies demonstrate a significant association between acute symptoms and the duration or intensity of exposure, which can be mitigated through the proper use of PPE.

Due to the numerous oil-derived toxins that can be inhaled, the use of an appropriate mask is paramount. In the *Hebei Spirit* spill, clean-up workers who used their masks properly showed a significantly lower self-reported prevalence of specific neurological and respiratory symptoms, including headache, nausea, dizziness, fatigue, sore throat, dry mouth, and runny nose (54,57). Zock et al. (37) likewise reported that clean-up workers who consistently wore their masks showed lower prevalence of lower respiratory tract symptoms (wheezing, cough, shortness of breath, and phlegm). On the other hand, workers who were inappropriately equipped (cloth masks) show very high prevalence of acute symptoms, including headache (28%), respiratory problems (38%), and nausea/vomiting (24%) (45). Regarding DNA damage and its potential long-term consequences, Laffon et al. (31) showed that wearing a cellulose mask reduced the prevalence of genotoxic effects in volunteer bird-cleaners, who tended to work indoors and may thus be exposed to poorer air quality.

Regarding the use of protective, waterproof clothing, wear-and-tear appears to make a difference. Failure to wear a suit at all increased the risk of skin lesions (rash, scrapes, blisters), eye symptoms, as well as nausea, dizziness, and drowsiness (57). Clean-up workers who re-used protective clothing and masks show increased chromosomal damage and elevated blood cortisol levels compared to workers with new suits (43). In fact, Suárez et al. (35) showed that workers who wore damaged protective suits showed more severe effects (especially nausea, vomiting, dizziness, respiratory symptoms, and physical lesions) than workers whose suits were used properly or those without suits at all, perhaps due to behavioural factors (*i.e.*, a false sense of security coupled with decreased caution leading to heightened exposure/injuries). Suárez et al. (35) also identified a unique risk factor for many of the acute symptoms observed among clean-up workers — having physical contact with oil on the face or neck — which the authors speculated could facilitate toxic effects via inhalation. However, in the same study, the authors noted that the majority of otherwise well-equipped clean-up workers did *not* make use of protective head-gear (hats or hoods), which may help to reduce this exposure. Failure to wear appropriate overalls and boots was found to be significantly associated with elevated urinary mercury levels (74).

Timely and thorough health and hygiene information is key to preventing acute toxic impacts among clean-up workers. Carrasco et al. (39) found that workers who received health information were more likely to use a more complete array of safety equipment (goggles, gloves, mask, suit, and boots), and less likely to work in damaged or torn equipment. In contrast, workers who did not receive a safety orientation demonstrated elevated risk for all acute symptoms, including itchy eyes, throat and respiratory complaints, and nausea, dizziness, and vomiting.

3.2 Mental health and related community health impacts

As noted by a number of investigators examining acute health impacts (27,46,52,60), environmental disasters can create a degree of anxiety among the affected population that may lead to over-reporting or exaggeration of acute symptoms (*e.g.*, prevalence of headaches or other effects). This can be corrected for statistically. However, mental health impacts are a serious public health concern in their own right and figure prominently in the literature on health impacts due to oil spills. This section will attempt to summarise some of the most commonly observed mental health impacts on communities as a whole and specific sub-populations therein, as well as to demonstrate the differences encountered when attempting to assess and mitigate mental *vs.* physical health impacts.

3.2.1 Short- and long-term mental health impacts

Mental health impacts can be observed in the short-term among those affected by oil spills. Within four weeks of the *Sea Empress* spill, Lyons et al. (27) saw a highly significant worsening in mental health scores and an increase in anxiety scores among the urban residents of towns directly impacted by the oil slick, in addition to the marked physical health impacts discussed in **Section 3.1.1**. These changes were significant both with respect to an unexposed control population living some distance away on an unaffected coastline, and with respect to baseline regional mental health data that had been collected two years before the wreck. Immediately after the MV *Braer* incident, exposed residents demonstrated more instances of mood change, both relative to their condition before the incident and with respect to unexposed control subjects (26). Furthermore, 6 months later, follow-up of the same cohort revealed that 24% of exposed individuals demonstrated mental health scores above the threshold of clinical concern (using a validated instrument), compared to only 3% of control subjects, with notable changes in those suffering from anxiety and insomnia, but not from personal dysfunction or severe depression (25). However, it should be noted that this follow-up study provided very little detail regarding some of the mental health measures used, and thus the strength of evidence for this particular paper is weak.

Very few studies have followed the mental health of oil-exposed populations over the long-term. The exception to this is work done in Alaskan communities impacted by the *Exxon Valdez* disaster in 1989. In Cordova, a community dependent upon a subsistence fishery badly impacted by the spill, residents showed changes in indicators of post-traumatic stress, including greater degrees of *intrusive stress* (recurrent, unprovoked, negative thoughts about the event) and a*voidance behaviour* (suppression of thoughts/behaviours related to the event) (16). Although intrusive stress declined somewhat over time, it remained significantly elevated compared to the less-impacted control community at 18 months after the spill, whereas avoidance behaviour remained constant over time. These data indicate the presence of persistent psychological harm over time at the individual level. Palinkas et al. (20,21) reported strong evidence of increased prevalence of psychiatric disorders among members of 11 Alaskan communities, which was significantly associated with an individual's degree of spill exposure (none, low, or high). After controlling for confounding factors, highly exposed individuals were found to be 3.7-fold more likely to show strong clinical indicators of generalized anxiety disorders (GAD), 2.6-fold more likely to show indicators of post-traumatic stress disorder (PTSD), and 2.13-fold more likely to show depressive symptoms above a threshold of clinical concern compared to unexposed individuals. Depressive symptoms were furthermore significantly associated with post-spill deterioration in social relationships, both within the family and with members of the broader community, signalling a linkage to higher level social disruption, conflict, and stress (22). Even 6–8 years after the spill, the elevated prevalence of anxiety, depression, and post-traumatic stress was observed among fishermen and fisherwomen, compared to baseline data; these effects were related to factors such as loss of income, involvement in litigation, and deterioration of kin and non-kin relationships (19). Seeking compensation through litigation can be particularly harmful, as the legal process itself requires the plaintiff to continually re-engage with stressful past experiences while detracting from other important activities, often over an extended period of time. This has been alternately termed 'litigation response syndrome' or 'forensic stress disorder' and involves a wide range of symptoms (anxiety, depression, irritability, emotional detachment, burnout, obsessive fixation) (75). For example, long-term data collected after the *Exxon Valdez* showed that simply being involved in litigation was linked to individual stress, work disruption, increased perceived risk of future oil spills, and lack of trust in institutions; all of these factors were also significantly associated with an increase in the individual's perception of damage to the community as a whole (76). Collectively, these studies demonstrate the long-term mental health impacts that spills may exert on local residents, particularly when those residents are heavily dependent on natural resources impacted by the spill (*i.e.*, so-called 'natural resource communities') (77).

These data from the *Exxon Valdez,* which demonstrate the severe and lasting impacts of oil spills on mental health, have prompted intensive research in the aftermath of the *Deepwater Horizon* disaster. Five months after the event, Gill et al. (15) collected data on psychological stress from residents (*n* = 412) of Mobile County, Alabama, and compared their findings to earlier data collected from Cordova, Alaska, after the *Exxon Valdez.* It was revealed that total impact and avoidance behaviour scores demonstrated by Mobile County residents were similar to those demonstrated by Cordova residents five months after the 1989 spill. As in Cordova in 1989, roughly 50% of the population reported being moderately or severely distressed by the incident and this stress was linked to the perceived risk of health impacts, worry for current and future income loss, and having ties to natural resource-based industries. Given this similarity in initial event-related psychological stress, the authors postulated that some of the more serious, long-term effects related to the *Exxon Valdez* might also manifest in Mobile County and other areas impacted by *Deepwater Horizon* (15).

Comparisons such as this one have prompted several large-scale studies, including the Mental and Behavioral Health Capacity Project (MBHCP) run by Louisiana State University[1] and the GuLF Worker study run by the National Institute of Environmental Health Sciences

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[1] Further details on the MBHCP can be found at: http://www.medschool.lsuhsc.edu/psychiatry/mbhcp.aspx

(NIEHS)[2], for which final data are not yet available. However, the Substance Abuse and Mental Health Services Administration (SAMHSA), in partnership with the Centers for Disease Control and Prevention (CDC) recently published survey results probing the acute effects of *Deepwater* on mental health impacts and substance abuse. This report, which in fact made use of data from three large-scale, population-based surveys, presented a mixed picture of mental and behavioural health[3] in the region. The data showed some evidence of a greater increase in substance abuse in some age groups in the pre- *vs.* post-spill period, compared to smaller increases during the same period in non-impacted areas of the Gulf Coast and the United States as a whole; however, there was no evidence of worsened mental health (*e.g.*, depressive episodes, suicide ideation, psychological distress, or healthcare utilization). In coastal *vs.* non-coastal communities of the Gulf states, reports of decreased household income and job loss were notable among coastal communities, but marked differences in mental health (depression, anxiety) were not observed (78). However, it should be noted that these surveys were blunt instruments that analyzed data across the entire population and did not investigate effects in potentially vulnerable sub-populations according to personal impact, socioeconomic factors, or being involved in specific industries (*e.g.*, fishing, clean-up work).

In contrast, a number of community-level assessments have suggested that residents of coastal areas did indeed show evidence of unusually prevalent mental illness in the year following the spill. Osofsky et al. (9) found that living closer to the oil spill was significantly associated with increased symptoms of post-traumatic stress, depression, and anxiety; overall, the prevalence of symptoms related to post-traumatic stress (12%) and mental illness (15%) in the impact area were well above the national baseline (3% and 6%, respectively). In a study of two communities coping with the *Deepwater Horizon* disaster, Grattan et al. (8) found that community members who lost income during the first months of the spill reported clinically significant levels of anger, fatigue, depression, tension/anxiety, and confusion compared to community members who were income stable. Furthermore, those who lost income showed a lesser degree of personal resilience and were more likely to behaviourally disengage or 'give up' coping with their distress, as determined

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[2] Further details on the GuLF study can be found at: http://www.niehs.nih.gov/research/atniehs/labs/epi/studies/gulfstudy/index.cfm

[3] Although 'mental health' and 'behavioural health' are often used interchangeably, in the referenced studies behavioural health impacts are referring (somewhat contentiously) to substance misuse disorders.

using clinically validated, standard measures, and thus may be more vulnerable to further psychological issues. One year after the accident, Morris et al. (5) found that the number of people showing signs of clinically significant anxiety and depression had dramatically *increased* within the lost-income group, indicating an exacerbation rather than amelioration of these impacts over time.

In a survey taken 5 months after the spill, Buttke et al. (6) reported that depression scores among Mississippi residents increased significantly post-spill compared to all-state data collected the year before the spill; this response was also observed for two coastal counties in Alabama, although the increase did not reach statistical significance. Importantly, residents who reported a loss in income also showed statistically significant increases in scores for depression and anxiety, and income loss was associated with increased stress regarding one's ability (or inability) to pay rent or the mortgage, a concern which spiked in mid-2010 (post-spill) compared to the previous state baseline in 2009 (6). Notably, mental health scores showed some improvement 1 year later, which may have been related to increased mental health care provision as a result of the previous year's study (7). Thus, although the studies by Buttke et al. were somewhat hampered by design limitations (*e.g.,* patchy baseline data), they demonstrate trends toward decreased mental well-being in coastal Alabama and Mississippi after the spill, likely related to income loss and financial uncertainty.

Finally, as mentioned, specific sub-populations tied to natural resource-based industries may have been disproportionately affected by the *Deepwater Horizon* spill. Cope et al. (10) found that households dependent on regionally impacted fisheries were particularly vulnerable to *worsening* health impacts over time, both in terms of physical health impacts (chest pain headaches, loss of appetite, joint pain, *etc.*), as well as affective or emotional state (feelings of sadness, worry, depression, anger, *etc.*). Oil and gas workers affected by the drilling moratorium were not affected to the same degree. In a much more specific analysis of a vulnerable sub-population, Ngo et al. (12) examined oil spill impacts among the Vietnamese coastal Gulf community, of whom an estimated 70–80% work or are associated with the seafood industry. In this qualitative study, participants in focus groups held in three Gulf cities (in Louisiana, Alabama, and Mississippi) frequently reported mental and somatic symptoms commonly associated with anxiety and depression, including constant worry, poor appetite, difficulty sleeping, irritability, weakness, fatigue, and indigestion. Participants also reported widespread loss of income (58% of respondents), loss of employment (27%), and being unable to pay bills (12%) (12). Taken together, these studies demonstrate the very great importance of analyzing effects in vulnerable sub-populations, which may otherwise be missed in broader-scale analyses of population data (*e.g.,* as in the SAMHSA report).

The *Prestige* accident in particular sheds light on the complex interplay of physical and social factors than can affect the assessment of mental health impacts, and serves as a very interesting contrast to the devastating long-term impacts of the *Exxon Valdez* spill, and the now emerging impacts of *Deepwater Horizon*. In a large study examining 2,700 coastal *vs.* inland residents 1.5 years after the accident, Carrasco et al. (33) analyzed health impacts according to two different characterizations of exposure. In the first, impacts were analyzed according to residence in a coastal *vs.* inland town, among subjects who otherwise showed similar socio-demographic and economic characteristics; this perspective revealed that coastal residents showed poorer general and mental health scores compared to inland residents, which were attributed to greater spill exposure (33). These results were roughly paralleled by Sabucedo et al. (34), who found that individuals living closer to the spill showed poorer mental health than those residing farther away. However, in a second analysis, Carrasco et al. (33) analyzed health impacts according to a detailed *individual* exposure index, dependent on factors like having participated in clean-up, having had to give up certain leisure activities, working as a fishermen, *etc*. The exposure index used here was very similar to that used by Palinkas et al. (21,22), and thus is also reflective of a natural resource-based community. However, analyses according to individual exposure level suggested that the highest level of exposure was in fact *inversely* related with depression. This somewhat counterintuitive finding was attributed, by the authors, to the rapid pay out of government aid to seriously affected individuals within 1-12 months of accident,[4] which may have alleviated economic distress, as well as an overwhelming show of social support in the form a very large volunteer clean-up response (32,33). Indeed, in a related study, individuals who reported a high degree of community support and overall

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[4] As noted by Carrasco et al. (33), the Spanish government responded quickly to the *Prestige* disaster, allocating €24 million in financial aid within 1 month, and an additional €114 million to fishermen within a year. The wider region also benefited from *Plan Galicia,* a €12 billion economic stimulus package aimed at education and infrastructure, which was approved within 2 months of the disaster.

satisfaction with compensation received showed improved scores for specific mental health indicators (somatization[5], inter-personal sensitivity, anxiety, hostility, and depression) compared to individuals who were less satisfied with financial aid received (32). In fact, individuals who were highly satisfied with compensation received showed improvements even over those *unaffected* by the spill on some indicators. Thus, social support (in the form of *both* financial aid and volunteer assistance) may have helped to avert some of the more severe effects observed after the *Exxon Valdez* spill.

Taken together, the studies from the *Exxon Valdez* and *Deepwater Horizon* disasters strongly suggest that spill-related income loss and financial uncertainty exert psychological distress on local populations, leading to mental health impacts. Furthermore, when compared with the positive effects of compensation satisfaction on depression scores observed among those most severely impacted by the *Prestige* spill, the data suggest that mitigating personal financial losses may be one of the most effective ways to avert or ameliorate mental health impacts.

3.2.2 Spatial and temporal considerations in mental health impacts

Mental health impacts are also different from physical health impacts in that the distinction between those who are 'exposed' and those who are 'unexposed' is more difficult to define. In a study of two communities on the Gulf Coast, Grattan et al. (8) found similarly heightened levels anxiety and depression in both communities compared to the regional norm, even though only one of these communities had been directly impacted by an onshore oil slick. The authors attributed this broader regional effect to the fact that although oil may not come ashore in a specific place, community members nevertheless view the same media coverage, take precautionary measures against the arrival of oil, and may leave their town to earn a livelihood or assist with clean-up in directly impacted areas. Similarly, Gallacher et al. (28) showed that although the reporting of acute toxicological symptoms was more strongly associated with geographically determined oil exposure, the reporting of mental health effects, such as anxiety and depression, were more strongly related with an individual's perceived risk of exposure on his or her well-being and

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[5] *Somatization* refers to the physical manifestation of psychological stress through physical complaints.

enjoyment, regardless of whether or not physical exposure occurred. The authors referred to this as 'psychological exposure,' and found that the estimated number of people impacted psychologically within the communities surveyed was in fact greater than the number of people potentially impacted by toxicological symptoms and reached well beyond the physical bounds of the exposure area (28).

Mental health impacts may also be heightened or exacerbated by previous experiences with other types of disasters in a given region. In their examination of post-*Deepwater* mental health impacts, Osofsky et al. (9) presented evidence suggesting that previous trauma from Hurricane Katrina may have subsequently predisposed members of Gulf communities to more severe mental impacts in the wake of the *Deepwater Horizon* disaster. Taken together, these studies demonstrate that, in contrast to physical health impacts, which are more predictably delineated by the exposure zone, mental health impacts may be observed over larger areas and may vary with regional context.

3.2.3 Mental health impacts on children

Furthermore, mental health impacts are not limited to adults. A large study (n = 1,361 participants) carried out after the *Hebei Spirit* spill in Korea found that elementary school-aged children attending school close to the affected coastline had a significantly higher risk of depressive symptoms, especially among girls, compared to their peers attending schools farther from the affected area. This risk remained elevated even after correcting for age, gender, time since the accident, and health concern/anxiety regarding the spill; furthermore, risk increased as distance to the contaminated coastline decreased. The risk of anxiety showed a similar trend, but did not reach statistical significance (53). Similarly, after the *Deepwater Horizon* disaster, Abramson et al. (13) reported that 27.5% of the children within the exposed survey population had experienced some form of mental distress (feeling sad, depressed, or fearful, having trouble sleeping or interacting with peers) during the first 3.5 months of the spill, compared to only 10.9% of non-exposed children. Furthermore, among the exposed, the percentage of children experiencing mental health effects appeared to increase among African American children compared to Caucasian children, and among children from low-income families (earning <$25,000 per year) compared to children from higher income families.

3.2.4 Mental health impacts on indigenous communities

Importantly, not all members of society are affected equally. In the wake of the *Exxon Valdez* disaster, several papers were published that probed the difference in mental health impacts between the community as a whole *vs.* that of local indigenous communities. Palinkas et al. (21) showed that indigenous Alaskans who were 'highly exposed' to the *Exxon Valdez* oil spill showed a significantly greater likelihood of depressive symptoms compared to the unexposed individuals and compared to exposed non-indigenous community members. As in non-indigenous communities, depressive symptoms were associated with deterioration of kin and non-kin relationships among indigenous community members, but to a greater degree; these data suggested that indigenous communities suffered greater damage to broader social support systems on which individuals rely during times of stress (22). Similarly, vulnerability to PTSD among indigenous community members was linked to a decline in family support, having participated in the clean-up, and turning away from culturally and economically valuable subsistence activities (79).

These severe mental impacts among indigenous community members may be surprising given that indigenous Alaskan communities participated to a greater degree in clean-up activities and thus saw the largest increase in household income because of these activities; however, increased income was reported as a negative impact as it created or enhanced unwanted social stratification (22). These psycho-social health impacts may be further related to other profound changes in the community, including the rise of a profound distrust of traditional food sources that could not be assuaged (or even communicated) through a conventional toxicological risk assessment approach, and subsequent feelings of loss or erosion of cultural identity when subsistence activities could not be continued (18). Researchers also noted heightened stress due to increased intra-community conflict, loss of privacy due to the influx of newcomers and state officials, and feelings of betrayal and dissatisfaction over how litigation and settlement proceeded (18). Overall, these collected studies suggest that indigenous communities, as a subset of natural resource-based communities, are particularly vulnerable to the mental and psychosocial impacts of oil spills.

3.3 Impacts on community health and resilience

Cumulatively, physical and mental health impacts at the individual level may lead to significant community impacts. In this section, we review literature that moves beyond the acute symptomology of mental health impacts to understand the root causes of these impacts and their implications for the overall health and resilience of communities.

3.3.1 Health care utilization and availability of services

Given the increase in physical and mental health impacts post-spill, it is reasonable to expect that spills will affect communities and governments in terms of their ability to access and provide services, respectively. After the *Sea Empress* spills, Lyons et al. (27) found that exposed residents were 2.3-fold more likely to consult a doctor; overall, roughly 10% of the exposed population visited a doctor in the first 4 weeks of the spill, compared to approximately 5% of the control population. After the Kalamazoo/Enbridge spill, a total of 145 spill-related visits to health care providers were captured through the public health surveillance system and roughly 12% of respondents from selected impacted communities reported visiting a doctor; however it is not clear whether these cases represented a significant increase over normal health care use (60). Medical visits and time required for recovery may subsequently impact productivity. Among those reporting acute effects from the *Tasman Spirit* spill, the mean number of days of missed work was 2.9 ± 6.3 days for those living on the shore (*i.e.,* the high-impact zone) *vs.* 1.0 ± 3.4 or 0.2 ± 1.5 days for those living 2 or 20 km away (46).

On the provider side, work on the *Exxon Valdez* spill indicated that the influx of people arriving for clean-up work and the rise in social conflict, alcoholism, drug abuse, and domestic violence strained the ability of small communities to provide social services (23). In contrast, on a much broader scale, the SAMHSA report (78) did not show an increase in overall health service utilization shortly after the Gulf Oil spill, although several initiatives were rapidly established to increase mental health services (7,80). Long-term assessment is required to determine whether or not this additional service provision was useful or effective.

3.3.2 Shifts in 'trusted' information sources

Public perception of the trustworthiness of various sources of information has implications for the rapid and effective communication of health information during a crisis. During the *Deepwater Horizon* disaster, the majority of coastal residents turned to television and newspapers as their perceived 'most reliable' source of health information (8). However, it was also noted that watching a large amount of media was associated with a state of negative hyperarrousal among viewers, suggesting that the media itself may exacerbate negative, anxiety-related health impacts (5). It was also observed that more people placed their trust in neutral governmental organizations (*e.g.,* the Coast Guard) than in the oil company (British Petroleum) or partisan public figures like the President (13). In contrast to these findings, Grattan et al. (8) found that people directly impacted by the *Deepwater Horizon* disaster were in fact *more* likely to trust the oil company (British Petroleum) than community members who were less impacted, and to trust health officials less. This counterintuitive result may be explained by the work of Safford et al. (17), who found that people who received compensation from BP (and thus had likely been seriously impacted) were more likely to perceive BP as effective in the spill response; compensation may thus have worked to overcome some of the initial ill feeling caused by the spill itself.

Work from the *Prestige* spill suggests that these shifts in trust or losses in confidence may also be related to the degree of social support perceived by the affected individual. Sabucedo et al. (32) found that people who had been affected by the spill and reported low social support (from family, friends, co-workers, society in general, and the authorities) showed decreased confidence in political leaders and various government institutions compared to those who were unaffected by the spill or those who were affected, but reported high social support. In the same study, individuals who were satisfied with the spill compensation received showed a greater degree of confidence in the same leaders and institutions.

3.3.3 Changes in food provision and reliance

In Alaskan communities impacted by the *Exxon Valdez* spill, both indigenous and non-indigenous community members reported a significant decrease in subsistence activities, which was linked with exposure status (high, low, or none). Decreases in time spent hunting, fishing, and gather, the total amount of natural foods harvested, and the amount of natural foods shared with or received from others were attributed to three primary reasons, including inability to access resources (*i.e.*, fishing grounds closed), food safety concerns, and lack of time due to involvement in clean-up activities (20). Indigenous communities, in particular, showed great distrust of potentially contaminated traditional foods, and conventional approaches to discussing or framing risk were wholly ineffective in assuaging this distrust (23).

Similarly, in the *Deepwater Horizon* disaster, 65% of respondents contacted through a telephone survey believed that seafood coming from the Gulf of Mexico was unsafe to eat (13). This level of distrust persisted despite strong messaging from health and government authorities ensuring that the toxicological risk of consuming Gulf-sourced seafood was minimal (13), which was in turn based on a widespread seafood testing campaign carried out by scientists and state and federal regulators (81). Although valid criticism had been raised regarding the methods and assumptions used in these toxicological risk assessments, foodborne contaminants (PAHs) did not exceed levels of concern even when more rigorous assumptions were applied to the original test data (82). Taken together, these studies show that oil spill impacts on food, which exert strong cultural, economic, and personal impacts on affected populations, merit special consideration in terms of effective risk communication and appropriate valuation of these losses.

3.3.4 Disruption of social networks and social order

A great deal of research from the *Exxon Valdez* has focussed on indicators of community disruption and social stress. In Cordova, Alaska, community members dependent on a heavily impacted subsistence fishery reported significant negative changes to their community life, work activities, family life, and personal stress levels up to 18 months the accident, in comparison to a socio-demographically similar community whose fishery was not heavily impacted by the spill (16). In a broader study of 11 oil-impacted Alaskan communities, disruption or deterioration of social support systems after the spill, as measured by self-reported, negative changes in both family and broader (non-kin) relationships with community members, was found to be a significant predictor of depressive symptoms (22). Furthermore, within impacted communities, both indigenous and non-indigenous residents reported significant decreases in social visiting, participation in community celebrations, religious activities, and volunteer work; these decreases were observed for the entire population, but were especially marked for those involved in clean-up work (20). In addition to decreases in positive social interactions, high exposure status was significantly associated a perceived increased in a number of social ills, including drinking, drug use, and fighting (physical and social) among friends and family and in the broader community (20). During the *Deepwater Horizon* disaster, large-scale, population-based surveys did not find strong evidence of increased domestic violence in coastal *vs.* non-coastal Gulf communities, perhaps due to inadequate statistical analysis and poor identification of potentially vulnerable sub-populations. However, other studies reported qualitative evidence of increased marital conflict, increased calls to domestic violence hotlines, and increased gambling (12,83), highlighting the need for much more rigorous research in this area.

Notably, it has been suggested that clean-up activities themselves and associated inflows of money and people to the community can have community health impacts in addition to economic benefits. Rodin et al. (23) noted that the clean-up response altered social order, particularly within indigenous communities, by supplanting the traditional consensus decision-making model with a more rapid, hierarchical model, in which youth were often empowered or financially enriched in a way that created resentment among the broader (and elder) community members. It was also noted that, in both indigenous and non-indigenous communities, access to jobs and the high wages they offered lacked fairness and transparency, causing a great deal of social conflict (23). Similarly, perceived unfairness in the compensation process can degrade social relationships. Through work with focus groups 1.5 years after the *Deepwater* disaster, Morris et al. (5) found that the majority of participants identified the compensation process as fundamentally unfair, frustrating, and a detriment to their personal recovery.

3.3.5 Community resilience

'Community resilience' broadly refers to the ability of a community to prepare for, respond to, and recover from disasters, and subsequently adapt for future events. Although the cumulative effect of the many physical and mental health impacts associated with oil spills could be conceived as a threat to community resilience, relatively little research has addressed this topic directly. One critical factor in community resilience to oil spill impacts is, unsurprisingly, the occurrence of previous oil spills. In coastal Louisiana, communities have historically suffered repeated losses due to both natural events (hurricanes and floods) and multiple past oil spills. As described by Colten et al. (84), these repeated insults allow communities to build 'inherent resilience,' which refers broadly to a toolkit of coping mechanisms that are used to overcome hardship (drawing on family and social networks, shifting to other local resources, *etc.*), which knowledge is passed down through elder community members. This authors contrast this inherent resilience with attempts to 'transplant' resilience through formal emergency planning relying on non-place-based mechanisms, such as stockpiling food and water, evacuation plans, and government aid or compensation. The authors argue that, in the case of coastal Louisiana, ignoring inherent resilience in favour of non-place-based mechanisms — especially compensation — may in fact be detrimental to recovery and resilience. Although this view contrasts somewhat with the apparently positive impacts of compensation in the *Deepwater Horizon* and *Prestige* spills (**Section 3.2.1**), it is consistent with studies from the *Exxon Valdez* disaster, in which dependence on 'outside money' (*i.e.*, clean-up income) was found to be highly socially disruptive (23).

It has also been postulated that the degree to which a community 'suffers' as a whole may be related to prior affective or emotional state, particularly with regard to an individual's affective state toward one's community. As discussed in depth by Lee and Blanchard (11), *community attachment* refers to an individual's sense of belonging or 'embeddedness' and satisfaction with the community in which he or she lives, which is turn rooted in factors such as the years spent in residence and the strength and density of social networks formed during that time. Generally, because community attachment is linked to individual well-being, it is thought to contribute to overall community resilience; however, as indicated in two recent studies examining the *Deepwater Horizon* disaster, strong community attachment (as well as ties to natural resource-based industries) may also pre-dispose individuals to more severe mental health impacts in the short-term. In coastal Louisiana, Lee and Blanchard (11) found that an individual's degree of community attachment was significantly associated with negative affect or emotional state attributed to the spill, particularly when the individual or a member of his or her household was dependent upon the heavily impacted regional fishing or oil and gas industry. However, a year later, it was found that community attachment was predictive of *lessened* negative mental health impacts, indicating that although attachment may exacerbate psychological stress initially, it may play a longer-term role in promoting individual and community resilience (10). Similarly, Osofsky et al.(9) noted that *Deepwater Horizon* impacts were lessened in those with higher individual resilience and place satisfaction scores. Together, these data suggest that although strong community attachment may at first intensify distress, policies that work to build attachment or reinforce or restore place satisfaction may help to speed recovery post-disaster.

3.4 Summary of health effects and strength of evidence

This section reviewed the documented physical and mental health impacts of historical spill events. It is important to note, as shown in **Table 2**, that each spill event is unique. Conditions such as the type of product spilled, the amount and extent of the spill (severity), and the degree to which human populations contact the oil (exposure) will greatly influence overall health impact of the spill. Furthermore, some effects (specifically mental health effects) may be linked to the size of the community impacted. Thus, caution must be exercised when comparing between historical spills and those modelled for Metro Vancouver, and between effects observed in the small Alaskan towns impacted by the *Exxon Valdez vs.* Metro Vancouver.

Regarding the strength of evidence for the observed impacts, there are several important factors to consider. *Strongly significant statistical association*s were observed between exposures (particularly during clean-up work) and an array of physical and mental outcomes, described below. These effects were generally *consistent* across multiple studies for a given outcome, taking into account that the degree of exposure and toxicological characteristics of the oil itself varied. The effects observed or reported were also *biologically plausible* given what is known about the environmental behaviour and toxicological properties of spilled oil (**Table 1**). Furthermore, exposure and outcome were generally related by *a dose–response relationship,* meaning that greater exposure led to more severe effects. Finally, although the majority of studies were cross-sectional in nature (*i.e.*, collecting data at a single point in time), cohort studies demonstrating physical and mental impacts are now available that have shown evidence of *persistent effects* over time. These four factors are strong arguments in favour of a true relationship between oil spill exposure and physical and mental outcomes. However, many of the physical and mental health impact studies relied on subjective self-reported measures, rather than the objective endpoints, such as biological samples (*e.g.*, urine/blood analysis) or standard, validated psychological assessment tools. Although there are some cases in which self-reported measures may be wholly appropriate, variation in how these data are elicited can make comparisons among studies difficult. Many of the studies examined did not include a non-impacted control group; this was due to the difficulty in finding nearby individuals or communities not impacted by the spill event, which in some cases affected more than a thousand kilometres of coastline. In such cases, researchers often stratified participants into high *vs.* low exposure groups, and in most cases were able to identify exposure-dependent effects. Furthermore, many of the studies were retrospective in nature, meaning that subjects were required to think back to past conditions, which may have introduced recall bias. Regarding the mental health studies, a number of studies showed relatively low response rates on surveys, which may have introduced a selection bias.

As noted above, many of the issues encountered here are *difficult or impossible to avoid* given the circumstances under which observational oil spill health effects studies must be conducted — that is, during a time- and resource-limited crisis situation. Even after taking this into account, the collected literature can be said to present highly suggestive (although not causal) evidence that oil spills are associated with both short-term and long-term physical health impacts in highly exposed adults (*i.e.*, clean-up workers), as well as long-term mental health effects in individuals (and communities) directly and indirectly impacted by spills.

The ***short-term physical impacts*** documented in the epidemiological literature include the symptoms listed in **Table 3**. Although the prevalence of these symptoms varies considerably, depending on the use of PPE, type of activity, duration of work, *etc*., it is apparent that headaches, respiratory effects, and eye and throat irritation are the most common short-term impacts. Furthermore, although these effects are generally assumed to be ‘short-lived’ or ‘reversible’, only one study has examined the duration of these symptoms. Because some effects (headaches, irritated eyes, nausea/dizziness) were in fact prolonged over the medium term (lasting > 6 months, (51)), they may consequently affect medical visits and work productivity and should not be disregarded as a serious health impact.

The ***long-term impacts*** of oil spill exposure have not been studied extensively. However, there is evidence to suggest persistent endocrine and immunological perturbation; other studies have observed evidence of persistent lung injury and airway remodelling up to 6 years after a short-term exposure (weeks to months). Regarding ***teratogenic*** and ***carcinogenic*** effects, there is insufficient evidence to discuss these risks due to the absence of long-term follow-up studies. However, cytogenetic and genotoxic assays demonstrate short-term or persistent DNA damage support the use of follow-up studies to monitor exposed individuals.

Mental health impacts of oil spills are another source of harm to populations, and combined with physical impacts have implications for the resilience of the community as a whole. By far the greatest part of the literature has dealt with the mental health impacts of oil spills and subsequent impacts on community. These studies demonstrate that the trauma associated with oil spills, whether due to income loss, disruption of culturally significant activities, or the stress of long-term uncertainty, can lead to the expression of clinically significant depression, generalized anxiety disorder, and post-traumatic stress. Unsurprisingly, lost income and uncertainty over future livelihoods are a consistent theme across spills, both for the general population and especially for those engaged in natural resource industries. Traumatic effects and other types of disruption to the community (influx of money and outsiders for clean-up work, *etc*.) can furthermore lead to significant increases in 'social ills' (alcoholism, drug abuse, and violence) that impact the community as a whole, although it should be noted that vulnerability to these effects will vary among communities.

Table 3. Prevalence (% of exposed) of acute symptoms among clean-up workers, volunteers, and residents.

Study	*Spill*	*Subjects*	*Head-aches*	*Resp. Effects*	*Sore eyes*	*Sore throat*	*Nasal irritation*	*Nausea or Vomiting*	*Fatigue or Weakness*	*Musculo-skeletal*	*Dermal*
Ha et al. (56)	HS	Volunteers	42	--	47	--	42	--	37	36	--
Sim et al. (57)	HS	Residents, volunteers, paid workers	29	41	18	--	--	28	--	36	5
Burnaby Public Health Office (unpubl)	BBY	Residents	15	--	3	6	2	6	--	--	--
Suárez et al. (35)	P	Well-equipped volunteers, paid workers	8	8	8	--	--	11	--	5	--
Lyons et al. (27)	SE	Residents	38	38	20	32	24	20	27	--	24
Meo et al. (45)	TS	Untrained, unequipped paid workers	28	38	32	28	36	24	--	--	--

BBY, Burnaby; HS, *Hebei Spirit* spill; P, *Prestige* spill; SE, *Sea Empress* spill; TS, *Tasman Spirit* spill.

Mental health impacts may thus have severe societal impacts in terms of the resources and expertise that must be allocated to provide treatment and care to affected individuals over extended periods of time. However, this literature review has demonstrated that it may be possible to mitigate mental health impacts, at least in part, through means other than conventional treatment. These means include promoting social support within communities, as well as removing a key ongoing stressor — concern for personal financial well-being — through prompt and satisfactory compensation.

4 Research Gaps in the Health Impacts Literature

Despite the rapidly growing body of evidence concerning oil spill health impacts, there remains several large gaps in knowledge that make it difficult to assess the overall risk of health impacts. These are discussed in the following section.

4.1 Characterizing exposure in affected populations

As noted in the Introduction, comparison of health impacts due to oil spills is hindered by the fact that each spill is unique in terms of its severity, potential toxicity, and the degree of direct or indirect exposure experienced by humans. In the literature summarized here, exposure was typically characterized according to time (days living or working in an impacted area) and severity of contamination (light or heavy) in that region. In contrast, relatively few of the studies described here quantitatively characterized exposure (*i.e.*, either environmental monitoring or human biomonitoring) as a variable against which to analyze observed health effects. In the *Hebei Spirit* spill, investigators noted that it was difficult to obtain the type of environmental or human biological samples necessary to quantitatively establish exposure levels in the immediate aftermath of a disaster; as a result, the period of highest probable human exposure was missed (54). This highlights the need to make provisions, in terms of expertise and equipment, for immediate environmental and human biological sampling should a spill occur.

4.2 Impacts on residents and vulnerable populations

Unfortunately, relatively few studies have focused on residents of affected areas, but instead tend to focus on clean-up workers. This is partly due to the fact that, as noted above, exposure is much easier to characterize among workers whose activities and hours worked can be tracked and recorded; it is also assumed that these individuals are in the greatest danger of adverse effects. However, because these studies generally include only healthy, working-age adults, less information is available regarding physical impacts on vulnerable populations, such as children, the elderly, and those with health conditions (*e.g.*, asthma), even though these individuals may work, reside, or attend school within the exposure area. Unsurprisingly, Zock et al. (37) found that people with asthma or other chronic respiratory conditions were under-represented among the generally healthy clean-up workers compared to unexposed population, likely due to the recommendations of local health authorities that such people avoid clean-up work. As a result, their data may have underestimated the risk of respiratory effects for the general population. Similarly, Carrasco et al. (33) partially attributed an unexpected inverse relationship between depression and high-level oil spill exposure to the healthy worker effect, although other factors were also likely at play (see **Section 3.2.1**).

Regarding impacts on those with chronic respiratory illnesses, Jung et al. (55) showed that children living within 2 km of the coastline in a heavily contaminated zone were at increased risk of asthma, compared to less-exposed children living outside this zone, even at 7 months after the accident. This is contrast to the findings of Crum (24), who reported no difference or deterioration in lung function during the 12-day period following the MV *Braer* oil spill for either healthy or asthmatic children living within 5 km of the wreck site. These contradictory findings serve to highlight the difficulty in comparing health impacts between populations when exposure conditions are poorly characterized. Furthermore, Gwack et al. (54) found that smokers who participated in clean-up activities showed a higher prevalence of insomnia, dry mouth, cough, back pain and fever compared to their non-smoking counterparts.

Gender may also play a role in susceptibility to oil spill exposures. Janjua et al. (46) reported that women living on the shore of a highly impacted zone showed more severe effects than men; this was attributed by the authors to male residents leaving the impact area during the work day. During the *Hebei Spirit* clean-up, female volunteers were at greater risk of back pain, eye symptoms, as well as dizziness, nausea, and drowsiness (57), and reported slower recovery from headaches compared to men after clean-up activities had finished (51). Regarding mental health, women with high exposure to the *Exxon Valdez* spill showed particular vulnerability for GAD, PTSD, and depressive symptoms (21).

Regarding socioeconomic factors and oil spill risk, data collected shortly after the Kalamazoo oil spill suggested that the prevalence of symptoms was highest within the poorest community (based on home values) and highest rates of smoking and chronic disease, and conversely lowest within the community with highest property values, lowest rates of smoking and chronic disease (60). Likewise, after the *Deepwater* Horizon, Abramson et al. (13) found that poor and/or African American children reported higher prevalence of mental health effects, and that poorer households were less likely to receive compensation than wealthier households.

4.3 Lack of long-term studies with sufficient sample size

Environmental monitoring research has revealed that some harmful components of oil spills, particularly PAHs, remain present and bioavailable within the marine environment for extended periods of time. These compounds have been observed to sporadically re-appear in Gulf Coastal waters in the two years after the *Deepwater Horizon* (85) and were detected on the Alaskan coastline up to 12 years after the *Exxon Valdez* disaster (86). However, despite this evidence of persistent exposure risk, the results of this literature review demonstrate that relatively few long-term studies have been conducted to assess the long-term physical, mental, and community health impacts of oil spills. Of the available long-term studies, the evidence derives primarily from cross-sectional rather than cohort studies. Unfortunately, the majority of cohort studies described here were generated from a single spill, the *Prestige* accident in northwestern Spain.

There are several possible reasons for the lack of long-term cohort studies on the health effects of oil spill. In general, long-term, cohort studies are relatively more expensive. They may also encounter difficulty in following up with or recruiting new study subjects as time passes, as community members originally involved in the even may migrate or change their contact information. This well-acknowledged issue with long-term cohort studies can be mitigated by over-sampling the initial population, although only few of the studies included here did so. However, residents may also simply lose the interest or will to continue engaging with a traumatic event that is receding into the past. For example, Miraglia et al. (18) noted that several Alaskan indigenous communities opted to drop their lawsuits against Exxon out of frustration with the litigation process, which may indicate a desire to move on from the traumatic event; furthermore, the influx of visitors, academics, and fact-finding missions to the community was perceived as having a negative impact on privacy. Given the very serious mental and community health impacts described by the studies included in this review, which included depression and post-traumatic stress disorder, it is not unreasonable to expect that those impacted by an oil spill may be more likely to decline to participate, even if they continue to suffer ill effects.

5 Public health considerations for oil spill response planning

Overall, the literature reviewed here has been useful in identifying instances of improved responses to oil spills, as well as failures in planning that may increase the likelihood of negative consequences. However, it is important to note that public health planning, although under-represented in the literature, remains just one of a number of 'human dimensions' that should be considered. For further discussion of these integrated dimensions, the reader is referred to the work of Chang et al. (3) and Webler and Lord (87).

5.1 Environmental monitoring

As noted in Section 4.1, oil spill health effects studies do not make consistent use of environmental or biological monitoring data, which creates difficulty quantifying exposure and comparing among events. None of the studies reviewed here had the necessary environmental exposure data for the first few hours of the spill, which may be unrealistic to expect. Similarly, health officials responding to the Kalamazoo/Enbridge spill found that in-house equipment was not sensitive enough to detect VOCs to the desired level (Martha Stanbury, pers. comm.). These experiences highlight the utility of previously identifying and sourcing the appropriate equipment and expertise to best characterize the earliest spill exposures. Furthermore, although most post-spill responses make use of environmental monitoring to assess exposure to the general public, personal breathing zone sampling is useful to characterize exposure in clean-up workers, as well as in residents of highly contaminated areas. Although several studies presented here used personal samplers, most were deployed during the later stages of the clean-up, after the most acute phase of potential VOC exposure had passed (43,58,66). Finally, rapid biological monitoring methods, such as urine analysis, have previously proved useful for detecting heavy metal and VOC exposures related to oil spills (52,56,67).

5.2 Risk communication

Previous experiences with public engagement and risk communication in response to oil spills have provided useful insights. During the Kalamazoo/Enbridge oil spill response, the lack of specialist health educators and community engagement personal skilled in the use of social media was identified as a hindrance in communicating technical knowledge and being able to ‘get out in front of the messaging.’ The result was that activists and political elements were able to influence public opinion to an undue degree, sometimes with false or misleading information, which officials subsequently found very difficult to counter (Linda Dykema, pers. comm.). During the Burnaby oil spill in 2007, Dr. Ray Copes (then Medical Director for Environmental Health at the British Columbia Centre for Disease Control [BCCDC]), noted several important factors in communicating risk to the media and concerned residents. The first was to quickly convene town hall meetings in which residents and the media could address a panel of representatives from the various agencies involved in the clean-up. Several such meetings were held during the clean-up. A second factor was the use of monitoring and remediation endpoints that were practical and easy for the general public to understand. For example, rather than referring to a set air quality standard for a given contaminant, discussion carried out in town hall meetings with local residents instead focused around returning VOC levels to those normally observed in other residential neighbourhoods, a benchmark that was much more meaningful to those concerned and did not in anyway compromise health protection. A third very important factor in risk communication in this case was that air quality data were available from the earliest hours of the spill, a rarity in most oil spills. Although these data were collected using a relatively unsophisticated piece of equipment that would not have been appropriate for a long-term air quality monitoring campaign, the data were sufficient to demonstrate publicly that initially very high VOC levels were declining rapidly as clean-up progressed (Ray Copes, pers. comm.). In addition to immediate public engagement, Janjua et al. (47) noted the importance of integrating stakeholder communication into public health research conducted post-spill.

5.3 Preparing for a clean-up response

Because clean-up workers come into direct contact with spilled oil during the period of higher exposure risk (*i.e.,* before volatilization and biodegradation have dispersed compounds of concern), it is extremely important to ensure that individuals who may or may not have existing health issues are properly informed, organized, equipped, and monitored. However, in a crisis situation, this task may be challenging given the need for a rapid response, or in the face of a massive volunteer response. For example, in past large spills, hundreds of thousands of people have been mobilized for individual clean-up responses, with estimates of 170,000 in the *Deepwater Horizon* response (4), 200,000 people in the *Hebei Spirit* response (57), and up to 300,000 people in the *Prestige* response (29). These people came from a broad demographic, and included resident volunteers, non-resident volunteers, untrained paid workers (*e.g.,* primarily military), and trained paid professionals. Notably, although the *Hebei Spirit* spill volume was much smaller than previous disasters, it affected a cherished ecological region famous for its natural beauty, migratory bird sanctuaries, and tourism revenues, which may have played a role in the volunteer response and overall mobilization. Thus, when planning for a future oil spill in Metro Vancouver, it is important to consider how spill size, location, and impact areas (*e.g.*, parks, tourist areas) may combine to affect the size of the necessary *vs.* the voluntary clean-up response, and how agencies must respond to keep responders/clean-up workers safe.

The *Prestige* spill in northern Spain stands out as example of how foresight can help to reduce the risk of adverse health impacts among clean-up workers. Overall, both paid and volunteer workers involved in the *Prestige* clean-up were well-equipped in terms of personal protective equipment (gloves, masks, boots, and waterproof suits) (39). As described by Major and Wang (88), all paid and volunteer workers and the public received health and hygiene information through a variety of formats, and in practice acute physical impacts were indeed lessened among those who used their equipment correctly (35,39). As detailed in **Section 3.1.6**, the availability of a full complement of appropriate personal protective equipment reduced the risk of both short-term acute symptoms and potential long-term effects. A 'full complement' includes an appropriate mask, gloves, boots, a water-proof suit, goggles and a hood or hat to protect the neck and head, although it has been noted that workers often do not make use of less comfortable pieces (*e.g.,* low use of eye-wear, (35,57). Once again, it is important to note that in past spills volunteers and untrained paid workers have engaged in clean-up with inadequate equipment (*e.g.,* cloth masks, (45)), with relatively poorer health outcomes. For this reason, a safety orientation covering the risks of clean-up participation and the proper type and use of equipment is necessary.

Compared to previous spills, the *Deepwater Horizon* clean-up was a truly massive undertaking that presents many useful lessons for future planning. To cope with the enormous quantity of oil released, a number of agencies[6] collaborated to train roughly 100,000 workers in a short period of time, supervised primarily by NIOSH and OSHA. A full

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[6] These agencies included NIOSH, OSHA, NIEHS, EPA, NOAA, USCG, FDA, SAMHSA, among others.

review of this impressive undertaking is provided by Michaels (14). Key lessons included, firstly, the importance of *creating a worker roster* to allow pre-hiring evaluation, placement, and follow-up of those involved in clean-up work. Once rostered, workers were given *pre-placement medical evaluations* to document past medical problems, current health status, and any other physical or mental health concerns, thus creating a baseline for future follow-up (89). Evaluation also helped to ensure that workers had the appropriate immunization, equipment, and training for a given task. A detailed pre-placement evaluation protocol has been provided online by NIOSH (89). NIOSH and OSHA also collaborated in developing *training materials* (both self-study and structured courses) in multiple languages; site visits by OSHA personnel ensured that only 'card-carrying' trained workers were on site (14). Many of these training and other materials have been made available online,[7, 8] creating a useful resource for future planning activities. Health surveillance of the workers is discussed in **Section 5.4.**

Finally, certain activities may require a degree of skill or risk that make them inappropriate for volunteer participation. Cleaning of birds (and other wildlife) is an activity of concern, given that interaction with wild animals in distress increases the risk of physical injuries to workers (35,66), and may also increase harm to the wildlife being treated. Nevertheless, this activity is often carried out by volunteers. During the Kalamazoo/Enbridge pipeline rupture in Michigan, volunteers were actively discouraged from attempting to work with wildlife on their own, but were instead encouraged to report animals in distress to trained personnel of the responsible state agency (Linda Dykema, pers. comm.). Thus, oil spill response planning must also include training for specialist activities in which it would not be reasonable to assume that volunteers could perform safely or adequately.

5.4 Launching broad-based public health surveillance

As noted by several authors reviewed in this report, the establishment of a public health registry for those impacted by oil spills is necessary. This is both to ensure that emergency procedures and resources are mobilized as appropriate (*i.e.*, distribution of PPE, decisions on evacuation orders), but also to facilitate medium- and long-term medical follow-up with

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[7] Available at: http://tools.niehs.nih.gov/wetp/index.cfm?id=2495

[8] For full details of the NIOSH/OSHA *Deepwater Horizon* response, please see: http://www.cdc.gov/niosh/topics/oilspillresponse/

those potentially exposed. In the case of the Kalamazoo spill, the local health authority quickly activated a multi-pronged response that included: mandatory reporting by healthcare providers and facilities, door-to-door community surveys, logging of calls to the local Poison Control Center, monitoring of the state-wide public health surveillance system, and a workplace survey to capture the concerns of clean-up workers (60). This approach was also used by the Louisiana Department of Health and Hospitals during the *Deepwater Horizon* response (66). This allowed both assessment of the needs and concerns of the community, and also facilitated communication and sharing of knowledge among health agencies and the responders regarding health impacts as they developed.

In addition to public health surveillance, it is also recommended to prepare in advance a bank of suitable physical and mental health assessment instruments (*i.e.*, surveys or questionnaires) (47), which should draw and improve upon previous assessments reviewed here. Although it is beyond the scope of this report to provide such an instrument, necessary items include the following: a strategy to appropriately (randomly) select participants from among the impacted population; demographic (including socioeconomic) information; health history; detailed spill exposure characterization, including potential alternative exposures (*e.g.*, smoking); measures of anxiety or perceived health changes as potential confounding factors; the occurrence of new or aggravated symptoms since the spill; and the prior identification of an appropriate control group for the potentially exposed population. Failure to prepare such instruments (to the extent that it is possible) before the event may result in delays that could compromise the quality of the data. In addition to assessment, some consideration should be given to the public health expertise included in the team administering the assessment (*e.g.,* familiarity with the use of standard physical and mental health instruments, experience in conducting interviews, *etc*.). Regarding the surveillance of workers, the creation of a roster or registry of clean-up workers was critical in both the *Deepwater Horizon* and *Prestige* spills, allowing public health officials and researchers to reach out to past clean-up workers and collect additional data regarding initial and continuing health effects (14,35,88).

5.5 Monitoring and communicating food and water safety

This review dealt almost exclusively with studies in which oil exposure is thought to have occurred via inhalation or via contact with the skin or mucus membranes. However, a third pathway through which oil spill may affect human health is the ingestion of contaminated food and water. Currently, there are no studies that have examined potential impact from eating contaminated food, specifically seafood, or drinking contaminated water as a result of an oil spill. However, the literature shows abundant evidence of indirect mental health impacts in people dependent on fisheries due to consumers *avoiding* seafood over fears of contamination. Thus, as pointed out by Janjua et al. (47), it is important for governments not only to monitor and assess seafood and water safety post-spill, but also develop an appropriate and effective risk communication strategy to protect consumers while at the same time preventing unwarranted avoidance. This may be challenging, however, for reasons noted in **Section 3.3.2 and 3.3.3.**

The fact that most previous studies have focussed on marine spills means that drinking water contamination has not been the focus of concern. However, pipeline spills are gaining more and more attention in the media for their impacts on rivers, soil, and, potentially, groundwater. This is because the movement of spilled oil into the anoxic zone of the soil may greatly reduce the rate of biodegradation and create long-term issues for soil and drinking water quality (90). Again, even perceived risk of contamination may impact individuals and communities through declining property values.[9] As a result of the Kalamazoo/Enbridge pipeline spill in Calhoun County, Michigan, concerns over drinking quality prompted the Michigan Department of Health to conduct a long-term groundwater screening study. Briefly, samples from > 168 wells located within 200 feet of the river high water mark were sampled and analyzed repeatedly for hydrocarbons and metals, beginning immediately after the spill and continuing for several years. No instances of unsafe drinking water were found that were *not* attributable to naturally occurring contaminants, such as arsenic and lead, which were not present in the oil itself (91). An important factor in this case is that all of the wells present were along stretches of the river in which groundwater flows out into the riverbed (*i.e.*, a 'gaining' river), rather than the opposite case in which river water recharges the underground aquifer and may also import contaminants (*i.e.*, a 'losing' river). Thus, when assessing potential groundwater impacts from oil spills into

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[9] Further discussion on the risk of oil spills to property values can be found in a recent, non-peer-reviewed report put out by the Vancouver-based NGO, Conversations for Responsible Economic Development (CRED). The report is available at: http://credbc.ca/wp-content/uploads/2013/12/Pipeline-spills-property-values.pdf

rivers, it is important to understand the hydrogeological context throughout the potentially contaminated area.

5.6 Designing and funding long-term public health research

Given the uncertainty surrounding the long-term health impacts of oil spills on human health, it is necessary to make provisions for long-term public health research through the *formation of a task force* to coordinate research activities (88,92). A second important factor in planning for health research is the identification of *funding sources* that can expedite sufficient financial resources for both short- and long-term studies. After the *Tasman Spirit* accident, lack of sufficient funding had a negative influence of study design and may have limited ability to detect more subtle outcomes than those reported (47). Similarly, health officials responding to the Kalamazoo/Enbridge pipeline spill identified independent, federal-level funding as a critical factor in their ability to carry out public health surveillance and community health impact surveys, although Enbridge was credited for covering some of the incidental costs of increased duties (Martha Stanbury, pers. comm.). Based on a review of the Acknowledgements and Conflict of Interest statements for the studies included in this review, only one of the studies presented here (the SAMHSA report, (78)) received financial support from the oil company involved.[10] In the absence of a clearly identifiable source for such funding in Canada, it is important to identify some other means of securing the resources necessary for both increased public health service provision and epidemiological studies into the health impacts of an oil spill in or around Metro Vancouver.

However, a new precedent may have been recently set in the *Deepwater Horizon* disaster, in which the oil company involved (British Petroleum, BP) has made a number of large public health contributions, both voluntarily and as a result of litigation. Among the billions of dollars paid so far, roughly $90 million USD were awarded to the state of Louisiana in a court settlement for the purposes of extending primary health care services (particularly mental and behavioural health care services), training community health care workers, and surveying regional health care needs through the Mental and Behavioral Health Capacity

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[10] This may due to the reasonable desire to avoid potential conflicts of interest or accusations of bias when examining health effects (47). Furthermore, oil companies may wish to avoid funding research that could potentially be used against them in litigation.

Project (MBHCP)[11] (93). In addition, BP voluntarily contributed $10 million USD to the GuLF Worker study,[12] a long-term cohort study being carried out by the National Institute of Environmental Health Sciences (NIEHS). The aim of this study is to characterize the physical and mental health impacts among the nearly 100,000 clean-up workers who were trained as part of the spill response (of which 33,000 are currently enrolled in the study). When completed, this study will be the largest investigation of oil spill response workers (paid and volunteer) to date. Finally, BP also allocated $500 million USD to establish the Gulf of Mexico Research Initiative (GoMRI),[13] which is currently investigating the ecological and human health consequences of the spill through research that claims to be fully peer-reviewed and independent of BP's influence. It should be noted that the Gulf Oil Spill was the largest oil disaster in US history, and thus it is understandable the propitiatory efforts of the company were scaled accordingly. Nevertheless, it is hoped that these actions will set a new benchmark for companies involved in oil spill disasters.

5.7 Prioritizing mental health assessment and services

As demonstrated by the literature, the mental impacts of an oil spill can be complex and long lasting. The complex array of linked, physical, mental, and community health impacts that arise in the wake of an oil spill demonstrate the need to have an integrated response. As identified by a number of commentators on this subject, such a response should encompass: 1) recognition by all involved parties that mental health is a critical component of public health; 2) interdisciplinary collaboration to train community health workers and unite appropriate research expertise; and 3) develop culturally sensitive services available in a range of formats to ensure broad accessibility (12,80,83).

As an example, researchers at the Louisiana State University Health Sciences Center (LSUHSC) attempted to address *Deepwater Horizon* impacts by developing a collaborative program providing research, training, and care services. This project,

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[11] Although at the time of writing, data from this study are not yet publicly available, further details on the MBHCP can be found at: http://www.medschool.lsuhsc.edu/psychiatry/mbhcp.aspx

[12] For further details on the GuLF study (for which preliminary data have not yet been released), please visit http://www.niehs.nih.gov/research/atniehs/labs/epi/studies/gulfstudy/index.cfm

[13] Further details on GoMRI can be found at: http://gulfresearchinitiative.org

known as the Mental and Behavioral Health Capacity Projects (MBHCP), used a novel model that integrated centralized case management and patient contact via *both* telemedicine and on-site mental health specialists and primary care providers, which promoted accessibility for both urban and more remote rural residents. This program was furthermore developed with the participation of community members, primary care providers, and clinics in target communities, giving it broad acceptability. Further details of this project are available from Osofsky et al. (80) or online.[14]

5.8 Putting a dollar value on oil-related health impacts

There is no shortage of previous work on the valuation of the economic, and environmental costs of oil spills (using a variety of methods), which broadly cover losses due to disruption of tourism, fisheries, and aquaculture, as well as clean-up costs (94–97). Previous costing work done on the *Amoco Cadiz* spill deemed health costs to be negligible, as acute effects appeared reversible and no information was available regarding long-term effects (97); mental health and community impacts were not considered. As noted by Loureiro et al. (94), even when health impacts are known or strongly suspected, health costs are difficult to estimate because the type of health data collected after an oil spill are often not amenable to the purpose. As result, health costs a typically omitted from such analyses.

Although it is beyond the scope of this study to provide a dollar estimate of the additional public health costs, the collected literature does identify several points that should be considered when attempting to do so. As noted in **Section 3.3.1,** health costs may increase as exposed residents or clean-up workers seek out family doctors and emergency room treatment. Acute symptoms, which may or may not persist over the long term (51), may also result in missed days of work (46). Spill events also exert excess strain on public administration (23); thus public health agencies will incur excess costs as they attempt to provide regular services in addition to increased surveillance of volunteers, workers, and the public. However, it should be noted that without a prior surveillance plan it would be difficult to attribute increased health care utilization to a spill, as some of the impacts are

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[14] Further details on the MBHCP can be found at:
http://www.medschool.lsuhsc.edu/psychiatry/mbhcp.aspx

not specific to the spill itself (*e.g.,* mental health, respiratory complaints, *etc*.).

In this review, only one study attempted to estimate the cost-to-treat for diseases occurring in response to an oil spill. Using the disability-adjusted life year (DALY) method, Kim et al. (50) estimated the burden of disease caused by the *Hebei Spirit* spill in South Korea. The study calculated years lived with disability (YLD) for a number of physical and mental illnesses based disease prevalence data collected in a large survey (*n* = 10,171) of residents living high-, medium-, low-, and no-impact areas. This approach indicated an excess incidence of rhinitis (3,625 cases), asthma (2,088 cases), dermatitis (1,976 cases), conjunctivitis (2,992 cases), PTSD (2,681 cases), and depression (2,326 cases). For rhinitis alone, excess incidence of disease amounted to a treatment cost of roughly $240,000 USD for one year (50). Although it should be noted that the method relied on a number of assumptions due to the lack of baseline data, these data suggest that oil spill impact (due to both residential proximity to contaminated coastline and participation in clean-up work) may increase disease burden and treatment costs within a relatively small area.

5.9 Evidence-based measures for mitigating health impacts

A key finding of this review is that, in addition to evidence for a significant association between oil spill and human health impacts, there also may exist specific means to mitigate those impacts. As discussed in **Section 3.1.6,** physical impacts (both acute toxic effects and physical injuries) can be lessened through the proper use of a full complement of personal protective equipment (PPE), as well as through the effective management of spill clean-up workers (*i.e.,* rostering, pre-placement evaluation, training, and follow-up) as described in **Section 5.3.**

Mental health impacts, on the other hand, may be amenable to mitigation through compensation and programs/mechanisms that promote social support and community resilience. As discussed in **Section 3.2.1,** financial losses are a key element in mental health issues suffered by spill victims. In some cases, such as the *Prestige* spill, there is evidence that rapid and satisfactory compensation in the form of government aid was able to attenuate these impacts. However, it is worthwhile noting that not all instances of financial 'assistance' have been beneficial: examples of this may include financial aid that inadvertently detracts from inherent recovery or resilience mechanisms (**Section 3.3.5**), the influx of clean-up money in a manner that disrupts social order (**Section 3.3.4**), and of course having to pursue compensation through stressful, drawn-out litigation. Finally, the significance of perceived social support on the ability to cope with or recover from mental health impacts is intriguing (**Sections 3.2.1**), in particular the importance of kin and non-kin social networks in both individual mental health recovery (**Sections 3.2**) and (theoretically) in promoting overall community resilience (**Section 3.3.5**). These four factors present valuable opportunities through which emergency planners can work to mitigate physical and mental health impacts.

6 Conclusions

This review examined the rapidly growing body of epidemiological and other evidence of the impacts of oil spills on human health. Unlike previous reviews that focus on sub-sets of this body of work, the evidence presented here includes support for a broad range of health impacts, including short- and long-term toxic effects, physical injuries, short- and long-term mental health impacts, as well as indicators of social disruption and distress that affect whole communities. Despite some limitations inherent to observational studies carried out during a crisis, these studies have demonstrated statistically significant associations between oil spill exposure and health outcomes, which are both plausible and have been observed in multiple studies using a variety of methods. This review has also identified a number of ways in which future oil spill impact studies can be designed to further strengthen and build upon the available evidence, as well as more general considerations for planning for the health dimensions of oil spills. Regarding mitigation, the literature suggest that measures such as provision of full PPE, mandatory health and hygiene orientation (for the public and workers), promoting programs that strengthen social support, and facilitating rapid, satisfactory compensation may help to ameliorate health impacts after a spill.

7 Literature search strategy and methods

7.1 Keywords and databases

A number of keywords were identified to focus on the variety of impacts (Term 1) that may occur in various populations (Term 2) in response to historic oil spills or general events (Term 3). Various combinations of the key words were used to search a number of academic databases, including Web of Knowledge, PubMed, and Google Scholar. Relevant studies were also identified through review of the first round of documents. Although this study relied primarily upon the peer-reviewed academic literature, government reports related to response efforts were also included. These were sourced through government portals dealing with specific oil spill events.

Table 4. Literature search terms.

Term 1 ***Impacts***	**Term 2** ***Impacted Populations***	**Term 3** ***Event***
Acute effects	Clean-up workers	Pipeline spill
Chronic effects	Volunteers	Hebei Spirit
Health effects	Residents	Oil spill
Long term effects	Children	*Prestige*
Mental health	Elderly	*Exxon Valdez*
Resilience	Indigenous	*Amoco Cadiz*
	Pregnant women	*Sea Empress*
		MV Braer
		Tasman Spirit
		Deepwater Horizon
		Kalamazoo

7.2 Summary of health effects studies

Table 5. Health effects studies included in this review.

Study	Design and Methods	Results	Strengths	Weaknesses
Deepwater Horizon, Gulf of Mexico, 2010				
Abramson et al. (13)	Cross-sectional telephone survey of children living with 16 km of 30 min of the impacted coastline during the first 3.5 months of the spill.	Roughly 40% of children exposed to oil spill, with approximately one-third of children experiencing physical or mental impacts related to the spill	Large sample size, captures a variety of variables as scoping for further studies.	Weak exposure characterization; no correction for confounding factors; subjective measures; vulnerable to recall bias
Buttke et al. (6)	Cross-sectional survey of Gulf Coastal communities in Alabama and Mississippi < 6 months after the spill	Communities in Alabama and Mississippi showing trends toward poorer mental health compared to pre-spill state baseline data.	Use of validated, standardized methods; takes advantage of existing regional baseline survey data	Patchy baseline data; vulnerable to recall bias
Buttke et al. (7)	Cross-sectional survey of Gulf Coastal communities in Alabama and Mississippi 1 year after the spill	Compared to previous cross-sectional survey (Buttke et al. (6), re-sampled households show slightly overall improvement in mental health indicators, but still worse than pre-spill state baseline.	Use of validated, standardized methods; takes advantage of existing regional baseline survey data	Patchy baseline data; vulnerable to recall bias
Cope et al. (10)	Cross-sectional telephone survey of residents of 3 Louisiana parishes, 2, 6, and 12 months after the spill.	Mental and physical health impacts decrease over time and with greater community attachment. Impacts increase with involvement in fishing, unemployment, long-time residence, female gender, less education, and Cajun ethnicity.	Shows change over time in successive cross-sectional surveys.	Weak exposure characterization; vulnerable to selection and recall bias
D'Andrea and Reddy (4)	Cross-sectional retrospective study of workers exposed to oil and dispersant for > 3 months.	Biomonitoring revealed haematological changes, and liver and renal dysfunction in exposed vs. unexposed subjects.	Makes use of biomonitoring data	No correction for confounding factors

Gill et al. (15)	Telephone survey of Alabama residents 5 months after the spill.	Data on total impact, intrusive stress, and avoidance behaviour in Gulf coast communities 5 months after the spill show very similar results to the same data collected in Cordova, Alaska, 5 months after the *Exxon Valdez* spill, suggesting the possibility of similar long-term effects	Collects new data to make a valuable comparison between the *Deepwater* and *Exxon Valdez* spills.	Vulnerable to selection bias; compares communities separated in time by 15 years.
Grattan et al. (8)	Cross-sectional following 94 residents in two communities in Florida and Louisiana for one year.	Anxiety and depression observed regardless of direct oil exposure; those who lost income as a result of the spill showing more severe impacts (anxiety, depression, less resilient, poorer coping)	Uses validated standardized methods.	Issues with sampling methodology; small sample size.
Lee and Blanchard (11)	Cross-sectional telephone survey of residents of 3 Louisiana parishes, 2 months after the spill.	Negative affective state *increases* with greater community attachment, pre-spill stress, routine worrying, and being involved in fishing; effect decreases among the retired.	Addresses differences among various sub-populations according to income (fishing industry, full *vs*. unemployment, retirement, *etc*.).	Weak exposure characterization; vulnerable to selection and recall bias
Morris et al. (5)	Cohort study (preceded by Grattan et al. (8)) following 93 residents in two communities Florida and Louisiana for one year.	Levels of anxiety and depression similar to previous analysis; income loss remained associated with poorer outcomes. Additional qualitative analyses revealed	Use of validated, standardized quantitative measures as well as contextualizing qualitative data.	Issues with sampling methodology; small sample size
Ngo et al. (12)	Focus groups analyzing the Vietnamese Gulf Coastal community in Alabama, Mississippi, and Louisiana	Emerging themes around reduced work/income, loss of employment, inability to pay bills and separation of falls due the oil spill, with subsequent mental health and somatic effect. Some unlikely to seek help due to stigmatization, lack of services, and barriers to access such as lack of English and disconnect form the mainstream media.	Identifies issues experienced in a very specific vulnerable sub-population	Qualitative, vulnerable to selection and recall bias

Osofsky et al. (9)	Cross-sectional survey of 452 residents of 4 Louisiana parishes 4-8 months after the spill.	Poor mental health scores (PTSD and general mental well-being) were correlated with previous Hurricane Katrina impact, overall disruption, oil spill concern, and geographic proximity. Poor scores were negatively associated with individual resilience and place satisfaction.	Use of standardized methods; addressed low telephone response rate with additional purposive sampling;	No non-impacted control group; comparisons made against normative data
***Exxon Valdez* tanker spill, Alaska, 1989**				
Arata et al. (19)	125 fishermen from Cordova, Alaska, roughly 6 years after the spill.	Revealed clinically significant depression and anxiety, as well as PTSD symptoms, related to factors such as resource loss, breakdown of kin and non-kin relationships, and deterioration of physical health, time spent in litigation, and income loss, among other factors.	Use of standardized methods; explores resource and energy loss factors rarely examined.	Vulnerable to selection bias due to low response rate; compares against normative cut-off values rather than a control community.
Palinkas et al. (22)	Cross-sectional study (face-to-face interviews) of 589 people living in 11 impacted and 2 non-impacted Alaskan communities, approximately 1 year after the spill	Found that Alaskan natives experienced more severe oil spill exposure, as reflected through a number of parameters, which was linked with more severe depressive symptomology compared to non-native residents.	In-depth look at cultural and social factors contributing to increased prevalence of mental disorders in a vulnerable sub-population.	Concerns regarding the use of psychological assessment tools in a population for which it has not been validated.
Palinkas et al. (20)	Cross-sectional study (face-to-face interviews) of 594 people living in 11 impacted and 2 non-impacted Alaskan communities, approximately 1 year after the spill	Reveals marked spill impact-related declines in social relationships and engagement in subsistence activities, and increases perceived physical health and mental disorders.	Uses detailed exposure characterization to demonstrate a clear dose–response relationship between spill exposure and impacts.	Due to its cross-sectional nature, study cannot determine if impacts are increasing, decreasing or static since the spill.
Palinkas et al. (21)	Cross-sectional study (face-to-face interviews) of 593 people living in 11 impacted and 2 non-impacted Alaskan	Reveals marked spill impact-related increases in generalized anxiety disorder (GAD), post-traumatic stress disorder (PTSD), and	Identifies spill exposure-related increases in mental disorders relative to an appropriate regional	Due to its cross-sectional nature, study cannot determine if impacts are increasing, decreasing or

	communities, approximately 1 year after the spill	depression; women and indigenous community members found to be particularly vulnerable	baseline.	static since the spill.
Picou et al. (16)	Cohort study of 118 residents of Cordova (impacted) and 73 residents of Petersburg (non-impacted), Alaska, at 9 and 18 months after the spill.	Impact community shows significant increase in social disruption and psychological stress compared to the control community at 5 months after the spill; effects lessen at 18 months, but remain elevated.	Well-matched control community and use of standardized measures.	Small sample size.
Picou et al. (76)	Cohort study examining residents of Cordova, Alaska, 3.5 years after the spill.	Revealed that perceived damage to the community and degree of psychological stress were associated with loss of trust, community attachment, work disruption, litigation stress, and perceived oil spill risk.	Highly valuable long-term follow-up of the impacted population, particularly among fishermen.	Weak exposure characterization.
***Hebei Spirit* tanker spill, South Korea, 2007**				
Cheong et al. (52)	Cohort study of 288 residents of three villages, at 2-6 and 8 weeks after the incident.	Urine analysis revealed elevated indicator of styrene exposure; also observed elevated blood lead, mercury and cadmium levels. Subjective physical symptoms (and some but not all biomarkers) increased with more severe exposure.	Use of human biomonitoring.	Vulnerable to selection bias due to convenience sample; urine analysis method may not have captured VOC metabolites accurately
Gwack et al. (54)	Cross-sectional survey of 2624 military personnel involved in clean-up for roughly 5 weeks, beginning immediately after the spill.	The prevalence of subjective physical symptoms was associated with duration of work and working in a highly contaminated area; use of PPE had a mitigating effect on some physical symptoms.	Large sample size examining a wide range of symptoms.	Vulnerable to recall bias; no non-exposed control group.
Ha et al. (56)	Study of 724 volunteer clean-up workers, 2-3 weeks after the accident.	The prevalence of subjective physical symptoms related to an increased work duration, although changes in VOC and PAH metabolite	Collection of baseline data before commencing clean-up work in a subset of participants.	Potential methodological issues with urine analysis; no non-exposed control group.

		levels were not.		
Ha et al. (53)	Cross-sectional study of 1,361 students attending schools at various distances from the impacted coastline, weeks to months after the spill.	Risk of depressive symptoms increases among children (especially girls) who attend schools closer to the impacted coastline, compared to children attending school farther away.	Use of validated, standardized psychological assessment tools; one of few studies identifying health impacts in children.	Lacked data to correct for socioeconomic status.
Jung et al. (55)	Cross-sectional study of 436 children living within 2 km or > 2 km of the contaminated coastline in heavily impacted Taean county, 1.5 years after the spill.	Children living closer to the spill showed increased prevalence of past asthma relative to the national baseline, increased airway hyperresponsiveness, and impaired lung function compared to children living farther away.	One of very few studies available in children; use of objective measures.	Vulnerable to selection bias; no non-impacted control group
Na et al. (51)	Cohort study (preceded by Sim et al. (57)) re-examining 442 clean-up workers one year after the spill	Data revealed that common symptoms (headaches, and eye, skin, and neurovestibular symptoms) had a mean duration of > 6 months, whereas respiratory symptoms and backpain resolved relatively quickly (< 2 months).	Only study to have looked at time required to resolve acute impacts.	Vulnerable to recall bias
Sim et al. (57)	Cross-sectional study of 846 people who worked for 7-14 days.	Prevalence data for a number of common acute symptoms, along with risk factors for specific symptoms.	Captures effects during the early emergency response	Vulnerable to selection bias; no non-impacted control group
***Braer* tanker spill, Scotland, 1993**				
Campbell et al. (26)	Cross-sectional study of 420 residents of an impacted community compared to 92 residents of an unaffected town.	Significant increased in subjective self-reported symptoms; however, no significant difference in lung, liver, or renal function or urine or blood analysis compared to control.	Captures effects occurs within < 10 days of the accident, and includes both environmental and human biomonitoring.	Air quality data dependent on a single station at the edge of the populated area.
Campbell et al. (25)	Cohort study (preceded by Campbell et al. (26)) examining 344 subjects from impact zone compared to 77 residents of an unaffected	Perceived decline in general health, but no significant difference in lung, liver, or renal function or urine or blood analysis compared to control.	One of few follow-up studies examining acute impacts in residents.	Very little methodological detail provided on expanded health questionnaire used.

	town.			
Crum et al. (24)	Cross-sectional study of children living within 5 km of the wreck site, 3-12 days after the accident.	No differences in lung function (as measured by peak expiratory flow) in healthy or asthmatic children at 3, 9, or 12 days after the accident.	One of few studies using an objective measure to examine early respiratory effects in a vulnerable sub-population.	Very little methodological detail provided.
***Nakhodka* tanker spill, Japan, 1999**				
Morita et al. (58)	Cross-sectional study of 282 clean-up workers, 3 weeks after the spill.	Characterization of self-reported subjective physical symptoms and use of protective equipment among volunteers.	Makes use of environmental and human biomonitoring methods.	No non-impacted control group
***Prestige* tanker spill, Spain,**				
Carrasco et al. (39)	Cross-sectional telephone survey of 799 clean-up workers, 6 months after the spill.	Informed workers show higher usage of appropriate PPE and lower acute physical impacts; certain worker groups were vulnerable to specific impacts.	One of few studies focussing on importance of health information and damage to PPE	Vulnerable to recall bias; no non-impacted control group
Carrasco et al. (33)	Cross-sectional study of 2,700 coastal and inland residents, 1.5 years after the spill	Coastal residence was associated with lower quality of life and worsened mental health compared to inland residence; *however*, more severe individual oil was associated with lessened mental impacts.	Stark difference in results depending on whether data are analyzed according to residential or individual exposure.	No non-impacted control.
Laffon et al. (31)	Cross-sectional study of 34 clean-up workers (bird cleaners) and 35 controls.	Indoor exposure to VOCs from oiled birds found to elicit increase DNA (but not cytogenetic) damage, which may be linked to specific variant alleles. Use of PPE mitigated genotoxic effect.	Demonstrates linkage between genotoxic effects and use of PPE	Small sample size
Laffon et al. (42)	Cross-sectional study of 54 exposed fishermen who participated in clean up for 2 months and 50 unexposed controls, 7 years after the spill.	Spill exposure linked to increases in serum cortisol and decreases in kynurenine and $CD16^{+}56^{+}$ natural killer cells; use of PPE showed effects on other immune parameters.	One of few studies to examine immune and endocrine endpoints; one of few long-term studies.	Potential issues with the control group; small sample size
Laffon et al. (29)	Cross-sectional study of 54	No significant difference in DNA	One of few long-term	Potential issues with the

	exposed fishermen who participated in clean up for 2 months and 50 unexposed controls, 7 years after the spill.	damage, cytogenetic damage, or T-cell mutagenicity between exposed and unexposed subjects, in contrast to data collected initially and 2 years after the spill.	studies.	control group; small sample size
Pérez-Cadahía et al. (43)	Cross-sectional study of 68 exposed and 42 unexposed individuals, 4-6 months after the spill.	Spill exposure resulted in cytogenetic damage, the degree of which was influenced by genetic polymorphism; exposure also increased blood heavy metals and decreased plasma prolactin and cortisol.	Use of environmental monitoring and human biomonitoring data.	Small sample size
Pérez-Cadahía et al. (40)	Cross-sectional study of 180 clean-up workers and 60 controls, 4-6 months after the spill. (expansion on Pérez-Cadahía et la. 2007)	Workers showed increased DNA damage, blood heavy metals, and hormonal disruption compared to controls; DNA damage was linked to use of PPE and genetic polymorphism.	Use of environmental monitoring and human biomonitoring data; analysis of workers according to activity.	Lacking methodological detail.
Pérez-Cadahía et al. (38)	Cross-sectional study of 159 exposed and 60 unexposed individuals, 4-6 months after the spill.	Clean-up workers showed increased cytogenetic and cytotoxic effects, which were linked to age and genetic polymorphism; longer term workers showed greater effects.	Evidence of a link between exposure time and genotoxic effects.	Lacking methodological detail.
Pérez-Cadahía et al. (41)	Cross-sectional study of 179 exposed individuals, 4-6 months after the spill.	Blood concentrations of heavy metals (Al, Cd, Ni, Pb, Zn) significantly associated with biomarkers of DNA damage and endocrine disturbance (plasma cortisol levels).	Use of objective measures and biomonitoring.	No comparison with non-impacted control
Rodríguez-Trigo et al. (30)	Cohort study (preceded by Zock et al. (37)) of 501 exposed and 177 non-exposed fishermen, 2 years after the spill.	Exposed fishermen demonstrated increased LRTS, 8-isoprostane and growth factors in exhaled breath condensate, as well as structural chromosomal damage, which was related to exposure status; however, no difference in lung function was	Use of a variety of objective measures and a well-matched control group.	Clinical significance of some of these indicators is unclear.

		observed with respect to control.		
Sabucedo et al. (32)	Cross-sectional study of 938 fishermen and control subjects from the same community, 1 year after the spill.	Individuals who perceived higher social support post-spill reported greater in institutions; individual who reported high satisfaction with financial aid received showed improved mental health scores.	Large sample size; use of standard methods; strong exposure characterization.	Vulnerable to recall bias.
Sabucedo et al. (34)	Cross-sectional study of 926 fishermen and control subjects from the same community, 1 year after the spill	Found that individuals highly impacted by the spill and those living closest to the spill site showed the greatest mental impacts, especially among fishermen and women.	Large sample size; use of standard methods; strong exposure characterization.	Vulnerable to recall bias
Suárez et al. (35)	Cross-sectional study of 799 clean-up workers	Working > 20 days associated with increased risk of toxic effects and physical injuries; women and those working at sea particularly affected.	Large sample size, investigating a wide range of potential acute effects	No non-impacted control group
Zock et al. (37)	Cohort study (followed by Zock et al. (36)) of 6,780 fishermen, 1-2 years after the spill.	Increased prevalence of lower respiratory tract symptoms (LRTS) among exposed *vs.* unexposed, which increased with exposure time and lack of PPE. Although LRTS risk decreased over time, remained elevated at 20 months.	Corrected for anxiety to reduce the influence of perceived health risk on reporting of symptoms.	Use of subjective, self-reported measures when suitable objective measures are available; some vulnerability to recall bias.
Zock et al. (36)	Cohort study (preceded by Zock et al. (37)) of 466 exposed and 156 non-exposed fishermen, 5 years after the spill.	Persistence lower respiratory tract symptoms (LRTS) remained elevated among exposed *vs.* unexposed, and persistence of LRTS and medication usage were associated with severity of exposure.	Use of non-exposed fishermen as a control; long-term follow-up on a well-designed study.	Use of subjective, self-reported measures when suitable objective measures are available; some vulnerability to recall bias.
Zock et al. (44)	Cohort study (preceded by Zock et al. (36,37)) of 158 exposed and 57 non-exposed fishermen, 6 years after the spill.	Follow-up studies using the same clinical indicators as in Rodríguez-Trigo et al. (30) presented a mixed message in terms of lung function between exposed vs. non-exposed	Use of objective measures; a multi-year cohort study	Suffered loss to follow-up; variation within the small control group.

		fishermen.		
***Sea Empress* tanker spill, United Kingdom, 1996**				
Gallacher et al. (28)	Cross-sectional survey of 1,089 residents of impacted and non-impacted towns on the coast of Wales, 7 weeks after the incident.	Whereas physical health impacts were related to physical exposure, mental health impacts (including anxiety) were associated with perceived risk, and were observed in both impacted and non-impacted towns.	Accounts for the effects of perceived health risk and anxiety on symptom reporting.	Vulnerable to recall bias; weak exposure characterization
Lyons et al. (27)	Cross-sectional survey of residents of impacted (n = 539) and non-impacted (n = 550) towns on the coast of Wales, 7 weeks after the incident.	Residents in impacted towns reported increased incidence of headaches, sore eyes, sore throat, anxiety, greater depression, and overall worse mental health	Accounts for the effects of perceived health risk and anxiety on symptom reporting.	Vulnerable to recall bias; weak exposure characterization
***Tasman Spirit* tanker crash, Pakistan, 2003**				
Janjua et al. (46)	Cross-sectional survey of 400 residents of Karachi, Pakistan, living on the shore, 2 km away, or 20 km away from the shore, three weeks after the spill	Physical symptoms were most prevalent among those living closest to the shore, followed by residents living 2 km away and then those 20 km away.	Explores wide range of symptoms; accounts for the effects of anxiety on symptom reporting; developing world context	Use of subjective measures; acknowledged sample size limitations.
Meo et al. (48)	Cohort study of 20 male clean-up workers and 31 unexposed controls, 1 month and 1 year after the spill	Marked decreases in lung function among exposed *vs.* unexposed men at 1 month after the spill, followed by recovery of function at 1 year.	One of few studies to examine recovery from acute physical impacts.	Potential issue with comparing outdoor clean-up workers with a 'matched' control group that primarily workers indoors.
Meo et al. (45)	Cross-sectional study of 50 male clean-up workers and 50 unexposed controls, 1 month and 1 year after the spill	Increased risk of acute physical impacts (respiratory symptoms, headache, nausea, and eye irritation) compared to matched controls.	Developing world context	Potential issue with comparing outdoor clean-up workers with a 'matched' control group that primarily workers indoors; lacking methodological detail.

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