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2019 State-of-the-Science of Dispersants and Dispersed Oil (DDO) in U.S. Arctic Waters: Public Health and Food Safety

Coastal Response Research Center

State-of-the-Science of Dispersants and Dispersed Oil (DDO) in U.S Arctic Waters

1.0 Introduction

Chemical dispersants were employed on an unprecedented scale during the Deepwater Horizon oil spill in the Gulf of Mexico, and could be a response option should a large spill occur in Arctic waters. The use of dispersants in response to that spill raised concerns regarding the need for chemical dispersants, the fate of the oil and dispersants, and their potential impacts on human health and the environment. Concerns remain that would be more evident in the Arctic, where the remoteness and harsh environmental conditions would make a response to any oil spill very difficult. An outcome of a 2013 Arctic oil spill exercise for senior federal agency leadership identified the need for an evaluation of the state-of-the-science of dispersants and dispersed oil (DDO), and a clear delineation of the associated uncertainties that remain, particularly as they apply to Arctic waters.

The National Oceanic and Atmospheric Administration (NOAA), in partnership with the Coastal Response Research Center (CRRC), and in consultation with the U.S. Environmental Protection Agency (EPA) embarked on a project to seek expert review and evaluation of the state-of-the-science and the uncertainties involving DDO. The project focused on five areas and how they might be affected by Arctic conditions: dispersant effectiveness, distribution and fate, transport and chemical behavior, environmental impacts, and public health and safety.

2.0 Objectives

The objectives of the State-of-the-Science of Dispersants and Dispersed Oil in U.S. Arctic Waters project were to:

- Identify the primary research/reference documents on DDO,
- Determine what is known about the state-of-the-science regarding DDO,
- Determine what uncertainties, knowledge gaps or inconsistencies remain regarding DDO science, and
- Provide recommendations on outreach/education materials needed for senior leadership to be prepared for communicating science regarding dispersant use in spill response.

3.0 Dispersant and Dispersed Oil Databases of Scientific Literature

CRRC created a database that compiled relevant research from 2008 through December 31, 2015. Research documents not published in peer reviewed scientific publications were included as part of this project if CRRC determined those references were subject to the appropriate review standards for each organization. The CRRC database was continually updated during the project as new research was identified by the expert scientific panels. The database, which is searchable, is available to the public through CRRC along with the subject area documents

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developed by each of the scientific panels. This effort also looked at the Louisiana University Marine Consortium (LUMCON) database that captured relevant literature prior to June 2008.

4.0 Project Process

The CRRC coordinated a discussion among scientists with dispersant research expertise, as well as those with Arctic expertise, to determine the state-of-the-science (knowns and uncertainties) regarding DDO, as it applies to Arctic waters. Scientific panels for each subject area were selected for their knowledge and expertise in that field. The Project Steering Committee, including the NOAA and EPA Project Liaisons, assisted CRRC in identifying individuals with dispersants and/or Arctic expertise. In developing each of the documents these panels reviewed relevant literature and, based on their expertise, developed statements of knowns and uncertainties regarding each focal topic.

The Steering Committee identified five general subject areas that were deemed important to understanding the State-of-the-Science of DDO. Separate scientific panels convened to focus on each of the following topics:

- Efficacy and Effectiveness;
- Physical Transport and Chemical Behavior;
- Degradation and Fate;
- Eco-Toxicity and Sublethal Impacts; and
- Public Health and Food Safety.

The process was initiated in January 2015 with a five-day workshop being conducted, one day for each subject area. Once established, each scientific panel continued to have regular conference calls over the next two to three years to continue the literature review and develop the knowns and uncertainties documents for each subject area. Dispersant use policies, including operational issues are not within the scope of this project and are not addressed in these documents.

5.0 Public Input Process

Each of the five subject area draft documents was released for a thirty-day public input period. Reviewers were asked to document their comments or recommend changes, substantiated by a citation of a peer reviewed research paper. Each scientific panel considered all relevant public input received on the draft documents, and when deemed appropriate, amended the original wording. The final subject review documents were released along with the database for each topic. (A sample public input form can be found here http://crrc.unh.edu/dispersant_science).

6.0 Scientific Panel

The scientific panels consisted of a broad spectrum of national and international experts. Their names are listed at the end of each document.

The scientific panel for *Public Health and Food Safety* met initially via face-to-face for 10 hours in January 2015 and then an additional 100+ hours of e-conference meetings (February 2015 to January 2019) reviewing publications, discussing the science, writing/editing the draft document

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and reviewing and addressing the public input for accuracy. Numerous additional hours were spent by the panelists in preparation for meetings and their individual reviews of the documents.

Disclaimer - This "State-of-the-Science on Dispersant Use in Arctic Waters: Public Health and Food Safety" document presents a compilation of individual opinions of the participants in this session of the State-of-the-Science for Dispersant Use in Arctic Waters initiative. To the extent that the Federal Government requested certain information, it did so on a purely individual basis. Similarly, the information herein was presented to the Federal Government by individual participants and represent the participants' individual views and policies. Therefore, the statements, positions, and research opinions contained in this document do not reflect any consensus on the part of any of the participants and may not necessarily reflect the views or policies of any individual federal department or agency, including any component of a department or agency that participated in developing this document. No federal endorsement should be inferred.

7.0 Public Health and Food Safety Document

State-of-the-Science for Dispersant Use in Arctic Waters
Public Health and Food Safety

Contents of this document:

General Statement:
The information provided under each topic includes a general statement, knowns, and uncertainties. This document provides the state of the knowledge by capturing observations obtained from multiple disciplines including toxicology, risk assessment, food safety, and risk communication. When there are limitations of information specific to the Arctic, we have chosen to consider relevant data from the scientific literature regardless of the geographic location. The panel acknowledges that the resources accessed for this document were restricted to information published (including advance publications) prior to December 31, 2015, and is aware of relevant and impactful references published since that time, that would add value for the topics discussed in this document.

I. Human Health and Toxicity

A. Human Exposure to Dispersants and Dispersed Oil

General Statement:
Individuals directly handling dispersants or in the immediate vicinity of dispersant applications during the *Deepwater Horizon* (DWH) oil spill may have been at greater risk of exposure and adverse effects than the general population. Exposure to dispersant-treated oil is also likely to be greater for response personnel. For the potential adverse health effects related to these exposures, see Section I. B. Potential Toxicological Impacts of Dispersants and Dispersed Oil.

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Knowns:

1. During the DWH oil spill, Corexit 9500 and 9527, containing dioctyl sodium sulfosuccinate, dipropylene glycol monobutyl ether (9500 only), 2-butoxyethanol (9527 only), and other ethoxylated alcohols, were applied from aircraft, vessels and/or subsea injection.

2. NIOSH (2011) reported that personal breathing zone and area air monitoring samples from two vessels were analyzed for several contaminants, including propylene glycol (a component of the dispersant), before and after a 50-gallon surface application of Corexit 9500 during the DWH incident. Aircraft application of an additional 125 gallons also occurred. NIOSH reported, "The measured substances were either not detected or were present at low concentrations below occupational exposure limits (OELs)."

   - However, "the lack of significant exposures to VOCs may reflect the lack of high volatility compounds from the oil at those worksites. Higher volatility compounds initially present in the oil may have dissipated shortly after release and during the weathering process so that concentrations on vessels and onshore were minimal" [by the time the measurements were recorded]. (NIOSH, 2011). The VOCs may also have dissolved (OSAT, 2010).

   - NIOSH used a convenience sampling approach to collect their measurement data. Thus, "it is recognized that changing conditions at worksites may present opportunities for exposures at levels differing from results obtained on the days NIOSH teams were present." (NIOSH, 2011)

3. Depending upon incident conditions, there is a range of potential occupational (response workers) and non-occupational exposures to dispersants and dispersed oil from shorelines to offshore (Picou and Martin, 2007; OSAT, 2010; Aguilera et al., 2010; NIOSH, 2011; Avens et al., 2011; Dickey, 2012). Potential exposure routes include inhalation, dermal and ocular contact, and ingestion. Occupational exposures can be minimized by the appropriate use of personal protective equipment (PPE).

4. During the DWH oil spill, specific dispersant- and oil-related chemical compounds were measured in environmental media, such as air and water.

   - The NIOSH Health Hazard Evaluation noted that offshore workers reported contact with dispersants. There was "no evidence of exposure to dispersant" by workers at shore cleaning sites following the DWH oil spill (NIOSH, 2011).

   - Operational Science Advisory Team (OSAT) found that none of the 6,000 water samples containing oil-and dispersant-related chemicals that were measured exceeded U.S. EPA benchmarks for protection of human health following skin contact and incidental ingestion by a swimmer (potential cancer and non-cancer risks) (OSAT, 2010).

- Potential exposure to specific oil and dispersant compounds via seafood consumption was considered below levels of concern (Ylitalo et al., 2012).
- DOSS concentrations in edible tissues of Gulf crab and finfish following the DWH oil spill were well below established levels of public health concern (Dickey and Dickhoff, 2011; Ylitalo et al., 2012; Fitzgerald and Gohlke, 2014).

[Note: For a discussion of potential exposure to dispersants or dispersed oil resulting from seafood consumption, see Section IV. Arctic Seafood Safety.]

Uncertainties:

1. Rigorous quantitative exposure assessments relating to oil spill response operations are difficult to conduct and thus have been limited.
2. The evaluation of chemical constituents when assessing human health risks following oil spills is not comprehensive, but is often focused on those components thought to be the most hazardous, based on the available science, see Section II. Risk Assessment below.
   - Data regarding background or baseline levels of exposure to oil- and dispersant-related chemicals in the environment are important, but may be limited.
   - It may be difficult to attribute the exact sources of exposure because humans are commonly exposed to chemical constituents found in oil and dispersants through other environmental pathways (e.g., Hayworth and Clement, 2012; Dickey and Dickhoff, 2011; ATSDR, 1999).
   - The environmental fate, transport, and potential exposure to some dispersant formulations are inadequately characterized under field conditions.
   - Dispersants are designed to alter the fate and transport of crude petroleum. However, the potential for dispersants to increase or decrease the extent of human exposure or alter the route of exposure to crude oil is uncertain.
   - Biomarkers of exposure for some petroleum-based hydrocarbons have been evaluated in human studies (Andreoli et al., 2015; Noh et al., 2015; Pérez-Cadahia et al., 2008a; Elovaara et al., 2006; Kim, 2015), but not as yet for dispersant-derived components. In all cases, such studies are limited by variability in timing between exposure and sampling, heterogeneity within human populations, other sources of exposure to petroleum-based compounds, and challenges in obtaining appropriate biological samples.

- The lack of available biomarkers is consistent with the following statement: "CDC and ATSDR guidelines issued during the *Deepwater Horizon* Oil Spill did not recommend the use of laboratory testing for specific chemicals to either determine exposure or guide delivery of clinical care…" (Centers for Disease Control and Prevention (CDC) ATSDR, 2011).

3. Limitations in exposure data make it difficult to fully elucidate and reliably disentangle health effects of oil alone, dispersant alone, dispersed oil or any combination of these. Limitations include:

    - The remoteness and extreme environmental conditions of Arctic locations where oil spills may occur can make rigorous exposure assessments challenging.

    - Response work activities and other sources of exposure will vary over time and geographic space, so a finite set of empirical observations may not fully represent all conditions encountered.

B. Potential Toxicological Impacts of Dispersants and Dispersed Oil

General Statement:
The toxicity of individual constituents of Corexit 9500 and 9527 dispersant formulations have been evaluated. (See reviews by Dickey and Dickhoff, 2011 and Fabisiak and Goldstein, 2011, for example). However, other commercial dispersant formulations and dispersed oil, including oil dispersed using Corexit 9500 and 9527, have not been well characterized toxicologically in appropriate mammalian models. We refer the reader to the *State-of-the-Science for Dispersant Use in Arctic Waters: Eco-Toxicity and Sublethal Impacts* report for a summary of knowns and uncertainties in a wide variety of marine species.

Although trace metals are components of oil, metals were not addressed in this document because they have not been considered as primary drivers of oil toxicity. The levels of metals analyzed in seafood after the DWH incident were not different from baseline levels in samples that were collected prior to the oil spill or from areas that were not directly impacted by the oil spill (U.S. FDA DWH Phase III Surveillance Samples – Metals: October 12, 2010 to June 21, 2011; Fitzgerald and Gohlke, 2014). However, data on how dispersants may impact the toxicity of metals in oil is limited (Gohlke et al., 2011).

What follows is a summary of toxicological literature regarding what is known and what is uncertain about the adverse effects of dispersants, their components, and dispersed oil, primarily in mammalian species. The summary focuses on three areas: in vitro culture studies, animal studies and human health effects. In vitro and non-human animal studies are often most useful as part of tiered analyses of adverse effects in humans. It should be noted that conditions used in experimental toxicological studies may not reflect route, dose or duration of exposure encountered in the field.

a. *In vitro* culture studies

Knowns:

1. Several *in vitro* studies using various Corexit formulations and other oil dispersants and oil-dispersant mixtures have been conducted to evaluate cytotoxicity to mammalian cultured cells.

   - Cytotoxicity to HepG2 cells, along with markers of oxidative stress and mitochondrial dysfunction, were observed with Corexit 9500 and 9527 ($LC_{50} \approx 250$ ppm), which appeared related to the content of the surface active component dioctyl sodium sulfosuccinate (DOSS) (Bandele et al., 2012).

   - Corexit 9527 and 9500 were cytotoxic to A549 human lung epithelial cells ($LC_{50} \approx 200$ ppm) (Shi et al., 2013).

   - In five mammalian cell lines, different from those mentioned previously, cytotoxicity of Corexit 9500 has been observed, with LC_{50}s ranging from 16 to 95 ppm (Zheng et al., 2013).

   - Mixtures of water-accommodated fractions (WAF) of DWH oil and Corexit (9527 or 9500) (chemically-enhanced-WAF (CEWAF)) were more cytotoxic to A549 lung epithelial cells than WAF prepared from oil alone (Wang et al., 2012). Major et al. (2012) hypothesized that this occurred because of the increased chemical complexity and concentration of petroleum-derived compounds contained within the CEWAF.

   - Two dispersants, JD 2000 and SAF-FRON GOLD were significantly less cytotoxic (LC_{50}s > 1000 ppm), in HEPG2 and HEK293 cell lines, compared to six other oil dispersant products chosen from the NCP (LC_{50}s, 28-670 ppm). The LC_{50}s for Corexit 9500 were 120-410 ppm (Judson et al., 2010).

   - Corexit 9500 and 9527 were cytotoxic to sperm whale skin fibroblasts over a range of 50-1000 ppm ($LC_{50s} \approx 350$ and 700 ppm, respectively) (Wise et. al., 2014).

2. Biological actions other than cytotoxicity of Corexit dispersants have also been demonstrated using *in vitro* approaches.

   - Using RNAseq to study global changes in gene expression, prolonged exposure (approximately 3 months) to Corexit 9500 alone and Corexit 9527 plus DWH oil produced differential expression of 84 and 46 genes, respectively in BEAS2B human airway respiratory cells (Liu et al., 2016; electronic publication in 2015).

   - Two of eight oil dispersant products (Nokomis 3 and F4ZI-400) tested showed a weak estrogen receptor signal in a cell-based multiplexed reporter gene assay battery contained in U.S. EPA ToxCast program (Judson et al., 2010).

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- DOSS, a major component of Corexit dispersants was characterized as a possible "obesogen" based on its ability to drive peroxisome proliferator-activated receptor gamma (PPARγ)-dependent gene reporter activity *in vivo* and *in vitro*, and adipocyte differentiation *in vitro* (Temkin et al., 2016; electronic publication in 2015).

- Corexit 9527 induced dose-dependent chromosomal aberrations in sperm whale skin fibroblasts throughout the range of 50-500 ppm, and required metabolic activation by a liver S9 fraction for maximal effect. Corexit 9500 only "induced a minimal increase in genotoxicity in sperm whale skin cells", was independent of S9 activation, and did not show a simple dose response relationship (Wise et al., 2014).

Uncertainties:

1. While *in vitro* cell culture assays may serve well as initial screens to test potential chemical toxicity, their overall relevance to predict human adverse effects following real-world exposures cannot be assumed. Detailed experimental validation of *in vitro* results is required to support extrapolation to human adverse effects.

2. Differences in results among *in vitro* studies may arise through the use of different cell lines, culture conditions and differences in exposure form, dose and duration.

3. Differences in results among *in vitro* studies may also reflect the use of different source oil and dispersant formulations.

b. Animal Studies

Knowns:

1. Shortly after the DWH incident, NIOSH undertook a series of experimental studies using whole animal exposure to Corexit 9500.

   - Following dermal exposure in mice, Corexit 9500 (EC_3= 0.4%), and its component DOSS (EC_3=3.9%), were identified as irritants and tested positive for allergic contact sensitization in the Local Lymph Node Assay and Mouse Ear Swelling Test (Anderson et al., 2011).

   - Acute inhalation exposure to Corexit 9500 (27 mg/m^3, 5 hr.) produced transient potentiation of adrenoreceptor agonist-induced increases in heart rate and blood pressure along with increased peripheral arterial vasomotor tone in rats (Krajnak, et al., 2011). No evidence of lung inflammation was observed following the same exposure, while dynamic lung compliance was transiently decreased in the absence of changes in breathing rate or airway resistance (Roberts et al., 2011).

   - Repeated inhalational exposures of rats to Corexit 9500 (25 mg/m^3, 5 hr. per day over 9 days (5 days on; 2 days off; 4 days on)) showed little change in most cardiovascular and respiratory endpoints except transient elevations in heart rate (Roberts et al., 2014).

- Several biochemical indices of neural dysfunction were observed in brain tissue of rats exposed to a single acute inhalation dose of Corexit 9500 (27 mg/m^3, 5 hr.) (Sriram et al., 2011).

Uncertainties:

1. Experimental toxicological studies on mammalian systems using oil dispersant products other than Corexit 9500A are limited.
2. Differences in results among animal studies may reflect the use of different species, source oils, dispersant formulations, and exposure route, dose and duration.
3. It is unclear how dispersant or dispersed oil exposure levels used in experimental animal studies compare with potential human exposures to dispersants or dispersed oil resulting from their use during oil spills.
4. It is unclear how dispersant or dispersed oil toxicity determined in experimental animal studies compares with potential human toxicity to dispersants or dispersed oil resulting from their use during oil spills.
5. Toxicities resulting from experimental exposure to dispersant and oil mixtures have not been well studied in mammalian systems.
6. Knowledge regarding complex system toxicities (e.g., endocrine, immune, reproductive) that may result from exposure to dispersants or dispersed oil is limited.

c. Human Health Effects

Knowns:

1. A Centers for Disease Control and Prevention (CDC) report on communities potentially exposed to dispersants and dispersed oil during the DWH oil spill concluded, "For several months CDC and state health departments tracked potential short-term health effects related to the oil spill in the affected communities. No trends in illnesses were identified by the multiple surveillance systems used. CDC surveillance did detect some complaints of non-specific symptoms such as throat irritation, eye irritation, nausea, headache and cough." (CDC/ATSDR 2011).

2. Limited studies have been conducted to assess human health impacts following oil spills, including potential biomarkers of effect and the impact of non-chemical stressors. (Elovaara et al., 2006; Laffon et al., 2006; Pérez-Cadahia et al., 2007; Zock et al., 2007; Picou and Martin, 2007; Pérez-Cadahia et al., 2008a; Pérez-Cadahia et al., 2008b; Pérez-Cadahia et al., 2008c; Meo et al., 2009; Aguilera et al., 2010; Rodríguez-Trigo et al.,

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2010; Goldstein et al., 2011; Monyarch et al., 2013; Laffon et al., 2013; Laffon et al., 2014; NIOSH, 2011; Andreoli et al., 2015; Kim, 2015; Noh et al., 2015).

- Such studies are often limited by sensitivity, variability in timing between exposure and sampling, heterogeneity within human populations, lack of specificity towards the ultimate source of exposure, and challenges in obtaining appropriate biological samples.
- In most of these studies, dispersants were not used during the spill response.
- There are some studies on the impacts of non-chemical stressors associated with oil spills (e.g., economic and social disruption, changes in resource availability, food security) on baseline mental health status in workers and communities (Osofsky et al., 2014; Choi et al., 2015; Fan et al., 2015; Gould et al., 2015; Lowe et al., 2015; Osofsky et al., 2015; Rosenberg et al., 2015; Rung et al., 2015; Shenesey et al., 2015). (See #5 below regarding mental health studies.)

2. Potential short-term health effects related to the DWH incident were evaluated in the affected communities by CDC and state agencies.
   - In door-to-door surveys conducted in Alabama and Mississippi coastal communities following the DWH incident in Aug 2010 and again in 2011, self-reported physical and mental health indicators were lower when compared to previous routine phone-based surveys conducted by CDC in 2008-2009 (Buttke et al., 2012a; Buttke et al., 2012b).
   - Results of the National Survey on Drug Use and Health indicated that there were increases in self-reported marijuana and alcohol use, past year depression, and suicidal indicators, but not other substance abuse or psychological indicators, in coastal counties after DWH (2011) as compared to before DWH (2004 and 2009) (SAMHSA 2013).
   - Results of the Gulf States Population Survey suggest no substantial differences in self-reported general, physical or mental health between coastal and noncoastal counties after the DWH, or between pre-DWH survey results (2004 and 2010) and post-DWH results within coastal counties; however, people living in coastal counties were more likely than those living in non-coastal counties to report decreased income or lost jobs because of the oil spill (SAMHSA 2013).
3. As stated in NIOSH (2011), "Nonspecific symptoms such as headache, eye and respiratory irritation, and fatigue were more commonly reported by responders who self-reported exposures to oil, dispersants, or other chemicals compared to workers who self-reported no such exposures."

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4. Toxicological information found in hazard communication materials (e.g., CDC (2010b), NALCO (2012a, b), NLM (2014)), indicates potential for crude oil and dispersants to produce dermatological and systemic effects. (See Section III Risk Communication for additional discussion).

5. Goldstein et al. (2011) reviewed potential mental health impacts of oil spills. Changes in mental health, sometimes long-term, have consistently been observed after the *Exxon Valdez* (Palinkas et al., 1993; Gill and Picou 1998), *Sea Empress* (Lyons et al., 1999; Gallacher et al., 2007), *Hebei Spirit* (Choi et al., 2015) and *Prestige* oil spills (Sabucedo et al., 2009; Sabucedo et al., 2010). Symptoms are usually characterized as depression, post-traumatic stress disorder (PTSD), and other anxiety disorders. Mental health symptoms do not appear to be related to direct chemical exposure. Symptoms in workers and residents of affected communities arise from multiple factors including fear of chemical exposure, loss of economic livelihood, and social disruption.

    - In the case of the DWH incident, psychological effects were observed in clean-up workers (Lowe et al., 2015) and their spouses (Rung et al., 2015), and resident adults (Osofsky et al., 2011) and may have been amplified by previous exposure to disasters such as Hurricane Katrina (Osofsky et al., 2010; Osofsky et al., 2011).

    - Severity and persistence of depressive and PTSD symptoms following natural and technological disasters, including oil spills, have been correlated to pre-disaster economic status (Dreshcher et al., 2014), degree of economic loss (Grattan et al., 2011), perceived resiliency (Shenesey and Langhinrichsen-Rohling 2015), and “level of acculturation” (Norris et al., 2009). More severe mental health impacts were observed in native indigenous people than in their non-indeigenous counterparts following the *Exxon Valdez* (Palinkas et al., 1992; Palinkas et al., 2004). Studies of the social effect of the *Exxon Valdez* on the residents of Cordova, AK showed continued prevalence of depressive and PTSD related symptoms up to 24 years after the incident. Some of these effects were confounded by factors such as the delay in the civil lawsuit and the collapse of the Prince William Sound herring fishery (Gill et al., 2014).

Uncertainties:

1. Baseline health information from exposed populations including potential sensitivities or vulnerabilities of ethnic groups (e.g., Alaska Natives) is limited (Yasuda et al., 2008; Hagan and Provost, 2009). The Alaska Native Tribal Health Consortium Epidemiology Center and the Alaska Cancer Registry are routinely collecting and updating these data, and numerous publications have become available since December 31, 2015.

- The limited studies available showed genetic differences in the principle xenobiotic metabolism and DNA repair pathways when comparing Inuit and Danish populations in Greenland (Ghisari et al., 2013, 2014).

2. Although there is a growing number of non-human studies, there remains uncertainty regarding adverse human health effects resulting from exposure to chemically-dispersed oil and dispersants, especially on long-term effects (e.g., cancer, reproductive and developmental effects including endocrine disruption, and epigenetic changes) and interactions between chemical and non-chemical stressors (e.g., heat, psychosocial stressors). (See B.c.1 above).
3. Limitations in many of the existing non-human toxicological studies include a) predominance of *in vitro* cell culture models and limited availability of *in vivo* studies, b) limited availability of studies on the effects of dispersed oil, and c) the frequent use of doses/concentrations that do not simulate real-world exposures.
4. The extent to which dispersants can modify biological barriers and, thus, alter permeation of oil-derived chemicals through various routes at different levels of human exposure are unknown.
5. Dispersant formulations have not been fully characterized toxicologically or environmentally under Arctic conditions.
6. Limited field data are available to evaluate how dispersants in spill response may modulate the fate and transport, bioavailability and/or potential adverse human health effects of chemically-dispersed oil.
7. Because of the limitations of observational study designs, causal associations between chemical exposures and self-reported symptoms may be confounded or modified by many factors such as physical stress, psychosocial stress, other chemical exposures, and pre-existing health conditions.

II. Human Health Risk Assessment

General Statement:
According to the U.S. EPA, "A human health risk assessment is the process to estimate the nature and probability of adverse health effects in humans who may be exposed to chemicals in contaminated environmental media, now or in the future."(Human Health Risk Assessment (https://www.epa.gov/risk/human-health-risk-assessment). Human health risk assessments for environmental contaminants are undertaken either proactively, to develop safe exposure levels, or retroactively, to determine whether exposure levels exceed established guidelines. Effective risk assessment involves careful consideration of potential hazards; identifying populations at-risk and examining any potential dose-response effects; exposure assessment; and ultimately risk

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characterization. Varying levels of uncertainty are inherent in any risk assessment because of the difficulties in adequately determining exposure and characterizing human toxicity.

***Knowns*:**

1. Community-based Participatory Research (CBPR) approaches are valuable for informing risk assessments by actively engaging spill-impacted communities in various research activities in a collaborative manner (Brown et al., 2012; Wilson et al., 2015). "CBPR in public health is a partnership approach to research that equitably involves, for example, community members, organizational representatives, and researchers in all aspects of the research process, in which all partners contribute expertise and share decision making and responsibilities" (Israel et al., 2005).

   - Following the *Exxon Valdez* oil spill, concern about the health risks among the Alaska Native populations and the difficulty communicating these risks to the local populations, prompted the formation of the multi-stakeholder Oil Spill Health Task Force (OSHTF). While this group did not specifically follow CBPR, it did have many of the same elements (Nighswander, 1999).

   - Following the DWH oil spill, concern about health risks among Vietnamese-American seafood consumers exposed to polycyclic aromatic hydrocarbons (PAHs) via consumption of contaminated shrimp prompted an additional risk analysis (Wilson et al., 2015).

     - "The risk assessment results show[ed] no acute health risks or excess cancer risk associated with consumption of shrimp containing the levels of PAHs detected in [the] study, even among frequent shrimp consumers" Acute health risks in this study were evaluated using U.S. EPA reference doses for non-cancer health effects.

2. Risk assessments in an Arctic environment will include species and oil and dispersant-related exposure levels that are not common in other environments (e.g., marine mammal consumption).

3. Risk assessments need to consider local observations, culture-based ideas concerning edibility, and traditional knowledge regarding resource conditions and behaviors (e.g., animal disorientation) (Fall, 1999; Fall et al., 1999; Nighswander and Peacock 1999).

4. Many Arctic indigenous populations display a high background (pre-spill) body burden of various environmental chemicals (e.g., organochlorines) by virtue of their high concentration in traditional marine foods, especially in species occupying high trophic levels (Dewailly et al., 1993; Egeland et al., 1998; Van Oostadam et al., 2004).

5. Consumption patterns of various marine species, especially those at the apex of the food chain, by Arctic indigenous populations will likely be higher than many other coastal populations living elsewhere in the world (AKF&G, 2014).

Uncertainties:

1. Dispersants and oil are complex mixtures. There are thousands of incompletely characterized compounds in crude oil, and studies looking at the entire composition of crude oils have identified a number of compounds whose bioavailability (McKenna et al., 2013) and toxicity is uncertain. As science progresses, additional data may refine the risk assessment process (e.g., chemicals of concern, toxic endpoints, exposure variables).

2. There are many components of oil and dispersants for which toxicological reference values are inadequate or lacking.

3. The ability to conduct an adequate exposure assessment cannot always be assured and this will present considerable uncertainty in the risk analysis.

4. Because background human exposures include chemical constituents also found in oil and dispersants, it may be difficult to attribute the source of chemical exposure to any oil spill event.

5. Baseline human health status among Alaska Native and other sub-populations may also be directly or indirectly affected by rapidly changing environmental parameters in the Arctic (e.g., climate change) (Bell et al., 2010; Clement et al., 2013).

6. The degree to which the background body burden of environmental contaminants (e.g., organohalides) in Arctic indigenous populations influences the toxicity of oil- and dispersant-related components is not well characterized.

III. Risk Communication

General Statement:
As defined by the U.S. EPA, “Risk communication is the process of informing people about hazards to their person, property, or community. Scholars define risk communication as a science-based approach for communicating effectively in situations of high stress, high concern or controversy.” (U.S. EPA, https://www.epa.gov/risk/risk-communication). However, many risk communication experts feel this definition does not adequately capture the complexity of human nature in controversial situations nor acknowledge the requirement for bilateral exchange of information between risk communicators and concerned stakeholders. Instead, a definition gaining favor includes “an interactive process of exchange of information and opinions among individuals, groups and institutions” concerning risk and potential risk to human health or the environment (NAS, 1989). This approach assimilates perceptions, concerns, and questions about

potential risks, and then develop information and strategies to address those concerns. Transparency in acknowledging the varying impacts and uncertainty unique in each risk determination is paramount to building and maintaining trust. Risk communication is particularly challenging during emergency events.

As one example, how one considers risk to and from consumption of subsistence resources, compared to non-essential or even recreational resources is highly relevant to Arctic indigenous peoples. While conducting day-long risk communication workshops among fisherman following DWH proved useful, tailoring that approach to populations living in Arctic environments is challenging. Sincere collaboration between experts and communities in data-gathering campaigns and management strategies also builds credibility and effectiveness.

***Knowns*:**

1. The following are examples of risk communication products that are available to workers and/or the community during oil spill incidents:

    - The Safety Data Sheets for Corexit 9500 (Nalco, 2012a) and 9527, (Nalco, 2012b) intended for use primarily by workers, includes, in part, the following:

        - "May cause skin irritation."
        - "These products are not expected to be sensitizers."
        - "May cause serious eye damage if not treated promptly."
        - "Frequent or prolonged contact with products may defat and dry the skin, leading to discomfort and dermatitis."

    - The National Institute for Occupational Safety and Health (NIOSH), National Library of Medicine (NLM) TOXNET (2014) indicates:

        - "Crude oil and its constituents, as well as oil dispersants, can cause skin irritation and inflammation."

    - The Centers for Disease Control and Prevention (CDC) fact sheets (CDC, 2010a; CDC, 2010b) during DWH stated the following related to skin impacts of Corexit 9500 and 9527:

        - "Ingredients are not considered to cause chemical sensitization; the dispersants contain proven, biodegradable, and low toxicity surfactants."
        - "Defatting and drying of the skin and possibly dermatitis, as a result of prolonged exposure."
        - "Skin contact may aggravate an existing dermatological condition."

2. It is of paramount importance that the results of a risk assessment and its uncertainties should be communicated effectively to the diverse stakeholders in the clearest and most

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transparent way to build trust in affected communities (Covello et al., 1989, Nighswander et al., 1999; Fall et al., 1999; Yender et al., 2002; White, 2011; Walker, et al., 2014).

3. CBPR is a valuable approach for risk communication and for gaining stakeholder acceptance. (Brown et al., 2012; Wilson et al., 2015).
4. Risk communication needs to take into account language as well as local customs, culture-based ideas concerning edibility, and traditional knowledge (Fall 1999; Fall et al., 1999; Nighswander and Peacock, 1999).
5. Perception of risk among individuals within impacted populations varies and may differ substantially from scientifically estimated risk.
6. Tolerance of risk also varies greatly among individuals. For example, people are often less willing to accept involuntary risk than voluntary risk (e.g., oiled fish vs. smoked fish) (Nighswander and Peacock, 1999; Yender et al., 2002).
7. An evaluation of risk communication in the news media related to seafood consumption after DWH suggests the public health community could improve risk communication by reaching out to newswires and online news aggregator services to help frame communications (Greiner et al., 2013).

Uncertainties:

1. It is unknown whether people impacted by a spill are aware of, or know how to obtain, relevant hazard information (e.g., III. Risk Communication, Knowns #1), some of which may be highly technical in nature.
2. The extent to which "cultural conflicts between the local populace and outside experts...can exacerbate risk communication problems" is unknown (Nighswander and Peacock, 1999).
3. The scientific process is complicated and iterative by nature and tends to produce results that may be conflicting and warrant resolution, making risk communication challenging. The litigious nature of oil spills may exacerbate this problem.
4. Effective methods of communicating the full range of health risks and the uncertainties associated with its assessment to Alaska Natives and other stakeholders are not well developed.

IV. <u>Arctic Seafood Safety</u>

General Statement:

This section will primarily discuss the state-of-the-science with respect to seafood safety as it relates to dispersants and dispersed oil. In the context of the Arctic, seafood consists of fish (anadromous and marine), marine mammals, marine invertebrates, and birds. It includes food harvested for traditional, commercial, recreational, and personal use. As used in this section, the meaning of the term "edible" would be determined by the food consumption norms of a region.

This section will not address other aspects of Arctic food security, which involve nutritional value of the food and its cultural significance, availability, and accessibility. Arctic food security is a complex and important issue; the reader is referred to the following references for more information (CCA, 2014; ICC-AK, 2015).

Knowns:

1. National seafood consumption rates, including species consumed and portions of animals consumed, are not representative of likely higher consumption by local populations in the Arctic.

2. From the perspective of subsistence food safety, there are data on consumption patterns in Arctic Alaska, Canada, and Greenland. The jurisdictions in these three regions have differing standards, but they often cooperate fairly closely in contaminant/toxicology and exposure research, in the form of the existing Arctic Council programs (e.g., Arctic Monitoring and Assessment Programme (AMAP)).

3. For Alaska, the critical importance of subsistence foods, and the composition and dimensions of harvests (a surrogate for general levels of consumption) are known for all coastal areas and most communities. Data are available through the Alaska Department of Fish and Game's (AKF&G) Community Subsistence Information System (CSIS) available on-line (AKF&G, 2015a website), AKF&G's, 2015b website), and other sources (e.g., Braund & Associates, 2012; North Slope Borough, 2015 website).

4. A variety of factors and assumptions (e.g. consumption rates, age sensitivity) are used to derive levels of concern (LOC) for specific contaminants. LOCs are human health risk-based values used to establish protocols for the re-opening of areas affected by oil spills (U.S. FDA, 2010; Gohlke et al., 2011; OEHHA, 2015).

5. PAHs in edible tissues of molluscan shellfish will depurate more slowly (typically weeks to months) (Mearns et al., 2014), compared to finfish and crustaceans (typically days to weeks) (Eisler, 1987; Yender et al., 2002; Helton et al., 2004; Watson et al., 2004; Ylitalo et al., 2012). However, it is important to note that studies vary as to the type of oil, species type, the exposure period, and the environmental conditions. Uptake and depuration of PAHs and other petroleum-derived compounds will vary by chemical structure, biological species, and prevailing oceanographic conditions (Yender et al., 2002). Following the dissipation of oil after a spill, residual and nonvolatile oil compounds in the environment can be remobilized and cause transient increases in PAH levels in seafood species that would be expected to be below peak levels occurring during the spill (Yin et al., 2015).

6. Fisheries may be closed after an oil spill for reasons other than human health risks (e.g., Coast Guard security zone, economic factors associated with perception of risk) (Moller et al., 1999; Yender et al., 2002; Wickliffe et al., 2014).

7. During the DWH incident, the U.S. FDA (2010) developed a protocol for re-opening oil-impacted areas closed to seafood harvesting once oil is no longer visible on the water. The protocol specifies that the waters can be re-opened if PAH and DOSS concentrations in seafood (oysters, crabs, shrimp, and numerous species of finfish) are below levels of human health concern (Ylitalo et al., 2012).

8. Because of the chemical properties of DOSS (Acros Organics, 2014) and its persistence in the environment, it was selected to be a marker for Corexit 9500 and 9527 (Dickey and Dickhoff, 2011).

Uncertainties:

1. The extent to which environmental factors unique to the Arctic may influence the bioaccumulation or biomagnification of oil- and dispersant-related components is not well understood.

2. Specific information about the consumption of subsistence foods by age and sex within "sensitive subgroups" (e.g., Alaska Native populations, pregnant women, young children, others who may be at increased risk from exposure) is very limited for risk assessments that are targeting these subgroups or segments of them.

3. The seafood safety ramifications of dispersants and dispersed oil are inadequately characterized in the Arctic environment.

4. Bioaccumulation and depuration rates of oil- and dispersant-related components in edible seafood tissue resulting from exposure to dispersed oil in the Arctic environments are not well characterized.

5. The ability of dispersants to alter the bioavailability and toxicokinetics of oil-related compounds in seafood species is not well characterized in Arctic environments.

6. Distribution patterns and levels of dispersant compounds and dispersed-oil components within various marine-based foods consumed by indigenous Arctic peoples is not well described.

7. The public health consequences of reduced seafood consumption as the result of a spill are not well studied.

8. The seafood safety ramifications of some dispersant formulations are inadequately characterized toxicologically or environmentally under conditions of use in the field and potential exposures, particularly in the Arctic environment.

9. It is unclear if regulatory policies (i.e., closing and re-opening) that limit commercial marine harvest in response to an oil spill will be as effective amongst an indigenous population of subsistence fishers, as it is in other parts of the world.

References cited

Acros Organics. Safety Data Sheet: DOSS. 2014. One Reagent Lane, Fair Lawn, NJ 07410.

Aguilera F., Méndez J., Pàsaro E., and Laffon B. 2010. Review on the Effects of Exposure to Spilled Oils on Human Health. *Journal of Applied Toxicology*. 30: 291-301.

AKF&G - Alaska Department of Fish and Game. 2014. Subsistence in Alaska: A Year 2014 Update. Division of Subsistence, *Alaska Department of Fish & Game*, 222 Raspberry Rd, Anchorage, Alaska 99518.

AKF&G - Alaska Department of Fish and Game. 2015a. Welcome to the Community Subsistence Information System: CSIS. *Alaska Department of Fish and Game*. https://www.adfg.alaska.gov/sb/CSIS/

AKF&G - Alaska Department of Fish and Game. 2015b. Fishing and Subsistence Publications Searchable Database. *Alaska Department of Fish and Game*. http://www.adfg.alaska.gov/index.cfm?adfg=fishingSubsistence.main

AMAP – Arctic Monitoring and Assessment Programme - an Arctic Council Working Group. Website: https://www.amap.no/

Anderson S., Franko J., Lukomska E., and 1 other author. 2011. Potential Immunotoxicological Health Effects Following Exposure to Corexit 9500A during Clean of the Deepwater Horizon Oil Spill. J. *Toxicology Environmental Health*, Part A, 74:1419-1430.

Andreoli R., Spatari G., Pigini D., and 9 other authors. 2015. Urinary Biomarkers of Exposure and Oxidative Damage in Children Exposed to Low Airborne Concentrations of Benzene. *Environmental Resources.* 142:264-272.

ATSDR – Agency for Toxic Substances and Disease Registry. Toxicological Profile for Total Petroleum Hydrocarbons (TPH). 1999. U.S. Department of Health and Human Services, Public Health Service, Agency for Toxic Substances and Disease Registry.

Avens H., Unice K., Sahmel J., Gross S., and 2 other authors. 2011. Analysis and Modeling of Airborne BTEX Concentrations from the Deepwater Horizon Oil Spill. *Environmental Science and Technology*. 45(17): 7372-7379.

Bandele O., Santillo M., Ferguson M., Wiesenfield R. 2012. *In Vitro* Toxicity Screening of Chemical Mixtures Using Hep G2/C3A Cells. *Food and Chemical Toxicology.* 50: 1653-1659.

Bell J., Brubaker M., Graves K. and Berner J. 2010. Climate Change and Mental Health: Uncertainty and Vulnerability for Alaska Natives. ANTHC/CCH Bulletin No. 3. Anchorage, AK.

Braund Stephen R. & Associates (SRB&A). 2012. Social Indicators in Alaska: Arctic Communities. North Slope Social Indicators Study Literature Review. Contract No. M11PC00032, Bureau of Ocean Energy Management (BOEM). Available Online.

Brown P., Brody J., Morello-Frosch R., Tovar J., and 2 other authors. 2012. Measuring the Success of Community Science: The Northern California Household Exposure Study. *Environmental Health Perspectives*. 120(3): 326-331.

Buttke D., Vagi S., Bayleyegn T., Sircar K., Strine T., and 3 other authors. 2012a. Mental Health Needs Assessment after the Gulf Coast Oil Spill—Alabama and Mississippi, 2010. *Prehospital and Disaster Medicine*. 27(5): 401-408.

Buttke D., Vagi S., Schnall A., Bayleyegn T., and 3 other authors. 2012b. Community Assessment for Public Health Emergency Response (CASPER) One Year Following the Gulf Coast Oil Spill: Alabama and Mississippi, 2011. *Prehospital and Disaster Medicine*. 27(6): 496-502.

CCA – Council of Canadian Academies. 2014. Aboriginal Food Security in Northern Canada: An Assessment of the State of Knowledge, Ottawa, ON. The Expert Panel on the State of Knowledge of Food Security in Northern Canada, Council of Canadian Academies.

CDC - Centers for Disease Control and Prevention. 2010a. Reducing Occupational Exposures While Working with Dispersants During the Deepwater Horizon Response. NIOSH Interim Information. *Department of Health and Human Services*.

CDC - Centers for Disease Control and Prevention. 2010b. Oil Spill Dispersant (Corexit ®EC9500A and EC9527A) Information for Health Professionals. *Department of Health and Human Services, Center for Disease Control,* and *Agency for Toxic Substances & Disease Registry*.

CDC/ATSDR. 2011. Guidance on the Interpretation and Use of Blood Laboratory Analyses for Volatile Organic Compounds. *Centers for Disease Control and Prevention (CDC), Agency for Toxic Substances and Disease Registry (ATSDR)*. CS221524-A.

Choi K., Lim M., Ha M., Sohn J., and 3 other authors. 2015. Psychological Vulnerability of Residents of Communities Affected by the Hebei Spirit Oil Spill. *Disaster Med Public Health Prep*. 10(1):51-8. doi: 10.1017/dmp.2015.68.

Clement J., Bengtson J., and Kelly B. 2013. Managing for the Future in a Rapidly Changing Arctic. A Report to the President. Interagency Working Group on Coordination of Domestic Energy Development and Permitting in Alaska (D. J. Hayes, Chair), Washington, D.C.

Covello V., McCallum D., and Pavlova M. 1989. Effective Risk Communication: The Role and Responsibility of Government and Nongovernment Organizations. Part of the

Contemporary Issues in Risk Analysis book series (CIRA, volume 4). Springer US10.1007/978-1-4613-1569-8.

Dewailly E., Ayotte P., Bruneau S., Laliberte C., and 2 other authors. 1993. Inuit Exposure to Organochlorines through the Aquatic Food Chain in Arctic Quebec. *Environmental Health Perspectives* 101:7, 618-620.

Dickey R. 2012. U.S. FDA Risk Assessment of Seafood Contamination after the BP Oil Spill. *Environmental Health Perspectives*. 120(2): 54-55.

Dickey R. and Dickhoff W. 2011. Dispersants and Seafood Safety: Assessment of the Potential Impact of Corexit® Oil Dispersants on Seafood Safety. *Coastal Response Research Center*. Dispersant Initiative and Workshop "The Future of Dispersant Use in Spill Response". Mobile, AL.

Dreshcher C., Schulenberg S., and Smith C. 2014. The Deepwater Horizon Oil Spill and the Mississippi Gulf Coast: Mental Health in the Context of a Technological Disaster. *Am J Orthopsychiatry*. 84:142-151.

Egeland, G., Feyk L. and Middaugh J. 1998. The Use of Traditional Foods in a Healthy Diet in Alaska: Risks in Perspective. Report of the Department of Health and Social Services, Division of Public Health, Section of Epidemiology, Anchorage, Alaska.

Eisler R. 1987. Polycyclic Aromatic Hydrocarbon Hazards to Fish, Wildlife, and Invertebrates: A Synoptic Review. *Contaminant Hazard Reviews*, *Biological Report*. 85(1.11): 55.

Elovaara E., Mikkola J., Makela M., and 2 other authors. 2006. Assessment of Soil Remediation Workers' Exposure to Polycyclic Aromatic Hydrocarbons (PAHs): Biomonitoring of Naphtha's, Phenanthrols, and 1-Hydroxypyrene in Urine. *Toxicology Letters*. 162:158-163.

Fabisiak J. and Goldstein B. 2011. Oil Dispersants and Human Health Effects. White Paper for the Future of Dispersant Use in Spill Response Workshop. *Coastal Response Research Center*. September 2011. Dispersant Initiative and Workshop, "The Future of Dispersant Use in Spill Response". Mobile, Alabama.

Fall J.A. 1999. Chapter 4: Changes in Subsistence Uses of Fish and Wildlife Resources Following the Exxon Valdez Oil Spill. In Evaluating and Communicating Subsistence Seafood Safety (54). In *Cross-Cultural Contexts: Lessons Learned from the Exxon Valdez Oil Spill*. Field L.J., Fall J.A., Nighswander T.S., Peacock N., Varanasi U. (eds). SETAC Press: Pensacola, FL.

Fall J.A., Field L., Nighswander T., Stein J. and Bolger M. 1999. Chapter 11: Overview of Lessons Learned from the Exxon Valdez Oil Spill: A 10-Year Retrospective. In Evaluating and Communicating Subsistence Seafood Safety (34). In *Cross-Cultural*

Contexts: Lessons Learned from the Exxon Valdez Oil Spill. Field L.J., Fall J.A., Nighswander T.S., Peacock N., Varanasi U. (eds). SETAC Press: Pensacola, FL.

Fan A., Prescott M., Zhao G., Gotway C., and Galea S. 2015. Individual and Community-Level Determinants of Mental and Physical Health after the Deepwater Horizon Oil Spill: Findings From the Gulf States Population Survey. *J Behav Health Serv Res.* 42(1):23-41. doi: 10.1007/s11414-014-9418-7.

Fitzgerald T. and Gohlke J. 2014. Contaminant Levels in Gulf of Mexico Reef Fish after the *Deepwater Horizon* Oil Spill As Measured by a Fisherman-Led Testing Program. *Environmental Science & Technology*. 48: 1993-2000.

Gallacher J., Bronstering K., Palmer S., Fone D. and Lyons R. 2007. Symptomatology Attributed to Psychological Exposure to a Chemical Incident: A Natural Experiment. *J. Epidemiol Community Health.* 61: 506-512.

Ghisari M., Long M., Bonefeld-Jørgensen E. 2013. Genetic Polymorphisms in CYP1A1, CYP1B1 and COMT Genes in Greenlandic Inuit and Europeans. *International Journal of Circumpolar Health.* 72:1, DOI: 10.3402/ijch.v72i0.21113.

Ghisari M., Eiberg H., Long M., and Bonefeld-Jørgensen E. 2014. Plymoprhisms in Phase 1 and Phase II Genes and Breast Cancer Risk and Relations to Persistent Organic Pollutant Exposure: A Case-Control Study in Inuit Women. *Environmental Health* 13:19. Available Online

Gill D. and Picou J. 1998. Technological Disaster and Chronic Community Stress. *Soc Nat Resour.* 11: 795-815.

Gill D., Picou J., and Ritchie L. 2014. Twenty-Four Years of Social Science Research on the Exxon Valdez Oil Spill: Sociocultural and Psychosocial Impacts in a Commercial Fishing Community. *2014 International Oil Spill Conference*. 300133; 80-92.

Gohlke J., Doke D., Tipre, M., Leader M., and 1 other author. 2011. A Review of Seafood Safety After the Deepwater Horizon Blowout. *Environmental Health Perspectives*. 119(8): 1062-1069

Goldstein B., Osofsky H., and Lichtveld M. 2011. The Gulf Oil Spill. *The New England Journal of Medicine*. 364: 1334-1348.

Gould D., Teich J., Pemberton M., Pierannunzi C., and Larson S. 2015. Behavioral Health in the Gulf Coast Region Following the Deepwater Horizon Oil Spill: Findings From Two Federal Surveys. *J Behav Health Serv Res*. 42(1):6-22. doi:10.1007/s11414-014-9441-8.

Grattan L., Roberts S., Mahan Jr. W., McLaughlin P., and 2 other authors. 2011. The Early Psychological Impacts of the Deepwater Horizon Oil Spill on Florida and Alabama Communities. *Environ. Health Perspect*. 119: 838-843.

Greiner A., Lagasse L., Neff R., Love D., and 3 other authors. 2013. Reassuring or Risky: The Presentation of Seafood Safety in the Aftermath of the British Petroleum Deepwater Horizon Oil Spill. *American Journal of Public Health*. 103 (7); 1198-1206.

Hagan K. and Provost E. 2009. Alaska Native Health Status Report. *Alaska Native Epidemiology Center* and *Alaska Native Tribal Health Consortium*.

Hayworth J. and Clement T. 2012. Provenance of Corexit-related Chemical Constituents Found in Nearshore and Inland Gulf Coast Waters. *Marine Pollution Bulletin*. 64:10, 2005-2014.

Helton D., Moles A., Short J., and Rice J. 2004. Results of the M/V Kuroshima Oil Spill Shellfish Tissue Analysis 1999, 2000, and 2004. *Report to the M/V Kuroshima Trustee Council*. NOAA, Ofc of Response & Restoration.

ICC-AK. 2015. Alaskan Inuit Food Security Conceptual Framework: How to Assess the Arctic From an Inuit Perspective. Technical Report. Anchorage, AK.

Israel B., Parker E., Rowe Z., Salvatore A., and 13 other authors. 2005. Community-based Participatory Research: Lessons Learned from the Centers for Children's Environmental Health and Disease Prevention Research. *Environ Health Perspect*. 113(10):1463-71.

Judson R., Martin M., Reif D., Houck K. and 9 others. 2010. Analysis of Eight Oil Spill Dispersants Using Rapid *in vitro* Tests for Endocrine and Other Biological Activity. *Environ Sci Tech.* 44 (15): 5979-5985.

Kim J., Hecht S., Mukherjee S., and 3 other authors. 2015. A Urinary Metabolite of Phenanthrene as a Biomarker of Polycyclic Aromatic Hydrocarbon Metabolic Activation in Workers Exposed to Residual Oil Fly Ash. *Cancer Epidemiology, Biomarkers & Prevention*. 14:687-692.

Krajnak K., Kan H., Waugh S., Miller G. and 8 others. 2011. Acute Effects of Corexit EC9500A on Cardiovascular Functions in Rats. *J Tox and Env Health, Part A.* 74:1397-1404.

Laffon B., Frago-Iriso R., Pérez-Cadahía B., and Méndez J. 2006. Genotoxicity Associated to Exposure to Prestige Oil During Autopsies and Cleaning of Oil-Contaminated Birds. *Food and Chemical Toxicology* (44): 1714-1723.

Laffon B., Aguilera F., Ríos-Vázquez J., García-Lestón J., and 3 other authors. 2013. Endocrine and Immunological Parameters in Individuals Involved in Prestige Spill Cleanup Tasks Seven Years after the Exposure. *Environment International*. 59: 103-11.

Laffon B., Aguilera F., Ríos-Vázquez J., and 2 other authors. 2014. Follow-up Study of Genotoxic Effects in Individuals Exposed to Oil from the Tanker Prestige, Seven Years after the Accident. *Mutation Research/Genetic Toxicology and Environmental Mutagenesis*. 760: 10-6.

Liu Y., Roy-Engel A., Baddoo M., and 3 other authors. 2016. The Impact of Oil Spill to Lung Health - Insights from an RNA-Seq Study of Human Airway Epithelial Cells. *Gene*. 578:38-51. Electronic publication 2015.

Lowe S., Kwok R., Payne J., Engel L., and 2 other authors. 2015. Mental Health Service Use by Cleanup Workers in the Aftermath of the *Deepwater Horizon* Oil Spill. *Soc Sci Med*. 130:125-34.

Lyons R. A., J. M. Temple, D. Evans, D. L. Fone and S. R. Palmer. 1999. Acute Health Effects of the Sea Empress Oil Spill. *J Epidemio Community Health* 53: 306-310.

Major D., Zhang Q., Wang G., and Wang H. 2012. Oil-Dispersant Mixtures: Understanding Chemical Composition and its Relation Human Toxicity. *Toxicological and Environmental Chemistry*. 94:9, 1832-1845.

Mearns A.J., Shigenaka G., Meyer B., and Drury A. 2014. Contamination and Recovery of Commercially-Reared Mussels Exposed to Diesel Fuel from a Sunken Fishing Vessel. *International Oil Spill Conference*. 299767:1686-1705.

McKenna A.M., R.K. Nelson, C.M. Reddy, J.J. Savory, N.K. and 3 other authors. 2013. Expansion of the Analytical Window for Oil Spill Characterization by Ultrahigh Resolution Mass Spectrometry: Beyond Gas Chromatography. *Environ Sci Technol*. 47: 7530-7539.

Meo S.A., Al-Drees A.M., Rasheed S., Meo I.M., and 3 other authors. 2009. Effect of Duration of Exposure to Polluted Air Environment on Lung Function in Subjects Exposed to Crude Oil Spill into Sea Water. *International Journal of Occupational Medicine and Environmental Health*. 22(1): 35-41.

Moller T.H., Dicks H., Whittle K.J., and Girin, M. 1999. Fishing and Harvest Bans in Oil Spill Response. *The International Tanker Owners Pollution Federation Limited*. #095, International Oil Spill Conference. Seattle, WA. 095:1-9.

Monyarch G., de Castro Reis F., Zock J-P., Giraldo J., and 10 other authors. 2013. Chromosomal Bands Affected by Acute Oil Exposure and DNA Repair Errors. *PLoS ONE*. 8(11): 1-7.

Nalco - Nalco Environmental Solutions LLC. 2012a. Safety Data Sheet: Corexit EC9500A. 7705 Highway 90-A, Sugar Land, TX 77478.

Nalco - Nalco Environmental Solutions LLC. 2012b. Safety Data Sheet: Corexit EC9527A. 7705

Highway 90-A, Sugar Land, TX 77478.

NAS, NRC- The National Academies of Sciences, Engineering and Medicine, National Research Council, Improving Risk Communication, 1989. Washington D.C.: National Academies Press.

Nighswander T., 1999. Chapter 3: The Role of the Alaska Oil Spill Health Task Force Following the Exxon Valdez Oil Spill. Evaluating and Communicating Subsistence Seafood Safety (18). In *Cross-Cultural Contexts: Lessons Learned from the Exxon Valdez Oil Spill.* Field L.J., Fall J.A., Nighswander T.S., Peacock N., Varanasi U. (eds). SETAC Press: Pensacola, FL.

Nighswander T. and Peacock N. 1999. Chapter 10: The Communication of Health Risk from Subsistence Food in a Cross-Cultural Setting: Lessons from the Exxon Valdez Oil Spill. In Evaluating and Communicating Subsistence Seafood Safety (32). In *Cross-Cultural Contexts: Lessons Learned from the Exxon Valdez Oil Spill*. Field L.J., Fall J.A., Nighswander T.S., Peacock N., Varanasi U. (eds).SETAC Press: Pensacola, FL.

NIOSH - National Institute for Occupational Safety and Health. 2011. Health Hazard Evaluation of Deepwater Horizon Response Workers. By King B.S. and Gibbins J.D.: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, NIOSH HETA No. 2010-0115 & 2010-0129-3138.

NLM - National Library of Medicine, TOXNET. 2014. Toxicology Data Network. https://toxnet.nlm.nih.gov/.

Noh S., Cheong H., Ha M., and 4 other authors. 2015. Oxidative Stress Biomarkers in Long-term Participants in Clean-up Work after the Hebei Spirit Oil Spill. *Science of the Total Environment*. 515-516:207-214.

Norris F., VanLandingham, M., and Vu, L. 2009. PTSD in Vietnamese Americans Following Hurricane Katrina: Prevalence, Patterns, and Predictors. *Journal of Traumatic Stress.* 22: 91–101.

North Slope Borough. 2015. Subsistence Harvest Documentation. North Slope Borough. http://www.north-slope.org/departments/wildlife-management/studies-and-research-projects/subsistence-harvest-documentation.

OEHHA - Office of Environmental Health Hazard Assessment. 2015. Protocol for Seafood Risk Assessment to Support Fisheries Re-Opening Decisions for Marine Oil Spills in California. *California Environmental Protection Agency, Office of Environmental Health Hazard Assessment*.

OSAT – Operational Science Advisory Team. 2010. Summary Report for Sub-Sea and Sub-Surface Oil and Dispersant Detection: Sampling and Monitoring. *Operational Science Advisory Team*.

Osofsky J., Osofsky H. and T. Hansel. 2011. Deepwater Horizon Oil Spill: Mental Health Effects on Residents in Heavily Affected Areas. *Disaster Med Public Health* Prep. 5: 280-286.

Osofsky J., Osofsky H., Weems C., and 2 other authors. 2014. Effects of Stress Related to the Gulf Oil Spill on Child and Adolescent Mental Health. *J Pediatr Psychol*. 41(1):65-72.

Osofsky H., Hansel T., Osofsky J., and Speier A. 2015. Factors Contributing to Mental and Physical Health Care in a Disaster-Prone Environment. *Behav Med*. 41(3):131-7.

Palinkas L., Russell J., Downs M. and Petterson J. 1992. Ethnic Differences in Stress, Coping, and Depressive Symptoms After Exxon Valdez Oil Spill. *J Nerv Ment Dis*. 180: 287-295.

Palinkas L., Petterson J., Russell J. and Downs M. 1993. Community Patterns of Psychiatric Disorders After Exxon Valdez Oil Spill. *Am J Psychiatry*. 153:1517-1523.

Palinkas L., Petterson J., Russell J. and Downs M. 2004. Ethnic Differences in Symptoms of Post-Traumatic Stress After Exxon Valdez Oil Spill. *Prehosp Disaster* Med. 19:102-112.

Pérez-Cadahía B., Lafuente A., Cabaleiro T., Pásaro E, and 2 other authors. 2007. Initial Study on the Effects of Prestige Oil on Human Health. *Environment International*. 33: 176-185.

Pérez-Cadahía B., Méndez J., Pásaro E, Lafuente A., and 2 other authors. 2008a. Biomonitoring of Human Exposure to Prestige Oil: Effects on DNA and Endocrine Parameters. *Environmental Health Insights*. 2: 83-92.

Pérez-Cadahía B., Laffon B., Valdiglesias V., Pásaro E, and 1 other author. 2008b. Cytogenetic Effects Induced by Prestige Oil on Human Populations: The Role of Polymorphisms in Genes Involved in Metabolism and DNA Repair. *Mutation Research*. 653: 117-123.

Pérez-Cadahía B., Laffon B., Porta M., Lafuente A., and 7 other authors. 2008c. Relationship Between Blood Concentrations of Heavy Metals and Cytogenetic and Endocrine Parameters Among Subjects Involved in Cleaning Coastal Areas Affected by the Prestige Tanker Oil Spill. *Chemosphere*. 71: 447-455.

Picou J. and Martin C. 2007. Long-term Community Impacts of the Exxon Valdez Oil Spill: Patterns of Social Disruption and Psychological Stress Seventeen Years after the

Disaster. *Final Report National Science Foundation, Office of Polar Research.* Award Number 0002572. Washington D.C.

Roberts J., Reynolds J., Thompson J., Zaccone E. and 10 others. 2011. Pulmonary Effects after Acute Inhalation of Oil Dispersant (Corexit EC9500A) in Rats. *Journal of Toxicology & Environmental Health* Part A. 74:21, 1381-1396.

Roberts J., Anderson S., Kan H., Krajnek K., and 7 other authors. 2014. Evaluation of Pulmonary and Systemic Toxicity of Oil Dispersants (Corexit EC9500®) Following Acute Repeated Inhalation Exposure. *Environmental Health Insights.*8(s1) 63–74 doi: 10.4137/EHi.s15262.

Rodríguez-Trigo G., Zock J-P., Pozo-Rodríguez F., Gómez P., and 7 other authors. 2010. Health Changes in Fishermen 2 Years after Clean-up of the Prestige Oil Spill. *Annals of Internal Medicine*. 153: 489-498.

Rosenberg L. and Ligenza L. 2015. The Deepwater Horizon Oil Spill and Ongoing Mental Health Impact. *J Behav Health Serv Res*. 42(1):1-2. doi: 10.1007/s11414-014-9443-6.

Rung A., Oral E, Fontham E, Harrington D. and 2 other authors. 2015. Mental Health Impact of the Deepwater Horizon Oil Spill Among Wives of Clean-up Workers. *Epidemiology*. 26(4):e44-6; 0.1097.

Sabucedo J., Arce C., Ferraces M., Merino H. and Duran M. 2009. Psychological Impact of the Prestige Catastrophe. *Int J Clin Health Psychol*. 34: 809-820.

Sabucedo J., Arce C. Senra C., Seoane G. and Vazquez I. 2010. Symptomatic Profile and Health-Related Quality of Life of Persons Affected by the Prestige Catastrophe. *Disasters* 34: 809-820.

Shenesey J. and Langhinrichsen-Rohling J. 2015. Perceived Resilience: Examining Impacts of the Deepwater Horizon Oil Spill One-year Post-spill. *Psychol Trauma.* 7(3):252-258.

Shi Y., Roy-Engel A., and Wang H. 2013. Effects of Corexit Dispersant on Cytotoxicity Parameters in a Cultured Human Bronchial Airway Cells, BEAS-2B. *JToxico Environ Health A.* 76 (13):821396.

Sriram K., Lin G., Jefferson A., Goldsmith W. and 5 others. 2011. Neurotoxicity Following Acute Inhalation Exposure to the Oil Dispersant Corexit EC9500A. *Journal of Toxicology and Environmental Health, Part A.* 74 (21):405-1418.

SAMHSA-Substance Abuse and Mental Health Services Administration and Centers for Disease Control and Prevention. 2013. Behavioral Health in the Gulf Coast Region Following the Deepwater Horizon Oil Spill. HHS Publication No. (SMA) 13-4737, Rockville, MD; Atlanta, GA: Substance Abuse and Mental Health Services Administration and Centers for Disease Control and Prevention.

Temkin A., Bowers, R., Magaletta, M., and 8 other authors. 2016. Effects of Crude Oil/Dispersant Mixture and Dispersant Components on PPARγ Activity *in Vitro* and *in Vivo*: Identification of Dioctyl Sodium Sulfosuccinate (DOSSl CAS #577-11-7) as a Probable Obesogen. *Environmental Health Perspec*tive. 124:112-119 [Advance Publication 2 July 2015].

U.S. EPA – U.S. Environmental Protection Agency. Risk Assessment. Human Health Risk Assessment. (https://www.epa.gov/risk/human-health-risk-assessment)

U.S. FDA – U.S. Federal Drug Administration. 2010. Protocol for Interpretation and Use of Sensory Testing and Analytical Chemistry Results for Re-Opening Oil-Impacted Areas Closed to Seafood Harvesting Due to the Deepwater Horizon Oil Spill. *U.S. Food and Drug Administration*. Available online.

U.S. FDA - U.S. Federal Drug Administration. 2011. DWH Phase III Surveillance Samples – Metals: October 12, 2010 to June 21, 2011. *U.S. Food and Drug Administration*. Available online.

Van Oostadam J., Dewailly E., Gilman A., Hansen J., and 10 others. 2004. Circumpolar Maternal Blood Contaminant Survey, 1994 – 1997 Organochlorine Compounds. *Science of the Total Environment.* 330:55-70.

Walker A., Pavia R., Bostrom A, Leschine T, and 1 other author. 2014. Communication Practices for Oil Spills: Stakeholder Engagement During Preparedness and Response. *Human and Ecological Risk Assessment: An International Journal*. 21(3): 667-690.

Wang H., Shi Y., Major D. and Yang Z., 2012. Lung Epithelial Cell Death Induced by Oil-Dispersant Mixtures. *Toxicology in Vitro.* 26 (5):746-751.

Watson G., Anderson O-K., Galloway T., and Depledge M. 2004. Rapid Assessment of Polycyclic Aromatic Hydrocarbon (PAH) Exposure to Decapod Crustaceans by Fluorimetric Analysis of Urine and Haemolymph. *Aquatic Toxicology*. 67:127-142.

White L. 2011. Human Health. *Deepwater Horizon Study Group*. Working Paper. Center for Catastrophic Risk Management. University of California – Berkeley. Available Online.

Wickliffe J., Overton E., Frickel S., Howard J., and 12 other authors. 2014. Evaluation of Polycyclic Aromatic Hydrocarbons Using Analytical Methods, Toxicology, and Risk Assessment Research: Seafood Safety after a Petroleum Spill as an Example. *Environmental Health Perspectives*. 122(1): 6–9.

Wilson M., Frickel S., Nguyen D., Bui T. and 5 other authors. 2015. A Targeted Health Risk Assessment Following the Deepwater Horizon Oil Spill: Polycyclic Aromatic Hydrocarbon Exposure in Vietnamese-American Shrimp Consumers. *Environmental Health Perspectives*. 123(2):152-159.

Wise C., Wise J., Wise S., Thompson W.D. and 2 others. 2014. Chemical Dispersants Used in the Gulf of Mexico Oil Crisis Are Cytotoxic and Genotoxic to Sperm Whale Skin Cells. 2014. *Aquatic Toxicology*. 152:335-340.

Yasuda S., Zhang L., and Huang S-M. 2008. The Role of Ethnicity in Variability in Response to Drugs: Focus on Clinical Pharmacology Studies. *Clinical Pharmacology & Therapeutics*, Vol 84:3.

Yender R., Michel J., and Lord C. 2002. Managing Seafood Safety after an Oil Spill. Seattle Hazardous Materials Response Division, Office of Response and Restoration, *National Oceanic and Atmospheric Administration*. 72pp.

Yin T., and Park, J. 2015. Optimum Processing Conditions for Slowly Heated Surimi Seafood Using Protease-laden Pacific Whiting Surimi. *LWT - Food Science and Technology*, 63(1), 490-496.

Ylitalo G. Krahn M., Dickhoff W., Stein J., and 11 other authors. 2012. Federal Seafood Safety Response to the Deepwater Horizon Oil Spill. *Proceedings of the National Academy of Sciences*. 109(50): 20274-20279.

Zheng M., Ahuja M., Bhattacharya D., Clement T. and 2 others. 2013. Evaluation of Differential Cytotoxic Effects of the Oil Spill Dispersant Corexit 9500. *Life Sciences*. 95:108-117.

Zock J-P., Rodríguez-Trigo G., Pozo-Rodríguez F., Barberà J.A., and 6 other authors. 2007. Prolonged Respiratory Symptoms in Clean-up Workers of the *Prestige* Oil Spill. *American Journal of Respiratory and Critical Care Medicine*. 176(6): 610-616.

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