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STATE OF KNOWLEDGE ON CHEMICAL DISPERSANTS FOR CANADIAN MARINE OIL SPILLS

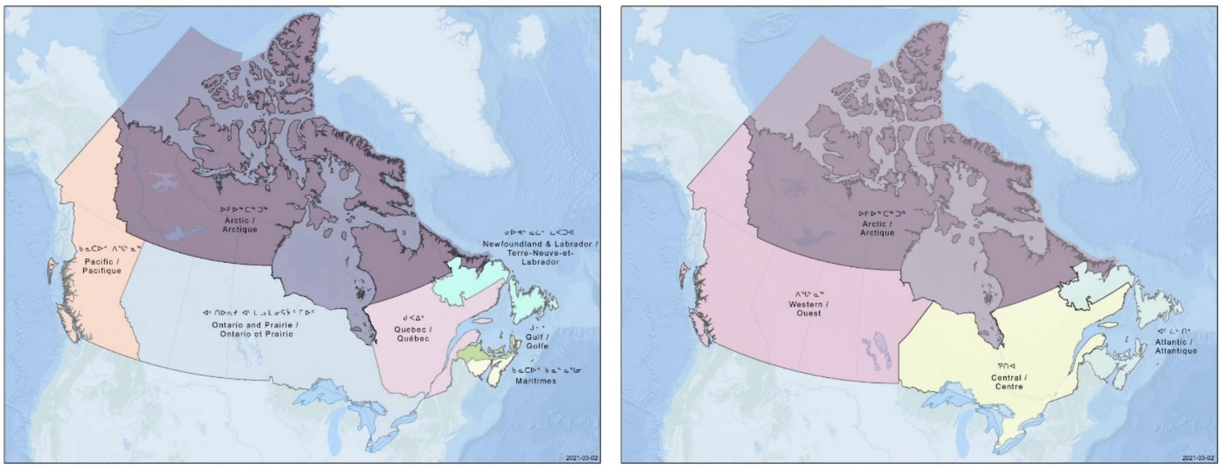

Figure 1: Fisheries and Oceans Canada (left) and Canadian Coast Guard (right) Regions (DFO 2021).

Context:

Canada has a strong marine safety system focusing around four major pillars: prevention; preparedness and response; liability and compensation; and recovery. In recent years, the Government of Canada has dedicated significant resources to further enhance specific aspects of this environmental protection and emergency response regime.

When there is an oil spill in the marine environment, Fisheries and Oceans Canada and the Canadian Coast Guard use science-based advice to inform decisions that facilitate cleanup and protect aquatic resources and ecosystems from negative impacts.

To support decision-making in the event of an oil spill, there is a need to understand the effectiveness of all available response tools that could reduce the potential for adverse effects on marine ecosystems, including the application of spill-treating agents such as chemical oil dispersants. Since the Deepwater Horizon spill in the Gulf of Mexico, there has been extensive research and scientific advancement related to dispersant use. This recent scientific information, available through various fora, has not yet been critically evaluated specifically to its applicability within a Canadian context.

This Science Advisory Report is from the March 1 to 12, 2021 National Advisory Meeting on the State of Knowledge on Chemical Dispersants for Canadian Marine Oil Spills. Additional publications from this meeting will be posted on the [DFO Science Advisory Schedule](#) as they become available.

SUMMARY

- Direct exposure to oil concentrated at the water surface or on shorelines and intertidal areas is typically very harmful to organisms and oil that reaches shorelines may persist for months to years. The use of dispersants is an important response option to mitigate the effects of an oil spill, including in cold climates and for treatment in ice-infested waters, particularly when there are limited viable removal options.
- Dispersion of oil into the water column is a natural process. Dispersants enhance the formation of smaller oil droplets, relative to natural processes, that remain in the water column and spread vertically and horizontally beneath the surface. This promotes the dissolution, dilution, and biodegradation of the oil over a larger volume of water.
- The dilution of smaller oil droplets following the effective use of dispersants reduces the potential for droplet collisions, thereby minimizing their coalescence and the reformation of surface slicks.
- Dispersants reduce the exposure to oil for organisms at the water surface and on shorelines and intertidal areas. Their use results in the temporary and localized increase in exposure to chemically dispersed oil for organisms (which may include species at risk) in the water column. Increased exposure to the benthic environment is possible.
- Typically, chemically dispersed oil has similar aquatic toxicity as oil alone (for commonly studied species); however, the duration and intensity of exposure to dispersed oil in the subsurface is mitigated by dilution, which quickly reduces oil concentration.
- Cold water species have similar sensitivities as temperate species to the acute toxicity of untreated and chemically dispersed oil.
- Lab-based toxicity tests provide critical information but are limited in representing the complexity of open water conditions. The effects of both untreated and chemically dispersed oil on marine biota are highly variable and are informed not only by toxicity but also by the interactions of physical, chemical, and biological factors. Modelling is useful for considering all parameters to predict potential effects to individuals, populations, and ecosystems.
- Monitoring requirements are site-, incident-, and context-specific. Operational monitoring is used to assess the effectiveness of dispersant application and measure against criteria to stop the application. Environmental monitoring is used to assess impacts and recovery from the spill event.

INTRODUCTION

Canada has a comprehensive marine safety system in place, founded on a polluter-pay principle with a strong emphasis on prevention and preparedness. The use of spill-treating agents (which are defined to include dispersants) is regulated through Canadian legislation. Presently, spill-treating agents are only available for use as a response tool related to offshore oil and gas activities, where a net environmental benefit is likely to be achieved (*i.e.,* legislation prohibits their use for any other oil spill source, such as ship-source). As a result of current moratoriums on offshore oil and gas activities in the Pacific and Arctic regions, this means they are only available as a response tool in eastern Canada. Presently, there is only one chemical dispersant approved for use in Canada: Corexit® EC9500A; however, to date it has not been used for response in Canadian waters.

This science advisory meeting is the first formal advisory process to consider expanding the use of dispersants in Canada. This science advice was developed to:

- Provide consensus-based, scientific advice to efficiently inform critical and time sensitive spill response decisions;
- Support the defensible communication of spill response decisions;
- Support and inform the development of regulations, policies, standards, and guidance for dispersant use; and,
- Support various other Government of Canada initiatives related to spill response.

Overview of Dispersants

A dispersant is a blend of surfactants in solvent(s) that is used to reduce the persistence of spilled oil and enhance oil biodegradation. Dispersants can be applied to a surface oil slick by aircraft or by boat, or directly into a blowout of oil (at any depth) through subsurface dispersant injection (SSDI). Dispersants are generally considered as an additional oil spill response tool where other response measures and natural attenuation are not expected to effectively mitigate spill impacts on their own.

Dispersion of oil into droplets within the water column occurs naturally (*e.g.,* when a surface slick is subjected to mixing energy created by breaking waves). Relative to natural processes, dispersants enhance the formation and stability of smaller oil droplets, promoting retention in the water column, as well as three-dimensional spread beneath the surface. This promotes the dissolution and dilution of the oil over a larger volume of water and enhances the rate of biodegradation. Dilution of smaller oil droplets following effective use of dispersants also reduces frequency of droplet collisions, hinders droplet coalescence, and minimizes reformation of surface slicks.

Commercially available chemical dispersants that are in current use, are specifically formulated for use in marine environments and generally function in the same way. That is, surfactants in the dispersant reduce the adhesive forces that limit mixing between oil and water molecules (i.e., interfacial tension), promoting the formation of small, stable oil droplets. Research and development is ongoing on new formulations and application strategies (*e.g.,* remotely operated vehicles) with different modes of action.

Dispersants are typically most effective when applied to freshly-released light crude oils and some medium crude oils. While dispersants can effectively disperse very light oils, they are typically not required due to the oil weathering processes (*e.g.,* rapid rates of evaporation and natural dispersion). Dispersants are generally less effective on oils that are very viscous, oils that are not flowing (*e.g.,* at temperatures below an oils' pour point), or oils that have emulsified with water. Field tests should always be conducted on a spilled oil product to confirm the potential efficacy of a dispersant.

There is a significant global body of peer-reviewed scientific literature available on the use of dispersants during oil spill response. There have also been substantial advancements since dispersants were first used in the 1960s. Nonetheless, it is acknowledged that every spill scenario is unique, and presents an opportunity for continued learning, validation, and refinement of the scientific knowledge regarding oil spill dispersants.

The scope of this review is not limited to any specific dispersant formulation or product, but instead speaks broadly to the modes of action that are applicable across most commercially available formulations. When the term "dispersed oil" is used in this document, it specifically refers to oil that has been chemically-treated with a dispersant (not naturally-dispersed oil). It should also be acknowledged that the statements and science advice reflected in this document assume that dispersants are being used following manufacturer protocols and product-specific limitations for operation.

Dispersants as a Response Tool

Direct exposure to oil concentrated at the water surface, shorelines, or intertidal areas, is typically very harmful to organisms. In addition, oil that reaches shorelines may persist for months to years.

Each oil spill response tool has advantages, disadvantages and operational limitations. Mechanical recovery, which physically removes the oil from the environment, will always be a preferred response tool; however, the effectiveness of mechanical recovery may be limited by environmental conditions (*e.g.,* high wind and waves), spill location, remoteness, and spill size. Even with significant resources and assets, only a portion of surface oil will typically be recovered by mechanical means in scenarios of large offshore oil spills.

Dispersant application can be an effective response option to mitigate the impact of an oil spill when performed in accordance with operational guidelines (established by the producer of the product and regulatory agencies) and informed by a net environmental benefit determination. They can also be considered for use as a primary response tactic, in conjunction with all other viable and technologically-feasible tactics (*e.g.,* mechanical recovery, *in-situ* burning) to implement the most effective, integrated response.

If applied at the water surface, chemical dispersants:

- Provide a response tool that can be rapidly applied from various platforms (including vessels and aircraft) with a high oil slick encounter rate;
- Offer an option when environmental constraints (*e.g.,* wind speed and wave height) or slick thickness (*e.g.,* slick has spread and is very thin) inhibit the effective use of other response tools;
- Reduce the amount of oil in surface slicks, volatile organic compound emissions and the subsequent transport of these slicks to nearshore or shoreline environments (*e.g.,* intertidal mudflats) where the potential impacts of the concentrated residual oil can be greatest; and,
- Reduce or prevent the formation of water-in-oil emulsions which can be more difficult to recover and generate a larger-volume of waste.

In sub-surface application (*e.g.,* well blowout scenario), chemical dispersants:

- Offer an effective and targeted approach that requires less dispersant and has a higher oil encounter rate relative to surface dispersant application;
- Can treat the majority of oil at the point of release;
- Once set up, can be applied continuously in most sea state/weather conditions (an important consideration for winter conditions in Canada with short daylight periods);
- Reduce oil migration to the surface and thereby reduce the potential for surface slicks and volatile organic compound emissions; and,
- May enhance (natural) biodegradation of oil at depth (depending on incident, scenario and environmental conditions).

Dispersants are an important response option to mitigate the effects of an oil spill, including in cold climates and in waters with the presence of ice, particularly when other physical oil options are limited. Oil spill response efforts should seek to consider the use of all suitable countermeasures and tools, and be informed by the location, size, scale, magnitude, risk, and complexity of the spill incident.

Informed Decision-Making

The decision to use a dispersant should be based on the results of a net environmental benefit analysis (NEBA). NEBA is a decision-making framework and communication tool that examines and balances the trade-offs associated with leaving the spilled oil untreated or responding to it by other means. The objective of a NEBA is to determine the response option(s) that offers optimal benefit for the protection of the ecosystem and/or priority resources, which are predicted to be impacted by an oil spill.

To the extent possible, decision-making processes should consider impacts of chemical dispersants to habitats and populations (including considerations of trophic-level dynamics), rather than individual-level impacts. The exception to this is for species at risk (i.e., species and habitats protected by Canadian legislation), which should be considered at the individual level due to their legal protection status and vulnerability. This analysis process should be informed by the best available information, scientific and technical expertise, as well as engagement from response partners and regulators. It should also clearly communicate where there are knowledge gaps and uncertainties, and where precautionary and conservative assumptions have been made to inform decision-making.

The window of opportunity to use chemical dispersants is typically short (*e.g.,* hours to days); however, dispersant effectiveness can be highly specific to spill conditions and oil properties. As such, the use of dispersants should not be constrained by pre-defined time frames. Rather, dispersant use should be informed by the oil type and the environmental conditions, which influence the fate, behaviour, and weathering of oil (before dispersant use) and dispersed oil droplets (after dispersant use).

Purpose of this Process

When there is an oil spill in the marine environment, Fisheries and Oceans Canada (DFO; the Department) and the Canadian Coast Guard (CCG) use science-based advice to inform response decisions and protect aquatic resources and ecosystems from negative impacts.

It is recognized that there is a need to improve public communications regarding the premise for dispersant use and its effectiveness, informed by science. In addition, key considerations for the use of dispersants, the decision-making process, and the requirements for their authorization in Canada all need to be identified.

This Science Advisory Report (SAR) summarizes the more detailed analysis presented in an associated Research Document (Creber et al. in prep)[1]. This process was specifically focused on the scientific premise for dispersant use and the associated considerations for the Canadian

[1] Creber, D. et al. State of Knowledge on Chemical Dispersants for Canadian Oil Spills. DFO Can. Sci. Advis. Sec. Res. Doc. In preparation.

marine environment. Both the legislative authorization to use dispersants and the specific decision-making processes regarding dispersant use were outside the scope of this process.

ASSESSMENT

For the purposes of this process, sensitive receptors were defined to include: aquatic species, habitats, and other sensitive coastal or marine areas. While these sensitive receptors are of particular significance, it is important to acknowledge that a NEBA would be informed by a broader range of considerations.

Cold Water Considerations

Specific to a Canadian context, the characteristics of our cold-water environments (including colder air and water temperatures, the presence of ice, and shorter daylight periods) can influence the fate and behaviour of spilled oil and consequently impact decisions about the potential use of chemical dispersants. When oil is released in the presence of sea ice, several interactions can occur, including oil:

- deposition onto the ice surface;
- absorption into snow;
- encapsulation into ice;
- becoming trapped in leads or in open water fields between floes, under ice in ridges and keels; and/or,
- build-up and entrapment within landfast ice edges.

Despite these interactions, the application of chemical dispersants has been demonstrated as an effective response option in cold climates. In addition, oil biodegradation rates remain faster when chemical dispersants are applied, relative to natural biodegradation for untreated oil (Mullin 2014).

Fate and Behaviour of Dispersed Oil

In support of informed decision-making, it is important to understand and be able to communicate where dispersed oil has gone and how it changes over time. Dispersion of oil droplets into the water column occurs naturally during both surface and subsurface releases. Generally, there is an understanding that oils that are dispersed (naturally or chemically) will dilute and naturally biodegrade over time. Oil-degrading microorganisms are present in all parts of the global marine ecosystem (including cold water and deep-sea environments). Small oil droplets have a larger surface area-to-volume ratio, which increases microbial colonization and enhances biodegradation by increasing accessibility to oil molecules. The extent of biodegradation varies based on the type of oil, the specific spill context, and the environmental conditions. Similarly, the concentration of applied dispersant associated with the oil will change over time in response to environmental factors.

When applied to oil slicks on the sea surface, dispersants facilitate the breakup of oil slicks into smaller droplets at lower levels of mixing energy than that required for natural dispersion. Subsequent waves, tides, currents, and eddies promote horizontal and vertical movement, dispersion and dissolution of the oil droplets in the water column. In the event of a blowout, SSDI at the point-of-release will also reduce the average size of the oil droplets formed. This slows the rate at which the oil rises to the surface and increases its extent of biodegradation and dissolution. Both of these application procedures lower the level of risk associated with surface slicks. It is important to note that enhanced dilution and/or dispersion of oil droplets also reduces the probability of droplet interactions that lead to the coalescence of the oil and the reformation of surface oil slicks.

Modelled Predictions

Models are important tools for supporting decision making and communication. Different models can be applied depending on the type of release (*e.g.,* surface versus subsurface) and whether the model is supporting contingency planning, operational spill modelling, or environmental impact modelling. Each model has slightly different approaches and degrees of complexity, with associated advantages and disadvantages (*e.g.,* refer to NASEM 2020). While the specific input requirements will vary depending on the model and its intended use, it is recognized that the reliability of the outputs are contingent on the quality of the inputs. Ongoing laboratory and field experiments, as well as real-world observations, support the refinement of existing models to inform future operational and trade-off decisions. To minimize the level of risk in decision making during oil response operations, technical experts are called upon to integrate precautionary assumptions into models, to analyze and interpret their outputs, and to provide recommendations.

Spill trajectory models, specifically, are used to predict and forecast the outcomes of a spill and/or the associated response actions (*e.g.,* the use of dispersants). Key information required to forecast the fate/behaviour of a dispersed oil plume includes:

- Oil droplet size (*e.g.,* diameter);
- Environmental conditions that influence where the oil droplets will go (*e.g.,* salinity, temperature, wind, waves, current, tides, eddies);
- Dispersant effectiveness; and,
- Rates of dissolution of soluble components into the water column.

Since the Deepwater Horizon spill in the Gulf of Mexico, a concern that has garnered attention is the formation of marine-oil snow and its potential impact to benthic ecosystems. Marine snow occurs naturally in the ocean due to organic detritus (*i.e.,* waste) or living microbes forming aggregates that sink and deposit on the ocean floor. When oil associates with marine snow, it is more likely to settle to the seafloor or be ingested. Existing tools and models can now incorporate considerations for marine snow which can inform decision-making processes.

Sensitive Receptor Exposure

Many of the aquatic resources that are most sensitive to oiling utilize the surface water and/or shoreline (including intertidal and subtidal) environments. Oil residues can persist for long periods of time on shorelines and in intertidal and subtidal areas, which may lead to chronic effects in marine organisms. Specific to cold climates, the presence of ice can make spills more difficult to clean up and may prolong exposure of sensitive receptors to oil. The use of dispersants can reduce the potential exposure of organisms to oil and the volume of oil in these areas by diluting, diffusing, and dispersing the oil over a larger volume of water, before it can reach sensitive shoreline areas.

The main mechanisms for exposure (*i.e.,* exposure routes) of aquatic organisms to oil include the following:

- Direct absorption and/or dermal contact from direct sea water, porewater (*i.e.,* water contained in the pores of rocks or soil), sediment, and/or droplet contact;

- Inhalation of aerosols and volatile substances present in dispersed-oil;
- Aspiration of dispersed-oil at the water surface;
- Uptake of oil from sediments and sediment porewater; and/or
- Food, prey, water, sediment, detritus and/or droplet ingestion.

The specific exposure pathways (*i.e.,* how an organism comes into contact with oil) for aquatic organisms between non-dispersed oil and chemically-dispersed oil are the same; however, the use of chemical dispersants may alter the extent of exposed individual organisms depending on their relative interactions with shorelines, surface water, water column and/or benthic zones.

As noted above, oil droplets naturally disperse into the water column, whether from a surface or subsurface spill. Facilitating the fragmentation of oil droplets through the use of chemical dispersants results in changes to the concentration, duration of exposure, and bioavailability of oil to receptors. Generally, this reduces the potential exposure of sensitive receptors that interact with the water surface or shorelines (including intertidal and subtidal areas), but temporarily increases potential exposure in the water column by increasing the proportion of oil in that compartment and altering the spatial scale and distribution of dispersed oil droplets. In a SSDI application, increased oil exposure to the benthic environment is possible but depends on many factors. Overall, dispersants generally reduce the exposure to oil for organisms at the water surface, on shorelines, and intertidal areas. Their use results in the temporary and localized increase in exposure to chemically-dispersed oil for organisms in the water column.

Understanding the spatial and temporal potential for exposure of sensitive receptors between an untreated and a chemically-dispersed oil plume scenario is critical for informed decision-making. The differences in these scenarios need to be supported by site-specific, three- dimensional trajectory models that take into account differences in the fate and behaviour of the oil over the entire life of the spill.

Relative to natural dispersion, the use of dispersants (including in cold climates) would be expected to result in the following, which can alter the exposure scenario for sensitive receptors:

- A shift in the particle size distribution of the dispersed oil to smaller sizes;
- Lower proportions of oil volume at the water surface that can strand on shorelines (including intertidal and subtidal zones);
- Temporarily moving higher proportions of the oil volume into the water column and as dissolved or water-accommodated oil fractions; and,
- An increase in the bioavailability potential of oil and its various chemical components.

The bioavailability of oil (and its individual chemical components) to marine organisms is temporarily increased with the use of dispersants; however, these aqueous concentrations are also rapidly diluted.

Aquatic Toxicity Study Interpretation

The existing scientific literature on the impacts of dispersed oil on sensitive receptors can appear confusing and sometimes contradictory. Some of the reasons this can occur include:

- There are different preparation and characterization methods available for toxicity tests.
- Closed-system laboratory studies provide important and valuable scientific knowledge but they are challenged in their ability to adequately reflect real-world conditions. For example,

the high concentration (compared to those measures in the field), extended duration and exposures at equilibrium (conditions often used in many laboratory studies) do not replicate scenarios typically observed in the natural environment due to rapid dilution and the lack of equilibrium between dispersed oil droplets and dissolved oil components. There are also distinctions and considerations related to organism behaviours between laboratory and real-world scenarios that will differentiate levels of exposure between settings. These are critically important factors to consider when interpreting and analyzing dispersed oil laboratory toxicity studies.

- There has been inconsistent reporting of the actual loading concentrations of oil to which organisms are exposed over time, both in lab and field studies. Canadian efforts are underway to define and characterize minimum measured chemistry and toxicity data reporting standards.
- There has been a lack of consistency in the interpretation and communication of dispersed oil toxicity on marine aquatic life.

Overall, lab-based toxicity tests provide critical information, but are limited in their ability to represent the complexity of the natural environment. The effects of both untreated and chemically-dispersed oil on marine biota in the natural environment are highly variable and are informed not only by toxicity data, but also by the interactions of physical, chemical, and biological factors. Modelling is most useful for considering all relevant parameters and predicting potential effects to individuals, populations and ecosystems.

Sensitive Receptor Effects and Impacts

For the purposes of this advice, effects are defined as “the broad range of potentially measurable changes that may be observed”. Impacts are defined as “effects that, with some certainty, cause adverse changes to ecosystem structure or function”. Bioavailability is defined as “the extent to which a substance is available to interact with a sensitive receptor from the air, water, sediment, or diet”.

Generally, reducing the concentration, duration, and magnitude of exposure of aquatic resources to either chemically-treated or -untreated oil, and preventing the oiling of shorelines, intertidal, and subtidal areas (which are more difficult to clean), will reduce the potential for delayed effects and/or long-term impacts to organisms that inhabit those areas.

It is acknowledged that particular attention should be paid to the potential effects on species at risk. Species at risk (defined in Canadian legislation as Endangered, Threatened or Extirpated) are protected at an individual level and have prohibitions against killing, harming, or harassing them, and damaging or destroying their habitat. Uncertainties and knowledge gaps on species-specific toxicity thresholds, exposure pathways (direct, indirect), and short- through long-term impacts must be appropriately considered in order to support informed decision making.

Some of the critical information to enable an understanding of receptor exposure, potential effects and impacts include (NASEM 2020):

- Spatial and temporal distribution of sensitive receptors;
- Comparison of time-varying exposure in the real-world to known acute or chronic toxicity thresholds for the specific oil, and for the species of concern;
- Duration of exposure in open water environments above known toxicity threshold; and,
- Species sensitivity to oil exposure.

Generally, the improved understanding of potential effects and impacts is more effectively achieved through modelling rather than field measurements, due to challenges associated with timely field data collection and rapidly changing conditions.

Current research and reviews from recent spills suggest the use of dispersants rapidly dilutes aqueous concentrations of oil substances below known, lab-derived, acute toxicity thresholds for a wide range of target test organisms, despite the increased bioavailability potential. However, while it is recognized and acknowledged that the surrogate species used in these acute toxicity threshold tests may not represent all species of concern and that acute thresholds, in of themselves, may not fully account for sublethal, delayed, or chronic effects; recent analyses from real-world spill examples have demonstrated that the use of dispersants can contribute to a net benefit for overall ecosystem health (Vikebo *et al.* 2015; French-McCay *et al.* 2018; Bock *et al.* 2018; Walker *et al.* 2018, NASEM 2020).

Specific to a Canadian context, cold-water species generally have similar acute sensitivities as temperate species to oil (and its chemical constituents, in both untreated and dispersed oil). Less is known about differences in potential long-term, delayed onset or chronic effects between cold-water and temperate species. As a result of morphological and physiological adaptations, cold-water species would be expected to take longer than temperate species to exhibit the effects of oil or dispersed oil exposure.

Overall, the effects and impacts of dispersed oil on sensitive receptors are highly variable and are a function of the exposure pathways, degree and duration of exposure, the concentrations of dispersed oil, the bioavailability of the chemicals within the dispersed oil, and the sensitivity of the species.

The specific mechanisms of dispersed oil impacts (*e.g.,* endocrine disruption) are important for hazard, risk, and damage assessments and can be used to inform model predictions. However, such detailed analyses are less relevant for time-sensitive response decisions, where a general understanding of potential impacts (e.g., impacts to growth, reproduction and/or survival) and implications at the population or ecosystem scale are more appropriate (except for species at risk listed as Extirpated, Endangered or Threatened, that should be evaluated at the individual level).

Sensitive Receptor Recovery Potential

The recovery of a population or community from an oil spill is complex and depends on a number of factors, including:

- The oil type;
- The degree of oil weathering;
- The duration and extent of oil exposure;
- The dose/concentration of oil;
- The interactions with the oil;
- The severity of spill impacts on sensitive species;
- The numbers of individuals affected; and,
- The sensitivity/resilience of the species and/or habitat.

Collectively, these factors will influence the recovery potential for a sensitive receptor and the marine ecosystem as a whole. Environmental monitoring can be used to examine changes in recovery status over time.

Monitoring

Monitoring requirements related to dispersant use are site-, incident-, and context-specific. Typically, there are two (2) types of monitoring initiated:

- **Operational Monitoring**: associated with evaluating dispersant use and effectiveness, measured against pre-defined criteria (*e.g.,* duration of use, estimated efficacy rates, applicability for the oil and environment conditions). This type of monitoring occurs during the operational application period.
- **Environmental Monitoring**: associated with measuring and examining potential environmental effects and impacts, including evidence of recovery. It involves activities that collect and compile environmental data to characterize the conditions in a region where dispersants may be applied or have been applied. This type of monitoring can occur before, during, and/or after a spill.

Monitoring needs are entirely dependent on the specific spill scenario (*e.g.,* scale, scope, and complexity), the response measures used, and the potential risks to resources that could be impacted. Regardless of the scenario, it is recommended that all monitoring include the consideration and analysis of both untreated and chemically-dispersed oil (to the extent possible), in order to enable comparative assessments.

Monitoring data are most useful when they can rapidly communicate the outcomes and results in an efficient and effective way. For any significant spill, the challenges of defining: data needs and intended uses, transmission, storage, quality assurance/quality control, interpretation and analysis, management, and communication protocols should not be understated. Being able to integrate data in (or near) real-time is critical to informing operational decision-making processes. Opportunities for automation and pre-planned integration into data-sharing platforms (*e.g.,* Common Operating Picture) are strongly encouraged.

Operational Monitoring

Although dispersants can be used as a response tool, there are no Canadian-specific standards or protocols for monitoring in the offshore regime in Canada today. International standards (such as the American Petroleum Institute (API 2015) and United States Special Monitoring of Applied Response Technologies [SMART] protocols; NOAA 2006) and industry best practices are commonly referenced within operational contingency plans. These contingency plans are reviewed and exercised by the responsible regulator prior to authorizing an activity, and are updated by operators on a regular basis to reflect new data, knowledge, technology, and monitoring plans.

Specific to operational monitoring, it is noted that the United States SMART protocol (NOAA 2006) is focused on operational effectiveness and is intended for surface application and short durations of dispersant use (*i.e.,* less than 96 hours). The Prolonged Surface Application Guidance (NRT 2013) should be considered for longer uses (which begins to integrate environmental considerations), and the Subsea Application Guidance (NRT 2013) should be considered for subsea applications.

It is acknowledged that most dispersant application operations happen quickly and for a short period of time (*i.e.,* less than 96 hours). In these cases, aerial or surface visual observations (and to a lesser extent, vessel radar technology) may be the only suitable and accessible monitoring options available, particularly for remote locations. However, such observations can also be impeded by the presence of ice (an important consideration for a Canadian context).

As this information is critical to inform operational response decisions (including both dispersant and untreated scenarios), the use of new tools and technologies (*e.g.,* automated underwater vehicles [AUVs], remotely operated vehicles [ROVs], canine detection, remote sensors, fluorometers) is encouraged in order to:

- Improve the ability to detect and track oil (including below ice);
- Ensure rapid deployment of dispersants;
- Enhance opportunities for near-real time data analysis and communication;
- Enable 24/7 monitoring capabilities;
- Support monitoring multiple, concurrent metrics; and,
- Support intentional and self-directed movements of equipment (compared to drifters for example).

Each tool and technique has limitations, which emphasize the benefit of having multiple lines of evidence to support informed response decisions.

Information obtained through operational monitoring enables:

- Iterative re-evaluation of the NEBA determination;
- Active re-examination of the use of dispersants to meet specified response objectives;
- Refinement and adjustment of operational tactics and strategies;
- An analysis of the effectiveness, validation, and calibration of specific tools and monitoring instruments;
- Opportunities to refine operational models based on real-world observations; and,
- Opportunities to advance scientific knowledge and research on the fate and behaviour of dispersed oil, efficacy of dispersant use, and new monitoring technologies.

Environmental Monitoring

Environmental monitoring should include such considerations as:

- Visual observations (*e.g.,* photography and video) which inform decisions for cleanup endpoints and restoration;
- Site characterization as it changes over time;
- Examining the movement and behaviour of sensitive receptors during the response operations in order to better understand how the organisms interact with spilled oil and support the refinement of models, protocols, and impact assessment approaches;
- Passive sampling (which could include monitoring to determine both oil and dispersant constituents over time);
- Source oil sampling;
- Water quality monitoring;

- Sediment quality monitoring;
- Habitat characterization/validation;
- Species presence and data validation; and/or,
- Environmental monitoring endpoints (determined by the impacts and recovery of marine life in the area along with details of the specific spill scenario).

In addition to those listed for operational monitoring, information obtained through environmental monitoring also enables:

- The re-examination of protection priorities and response objectives;
- Scoping of long-term monitoring requirements, including recovery monitoring;
- Opportunities to refine environmental fate and effects models based on real-world observations; and,
- Opportunities to advance scientific knowledge and research on sensitive receptors, exposure routes and mechanisms, effects, impacts, recovery, and/or new technologies.

Sources of Uncertainty

The science of dispersant use is challenged by the scale, scope, and complex realities of oil spills in marine ecosystems and subsequent spill response. Every incident is unique and will present different challenges, limitations, and sources of uncertainty. There is an extensive international knowledge base, which is relatable to Canadian contexts. In addition, evidence and experiences from past spills, predictive modelling, and ongoing scientific research continue to reduce uncertainty and improve evidence-based decisions. The current state of knowledge on dispersants combined with conservative assumptions where uncertainty exists, allows for informed decision-making.

CONCLUSIONS

Direct exposure to oil concentrated at the water surface or on shorelines and intertidal areas, is typically harmful to the environment and organisms, and may persist for months to years.

Each response tool has strengths, weaknesses, and operational limitations. Mechanical recovery, which physically removes the oil from the environment, will always remain the preferred response tool. Nonetheless, even with ample resources and assets, past experience has demonstrated that only a fraction of surface oil can be recovered mechanically for large, offshore oil spills.

Dispersants can be an effective response option to mitigate the impact of an oil spill when used in accordance with operational guidance and informed by a net environmental benefit analysis determination. They should be considered for use as a primary response tactic, in conjunction with all other viable and technologically feasible tactics (*e.g.,* mechanical recovery and in-situ burning) to implement the most effective, integrated response.

Cold water and temperate species have similar sensitivities as temperate species to the acute toxicity of untreated and/or chemically dispersed-oil. While cold-water conditions may require the use of different dispersant application methods, the use of chemical dispersants has been demonstrated as an effective response option in these conditions.

It is well understood that making timely and informed decisions following a spill is critical. Other international jurisdictions (*e.g.,* United States, United Kingdom, and France) have decision-making frameworks and preparedness/contingency plans that integrate dispersants to support such timely decisions. These plans generally integrate the following: operational constraints, planning, training, communication, and stakeholder engagement in advance of an incident.

In order to further support the regulatory regime and provide timely decision-making for the use of dispersants in Canada, the following future science efforts should be considered.

Future Efforts: Overall

- Develop improved national inventories and mapping of key sensitive receptors and critical habitats (including spatial, temporal, seasonal, biohistorical, and environmental compartment use).
- Consolidate knowledge about sensitivities, vulnerabilities, and recovery potential for Canadian species (with consideration of sensitive life stages) to both untreated and dispersed oil.
- Improve formulation and functionality of bio-surfactants, enzyme-based dispersants, and other new formulations.
- Conduct a comprehensive review of past incidents, both with and without dispersant use, to identify additional insights relevant to a Canadian context from other real-world scenarios.
- Develop comprehensive contingency plans that include:
    - Baseline environmental, ecological and biological data for a specific region (including Indigenous Knowledge);
    - Identification of what resources (*e.g.,* biological, ecological, cultural, economic) could potentially be at risk in a specific area;
    - Baseline hydrodynamics and meteorology (*e.g.,* tides, currents, weather, wind);
    - Baseline data on oil substance concentrations (including organic matter, hydrocarbons, metals, and other pollutants);
    - Baseline shoreline delineations and characterizations; and,
    - Considerations for net environmental benefit.

Future Efforts: Fate and Behaviour

- Improve our understanding of the minimum mixing energy required for effective dispersant use, and an analysis of suitability for use in calm waters.
- Review and refine dispersant application methodologies, application rates (*e.g.,* currently using a 1:20 dispersant-to-oil ratio for Corexit 9500), and target oil droplet size required to support effective dispersant use.
- Improve our understanding of how oil composition (*e.g.,* oil contents of saturates, aromatics, resins, and asphaltenes contents) affect biodegradation and the fate of dispersed oil.
- Improve our understanding of the processes by which dispersants and oil dissociate from each other over time, and their respective fates under different environmental conditions (*e.g.,* salinity).
- Comparatively analyze the time-evolving fate and behaviour of oil spilled using different response measures (including dispersant applications), for the same incident, to demonstrate and support improved communications about differences in fate and behaviour.

- Analyze the correlation between specific oil properties and biodegradation rates, to support further improvements to biodegradation model projections.
- Improve our understanding of the specific mechanisms and processes by which microbes react to, respond to, and consume dispersed oil, particularly with respect to biodegradation pathways and to further improve biodegradation model projections.
- Develop standardized methods and techniques to quantify oil biodegradation rates in the field to improve consistency and comparability, and facilitate future integration into bioavailability models.
- Validate the impacts of chemical dispersants on biodegradation rates under natural conditions in order to improve predictive models and the understanding of potential impacts.

Future Efforts: Modelling Predictions

- Regularly update and continually improve models to integrate the latest scientific findings (*e.g.,* advances in biological effects).
- Develop standardized formats for the clear communication of inputs, knowledge gaps, uncertainties, and assumptions integrated into models.
- Develop standard methods and techniques to measure particulate and dissolved-oil concentrations in laboratory tests to improve consistency and comparability, and facilitate future integration into fate, behaviour, and effects models.
- Validate (using real-world examples) the impact of dispersants on marine oil snow formation, any resulting effects on the fate of dispersed oil over time, and the associated implications for potential organism exposure routes.
- Validate (using real-world examples) the impact of dispersants on aerosolization of oil constituents, any resulting effects on the fate of dispersed oil over time, and the associated implications for potential organism exposure routes.

Future Efforts: Sensitive Receptor Exposure

- As a preparedness effort, it would be beneficial to better understand, document, and communicate how different receptor groups (*e.g.,* marine mammals, species at risk, different types of birds), particularly in their sensitive life stages, interact with surface waters and the water column, in order to support an assessment of how they could be differentially exposed.
- Undertake additional opportunistic field studies to examine sensitivity of specific species (*e.g.,* species at risk, marine mammals, reptiles and amphibians, invertebrates, diving birds) and sensitive life stages to dispersed oil.
- Undertake field-based ecological studies to improve the understanding of the ecological relevance and significance of dispersed-oil exposure real-field conditions in the natural environment.
- Explore alternative methods to infer or model the potential impacts of dispersed oil on species at risk (*e.g.,* biopsy methods, genetic biochemical markers) to help address knowledge gaps for species-specific exposure pathways, acute and chronic toxicity thresholds, as well as short- and long-term impacts.

- Develop “pathway of effects” models for key Canadian species including species at risk and their critical habitats.

Future Efforts: Toxicity Study Interpretation

- Improve and standardize methods for the preparation and characterization of contaminated water test solutions and oil’s chemical (molecular-level) composition.
- Improve and standardize analytical chemistry protocols to fully characterize oil constituent composition and concentrations in the tested exposure media to identify the specific oil and dispersed-oil constituents most critical for impacting sensitive receptors.
- Improve and standardize toxicity testing experimental designs.
- Examine and correlate oil concentration, exposure time, and species responses to aid interpretation of toxicity reference values and thresholds that exist in databases (*e.g.,* Chemical Aquatic Fate and Effects (CAFE) Database; NOAA 2020).
- Improve understanding of the potential for aerosol formation and its potential impacts on sensitive receptors that utilize the water surface.
- Validate (using real-world examples) the avoidance behaviour of aquatic species (*e.g.,* marine mammals) to spilled oil and dispersed oil plumes in real-world contexts where priority would be placed on vulnerable species that frequent higher oil spill risk areas.

Future Efforts: Sensitive Receptor Effects

- Perform comparisons of long-term impacts to, and recovery potentials of, biota exposed to dispersed versus non-dispersed oils to enable comprehensive consideration of impacts and subsequent trade-offs of dispersant applications.
- Conduct additional research regarding the toxicity of photodegraded and biodegraded hydrocarbons (PAHs) oil constituents.
- Increase understanding of ingestion pathways for dispersed oil droplets, bioaccumulation and trophic interactions to understand, the resulting potential effects to support improvements to predictive models.
- Improve understanding of the potential impacts from delayed and sub-lethal effects on sensitive receptors and the resulting impacts on populations and trophic/food web dynamics.
- Improve understanding of the potential physical and mechanical impacts of dispersants contact with specific receptors (*e.g.,* marine mammals and birds).
- Determine how the effects of dispersant use on habitats, mammals, reptiles, amphibians, birds, and species at risk can best be predicted, to create and expand existing dose-response curve relationship data (*e.g.,* CAFE Database; NOAA 2020) for these groups.
- Improve understanding of population-level and ecosystem impacts.

Future Efforts: Monitoring

- Explore opportunities for automation and pre-planned integration into data-sharing platforms (*e.g.,* Common Operating Picture).

- Continuously improve operational monitoring, tracking, and post-operational monitoring following the use of dispersants.
- Improve understanding of biomonitoring needs and considerations.
- Evaluate the implications of dispersant use on the suitability of biomarkers as analytes during environmental monitoring.
- Improve understanding and comparative analysis of different fluorometer technologies (*e.g.,* multi-spectrum devices) for different oil types and weathering conditions (*e.g.,* emulsions) to help define the range of expected maximum fluorescence and inform the refinement of monitoring protocols and practices.
- Advance automation and technologies that enhance remote monitoring capabilities.
- Validate (using real-world examples) whether the use of AUV/ROV monitoring technologies and tools temporarily attract specific species (*e.g.,* dolphins, sharks) to oil spill sites.

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SOURCES OF INFORMATION

This Science Advisory Report is from the March 1 to 12, 2021 National Advisory Meeting on the State of Knowledge on Chemical Dispersants for Canadian Marine Oil Spills. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

American Petroleum Institute (API). 2015. Aerial and Vessel Dispersant Preparedness and Operations Guide. API Technical Report 1148. Washington (DC): API.

Bock, M., Robinson, H., Wenning, R., French-McCay, D., Rowe, J., and Walker, AH. 2018. Comparative risk assessment of oil spill response options for a deepwater oil well blowout: Part II. Relative risk methodology. Marine Pollution Bulletin. 2018 (133): 984-1000.

DFO. 2021. News Release: Fisheries and Oceans Canada and Canadian Coast Guard Confirm New Regions' Boundaries to Improve Services to the Arctic; [accessed March 23, 2021].

French-McCay, D., Crowley, D., Rowe, J., Bock, M., Robinson, H., Wenning, R., Walker, AH., Joeckel, J., Nedwed, T.J., and Parkerton, T.F. 2018. Comparative Risk Assessment of spill response options for a deepwater oil well blowout: Part 1. Oil spill modeling. Marine Pollution Bulletin. 2018 (133): 1001-1015.

Mullin, J.V. 2014. The Arctic Oil Spill Response Technology – Joint Industry Program. Proceedings of the OTC Arctic Technology Conference; Houston (TX). OTC-24591-MS.

National Academies of Sciences, Engineering and Medicine (NASEM). 2020. The use of dispersants in Marine Oil Spill Response. Washington (DC): The National Academies Press.

National Oceanic and Atmospheric Administration (NOAA). 2020. Chemical Aquatic Fate and Effects (CAFE) Database; [accessed March 17, 2021].

National Response Team (NRT). 2013. Environmental Monitoring for Atypical Dispersant Operations; [accessed March 16, 2021].

U.S. Coast Guard, National Oceanic and Atmospheric Administration, U.S. Environmental Protection Agency, Centers for Disease Control and Prevention, and Minerals Management Service. 2006. Special Monitoring of Applied Response Technologies. Seattle (WA): National Oceanic and Atmospheric Administration [NOAA]; [accessed March 16, 2021].

Vikebø, F.B., Rønningen, P., Meier, S., Grøsvik, B.E., and Lien, V.S. 2015. Dispersants Have Limited Effects on Exposure Rates of Oil Spills on Fish Eggs and Larvae in Shelf Seas. Environmental Science and Technology. 2015 (49): 6061-6069.

Walker, AH., Scholz, D., McPeek, M., French-McCay, D., Rowe, J., Bock, M., Robinson, H., and Wenning, R. 2018. Comparative risk assessment of spill response options for a deepwater oil well blowout: Part III. Stakeholder engagement. Marine Pollution Bulletin. 2018 (133): 970-983.

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