Spill Impact Mitigation Assessment for CNOOC Petroleum North America ULC Flemish Pass Exploration Drilling Project, 2018–2028

Prepared by

Prepared for

CNOOC Petroleum North America ULC

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List of Acronyms and Abbreviations

ADDS	Airborne Dispersant Delivery System
API	The American Petroleum Institute
BdN	Bay du Nord
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CERA	Consensus Ecological Risk Assessment
C-NLOPB	Canada-Newfoundland and Labrador Offshore Petroleum Board
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
DFLR	Newfoundland and Labrador Department of Fisheries and Land Resources
DFO	Department of Fisheries and Oceans
DOR	Dispersant to Oil Ratio
DWH	Deep Water Horizon
EBSA	Ecologically and Biologically Significant Area
ECCC-CWS	Environmental and Climate Change Canada-Canadian Wildlife Service
EEM	Environmental Effects Monitoring
EEZ	Exclusive Economic Zone
EIS	Environmental Impact Statement
EL	Exploration License
EPA	Environmental Protection Area
EPLMA	Eastport Peninsula Lobster Management Area
ESA	*Endangered Species Act*
EU	Environmental Unit
FSC	Food, Social and Ceremonial
GAI	Geographic Area of Interest
IBA	Important Bird Areas
ICS	Incident Command System
IMS	Impact Modification Factor
IOGP	International Association of Oil & Gas Production
IPIECA	International Petroleum Industry Environmental Conservation Association
ISB	*In Situ* Burning
ITOPF	International Tanker Owners Pollution Federation Limited
IUCN	International Union for the Conservation of Nature
MPA	Marine Protected Area
NAFO	Northwest Atlantic Fisheries Organization
NEBA	Net Environmental Benefit Analysis
NMCA	National Marine Conservation Area
NMFS	National Marine Fisheries Service (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
NRC	Natural Research Council
NRI	Numerical Relative Impact
OSAT	Operational Science Advisory Team

OSRL	Oil Spill Response Limited
PAH	Polycyclic Aromatic Hydrocarbons
ppb	parts per billion
ppm	parts per million
PRI	Potential Relative Impact
RIMS	Relative Impact Mitigation Score
ROC	Resources of Concern
ROV	Remotely Operated Vehicle
RRT	Regional Response Teams
SARA	*Species at Risk Act* (Canada)
SDA	Surface Dispersant Application
SEA	Strategic Environmental Assessment
SIMA	Spill Impact Mitigation Assessment
SML	Surface Microlayer
SSDI	Subsea Dispersant Injection
THC	Total Hydrocarbon Concentrations
TPH	Total Petroleum Hydrocarbon
UA	Unit Area
USCG	United States Coast Guard
VC	Valued Component
VME	Vulnerable Marine Ecosystem
VOC	Volatile Organic Compound
WCCD	Worst Credible Case Discharge

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1.0 Introduction

1.1 Background

This Spill Impact Mitigation Assessment (SIMA) Report prepared for CNOOC Petroleum North America ULC (CNOOC) (formerly known as Nexen Energy ULC [Nexen]) serves as part of the contingency planning process for exploration drilling in the Flemish Pass area in the Newfoundland and Labrador offshore. The objective of this SIMA is to evaluate feasible response options to minimize potential impacts from an oil spill in the northern Flemish Pass area. Unique meteorological and oceanographic conditions characterize the Flemish Pass area and may complicate oil spill response at certain times of the year. However, these environmental conditions also enable a high degree of natural dispersion. This SIMA evaluates feasible and potentially effective response options in the Flemish Pass area.

This SIMA considers a worst-case scenario involving a Tier 3 spill due to an uncontrolled blowout at a potential deep-water drilling site in the northern Flemish Pass. A Tier 3 spill is a category of oil spill defined by the International Petroleum Industry Environmental Conservation Association (IPIECA). The category of a spill is determined by the capabilities of the response option rather than the volume or size of the spill. The worst-case spill scenario allows for the evaluation of all possible response options that are available for implementation by CNOOC using their contractual agreements with Eastern Canada Response Corporation (ECRC) and Oil Spill Response Limited (OSRL). The worst-case Tier 3 spill modelling scenario is compared to three other Tier 3 spill scenarios as a means of justifying its selection as the worst-case scenario. Tier 1 spill scenarios (i.e., surface batch spills of marine diesel, and a larger surface spill of marine diesel representing a release due to a vessel collision) are also briefly considered in this SIMA.

This document is based primarily on information provided in the following reports. Note that Nexen Energy ULC is presented as the proponent in the Environmental Impact Statement (EIS) but that the company name changed to CNOOC after EIS preparation.

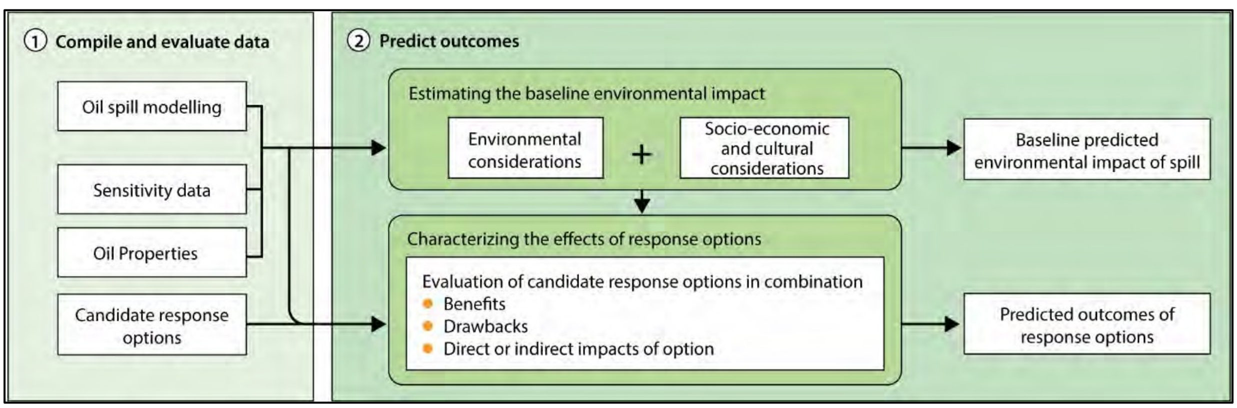
- Nexen Energy ULC. 2018. Flemish Pass Exploration Drilling Project (2018–2028) (CEAR 80117) – Environmental Impact Statement. Prepared by Amec Foster Wheeler Environment & Infrastructure, St. John's, NL, Canada. March 2018.
- CNOOC 2019.CNOOC International Flemish Pass Exploration Drilling (2018–2028) – Environmental Impact Statement Addendum (Revised) Responses to Information Requirements and Required Clarifications. 336 p. + appendices.
- RPS. 2019. Trajectory Modelling in Support of the Nexen Energy ULC Flemish Pass Exploration Drilling Project (2018–2028) Relief Well Modelling. 94 p.
- RPS. 2018. Trajectory Modelling in Support of the Nexen Energy ULC Flemish Pass Exploration Drilling Project (2018–2028). Appendix G of Flemish Pass Exploration Drilling Project (2018–2028) – Environmental Impact Statement. 84 p.

- SL Ross Environmental Research Ltd. 2017. Spill Probability Assessment for Nexen Energy ULC Flemish Pass Exploration Drilling Environmental Assessment. Appendix F of Flemish Pass Exploration Drilling Project (2018–2028) – Environmental Impact Statement. 13 p.
- Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB). 2014. Eastern Newfoundland Strategic Environmental Assessment (SEA) Report. Report by Amec Environment & Infrastructure, St. John's, NL for C-NLOPB., St. John's, NL. 527 p. + appendices.
- C-NLOPB. 2010. Southern Newfoundland Strategic Environmental Assessment. Report by LGL Limited, St. John's, NL, Oceans Limited, St. John's, NL, Canning & Pitt Associates, Inc., St. John's, NL, and PAL Environmental Services, St. John's, NL, for Canada-Newfoundland and Labrador Offshore Petroleum Board, St. John's, NL. 333 p. + appendix.
- C-NLOPB. 2008. Strategic Environmental Assessment Labrador Shelf Offshore Area. Report by Sikumiut Environmental Management Ltd., St. John's, NL, for Canada-Newfoundland and Labrador Offshore Petroleum Board, St. John's, NL. 519 p. + appendices.
- IPIECA (The Global Oil and Gas Industry Association for Environmental and Social Issues) and IOGP (International Association of Oil & Gas Producers). 2015a. Response Strategy Development Using Net Environmental Benefit Analysis (NEBA) – Good practice guidelines for incidental management and emergency response personnel. 32 p. + appendices. Retrieved from: http://www.ipieca.org/resources/good-practice/response-strategy-development-using-net-environmental-benefit-analysis-neba/
- IPIECA and IOGP. 2015b. Dispersants: subsea application. Good practice guidelines for incident management and emergency response personnel. London, UK. Retrieved from: http://www.ipieca.org/resources/good-practice/dispersants-subsea-application-good-practice-guidelines-for-incident-management-and-emergency-response-personnel/
- IPIECA and IOGP. 2016. Controlled in-situ burning of spilled oil. Good practice guidelines for incident management and emergency response personnel. London, UK. Retrieved from: http://www.oilspillresponseproject.org/wp-content/uploads/2017/01/Controlled_in-situ_burning_of_spilled_oil_2016.pdf
- IPIECA, API (The American Petroleum Institute) and IOGP. 2017. Guidelines on Implementing Spill Impact Mitigation Assessment (SIMA) – A technical support document to accompany the IPIECA-IOGP guidance on net environmental benefit analysis (NEBA). 30 p. + appendices. Retrieved from: http://www.ipieca.org/resources/awareness-briefing/guidelines-on-implementing-spill-impact-mitigation-assessment-sima/

IPIECA and IOGP (2015a) defines the following four stages of the SIMA process.

1) Compile and evaluate data to identify an exposure scenario and potential response options, and to understand the potential impacts of that spill scenario;
2) Predict the outcomes for a given scenario to determine which response techniques are effective and feasible;
3) Balance trade-offs by weighing a range of ecological benefits and drawbacks resulting from each feasible response option. This will also include an evaluation of socio-economic benefits and costs resulting from each feasible response action; and
4) Select the best response options for a given scenario, based on which combination of tools and techniques will minimize impacts.

The first two stages in the SIMA process are summarized in Figure 1-1 and detailed in Sections 2.0–4.0 of this report. The third stage of the SIMA process, which involves the conduct of an impact analysis for each response option, is presented in Section 6.0. Recommendations for the most appropriate spill response options for the CNOOC Flemish Pass Project Area are provided in Section 7.0.



Source: IPIECA and IOGP (2015a).

Figure 1-1. Summary of Stages 1 and 2 of the SIMA Process including types of data used to assist with characterization of response options.

1.2 Overview of SIMA

The term Net Environmental Benefit Analysis (NEBA) has been used extensively in the past to describe the structured process used by the oil spill response community and stakeholders for guiding the selection of the most appropriate response that will minimize the net impact of an oil spill on the environmental and socio-economic resources at risk. In 2016, to better reflect the process and its objectives, the oil and gas industry decided to transition to a different moniker (i.e., SIMA) (IPIECA et al. 2017).

As previously stated, the objective of a SIMA is to provide an evaluation process to aid spill responders and stakeholders in choosing the appropriate response option(s) that would result in the least negative effect on the environment while maintaining the safety of responders. It is likely that for most spill scenarios, no single response option will be completely effective so multiple response options are usually the best approach. The characteristics of the oil spill will be a key determinant in the type, timing, and level of effort of the response option(s). The SIMA process recognizes that some environmental impact on the marine environment will occur once oil has been spilled, regardless of what response options are selected.

1.3 Using SIMA to Support Contingency Planning and Spill Response

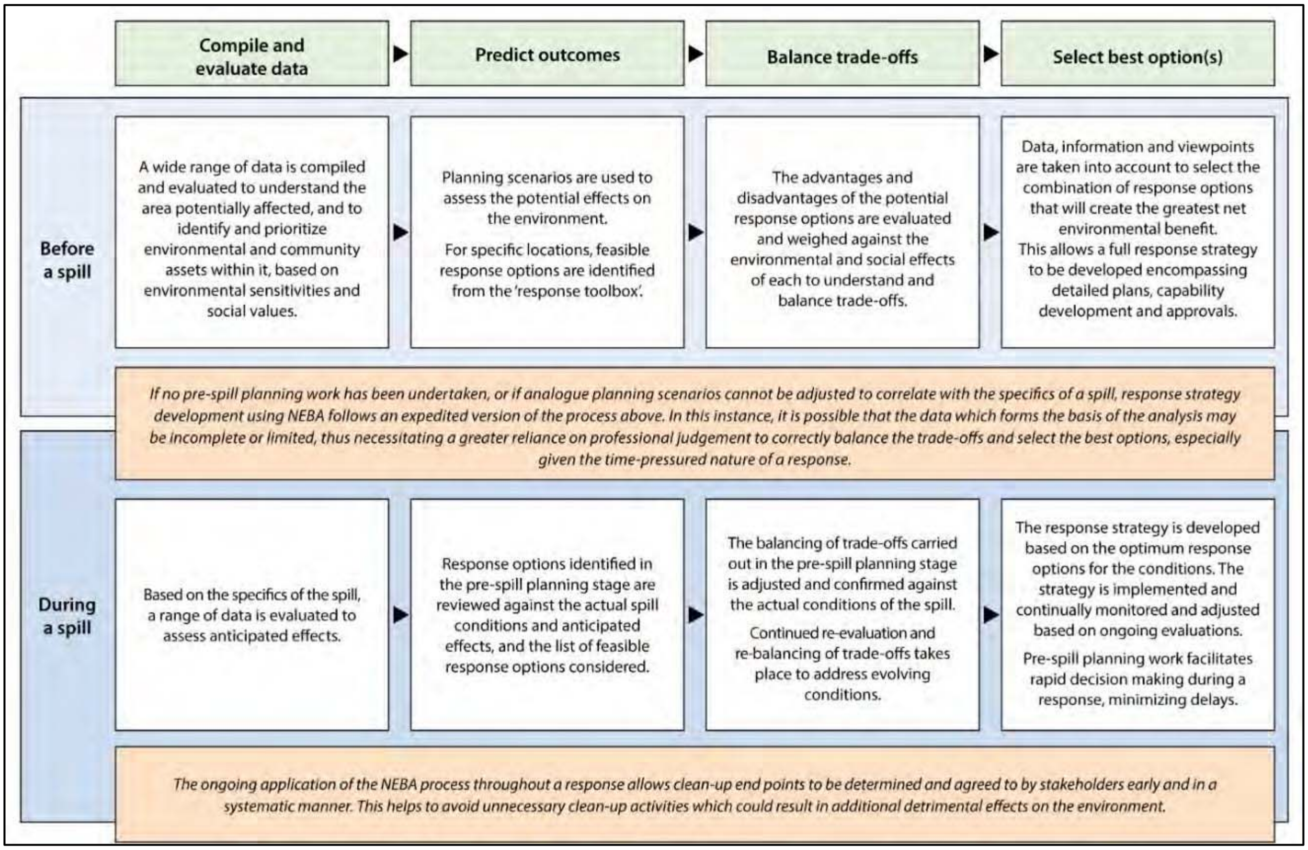
Aspects of emergency management that are supported by the SIMA process include the following:

- **Contingency planning:** The SIMA ensures that response strategies for planning scenarios are well informed and the best response options for those scenarios are identified. Additionally, the use of the SIMA in contingency planning allows for stakeholder involvement in the planning process.
- **Exercises or drills:** A SIMA that is developed during the contingency planning phase can be fine-tuned to a specific spill scenario or season.
- **Training:** The SIMA can inform the incident management team on the feasibility and effectiveness of various response options in specific locales, and on resource trade-offs that are characteristic when selecting one response option over another.
- **Spill Response:** The SIMA process allows for adaptive management during a spill response as it enables an understanding of evolving conditions such that the response strategy can be adjusted as required.

The SIMA process can be applied both before and during a spill. Its application during a spill response may differ from the planning phase, depending on the similarity of an actual spill event to the conditions of the scenario analyzed for the SIMA. An overview of how SIMA is applied in both instances is provided in Figure 1-2.

The principles of the SIMA may be utilized to develop and adapt the response option(s) in real time to fit the situation. During a spill, the SIMA process can function in two ways:

1. When the spill event closely reflects planning, the contingency planning SIMA may be enacted and adjusted to meet scenario specifics that were not included in the planning process; and
2. When the spill event is somewhat different than that associated with the contingency planning SIMA, a more relevant SIMA to the actual spill event can be conducted using an approach that relies heavily on expert judgement of the stakeholders and response subject matter experts.



Source: IPIECA and IOGP (2015a).

Figure 1-2. Application of SIMA process before (contingency planning) and during a spill.

In Canada, response actions for a spill are typically managed through use of the Incident Command System (ICS). The ICS, which is used by both regulatory agencies and industry, provides a common functional organizational structure, and standardized nomenclature and terminology. The use of the SIMA would occur primarily within the Environmental Unit (EU), which includes industry and agency personnel and provides advice to the incident commander on environmental issues. The EU assesses real-time spill conditions (e.g., oil type, quantity, trajectory, etc.), reconfirms information about ecological and socio-economic resources in the area, and then adapts conclusions from planning SIMAs to the actual spill conditions. The SIMA process readily adaptable in that the plan can be changed to meet evolving spill conditions.

SIMA developers must carefully assess any assumptions that have been made while framing the spill scenario. It is important to ensure that strategy selection is made with flexibility and adaptability in mind. This approach will assist responders in shaping the response strategy as event-driven data are gathered and evaluated. An overview of past SIMA usage in Canada and the United States is presented in Slaughter et al. (2017).

2.0 CNOOC Flemish Pass Area SIMA Overview

Overviews of the Geographic Area of Interest (GAI) (Section 2.1), its Physical Environment (Section 2.2) and Potential Oil Spill Scenarios (Section 2.3) provide information needed to evaluate the potential impacts of an oil spill within the CNOOC Project Area, as defined in the EIS (Nexen 2018).

The description of the physical environment is based on information provided in the EIS and three SEAs:

- CNOOC EIS (Nexen 2018);
- Eastern Newfoundland SEA (C-NLOPB 2014);
- Southern Newfoundland SEA (C-NLOPB 2010); and
- SEA Labrador Shelf Offshore Area (C-NLOPB 2008).

The oil spill modelling scenarios presented in this SIMA are based on results presented in the following reports prepared for CNOOC:

- RPS. 2019. Trajectory Modelling in Support of the Nexen Energy ULC Flemish Pass Exploration Drilling Project (2018–2028) Relief Well Modelling. Appendix B of Flemish Pass Exploration Drilling Project (2018–2028) – Environmental Impact Statement Addendum (February 2019). 94 p.
- RPS. 2018. Trajectory Modelling in Support of the Nexen Energy ULC Flemish Pass Exploration Drilling Project (2018–2028). Appendix G of Flemish Pass Exploration Drilling Project (2018–2028) – Environmental Impact Statement. 84 p.
- SL Ross. 2017. Spill Probability Assessment for Nexen Energy ULC Flemish Pass Exploration Drilling Environmental Assessment. Appendix F of Flemish Pass Exploration Drilling Project (2018–2028) – Environmental Impact Statement. 13 p.

Both trajectory modelling reports listed above included blowout scenarios at hypothetical locations in EL 1144 and EL 1150. The initial trajectory modelling (RPS 2018) used a 30-day release duration and a 60-day simulation duration, while the second trajectory modelling (RPS 2019) used a 120-day release duration and a 160-day simulation duration. The initial modelling was meant to represent the time required to cap the well, while the second modelling exercise represents the time required to drill a relief well. Results of the second modelling exercise, considered a worst-case scenario, are used in this assessment.

2.1 Geographic Area of Interest

The GAI used in this SIMA is presented in Figure 2-1. The area represented by the GAI encompasses the area for which the 'Existing Biological Environment' and fisheries data were presented in the EIS. This is an important point given that the SIMA relies heavily on what biological resources and associated habitats could potentially be impacted by a spill. Although results of the spill modelling indicate that most of the crude oil would move northward, southward and eastward from the release locations, there is a paucity of biological data related to these deep ocean areas. Therefore, the size of GAI is substantially smaller than the domains associated with both spill modelling exercises (RPS 2018, 2019). Resultant predicted movement of released crude to the west of the release locations is assessed as far as 56°W (i.e., western boundary of GAI) given the very low probability of crude reaching areas west of this longitude.

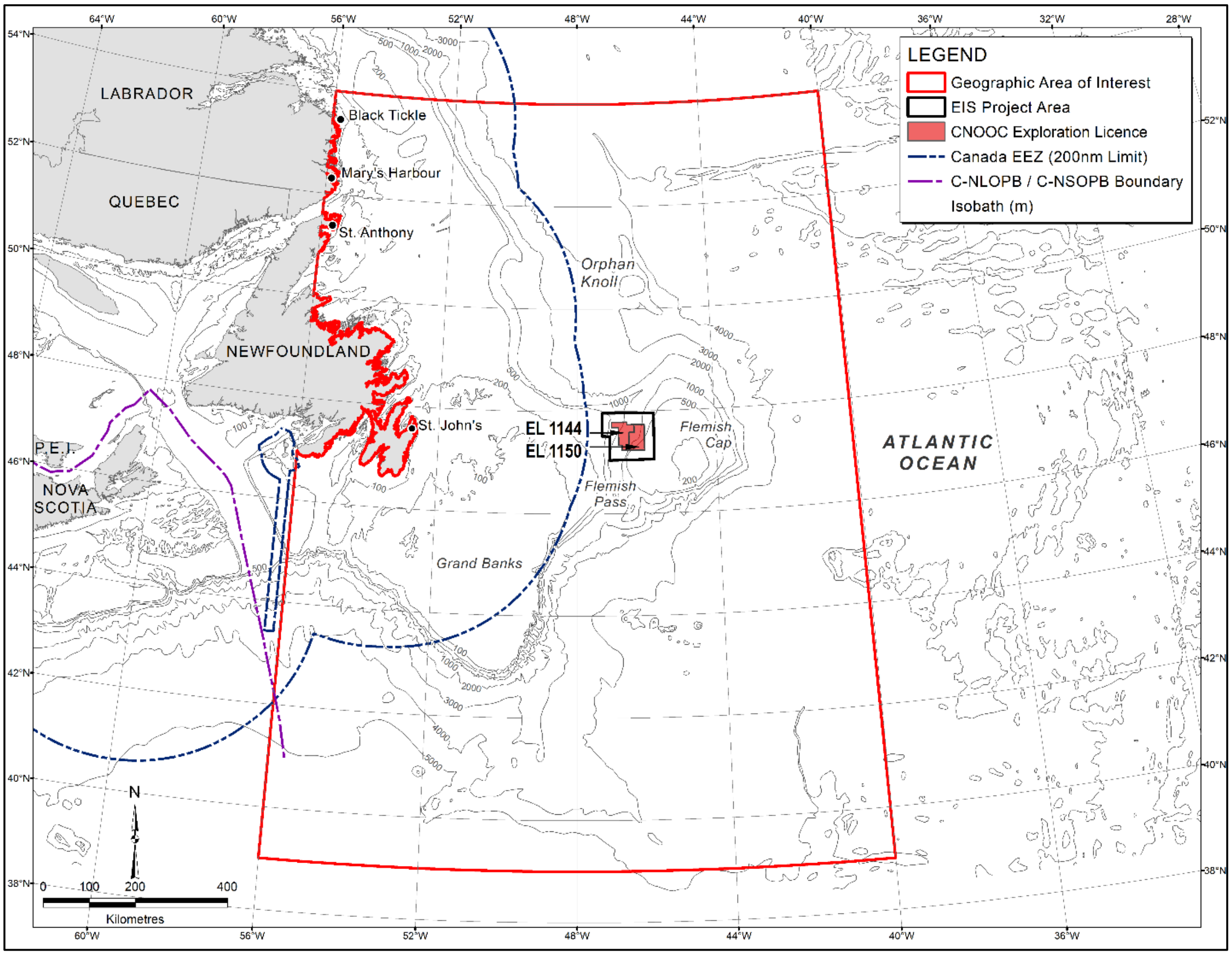


Figure 2-1. **SIMA Geographic Area of Interest, CNOOC EIS Project Area, and Exploration Licenses of interest.**

The GAI extends east-west from 40°W to 56°W, and north-south from 39°N to 54°N. It includes Newfoundland shoreline from the Connaigre Peninsula counterclockwise to the Baie Verte Peninsula (i.e., eastern part of Newfoundland), and extending to the north-northeastern Northern Peninsula. Also included in the GAI is a portion of the southeastern Labrador shoreline between Mary's Harbour and Black Tickle.

2.2 Physical Environment

The description of the physical environment (e.g., oceanography, climatology, meteorology, and ice conditions) for the GAI is described in detail in the EIS (Section 5.0 *in* Nexen 2018). With the exception of wind speed, wave height (Tables 2-1 and 2-2), ocean currents (Figures 2-2 to 2-5), and ice conditions (Section 2.2.3), other physical environment data from the EIS have not been reproduced here. Additional information on the physical environment in the GAI is available in the three relevant SEAs (C-NLOPB 2008, 2010, 2014).

2.2.1 Wind and Wave Data

During the development of the EIS, 53 years (1962–2015) of hourly wind and wave data were obtained from a single grid point located in the Project Area (Table 2-1). Extreme wind and wave data collected from the grid point during 1962–2015 were also presented in the EIS.

Table 2-1. Historical wind and wave data for the EIS Project Area (53-year average)[1].

Month	Mean Wind Speed (m/s)[2]	Most Frequent Wind Direction[3]	Mean Significant Wave Height (m)[4]	Most Frequent Wave Direction[5]
January	11.7	W	4.5	W
February	11.5	W	4.0	W
March	10.2	W	3.3	SW
April	8.5	W	2.8	SW
May	7.3	SW	2.3	SW
June	6.8	SW	2.0	SW
July	6.2	SW	1.7	SW
August	6.6	SW	1.9	SW
September	7.8	W	2.5	SW
October	9.3	W	3.1	NW
November	10.0	W	3.6	NW
December	11.1	W	4.2	NW

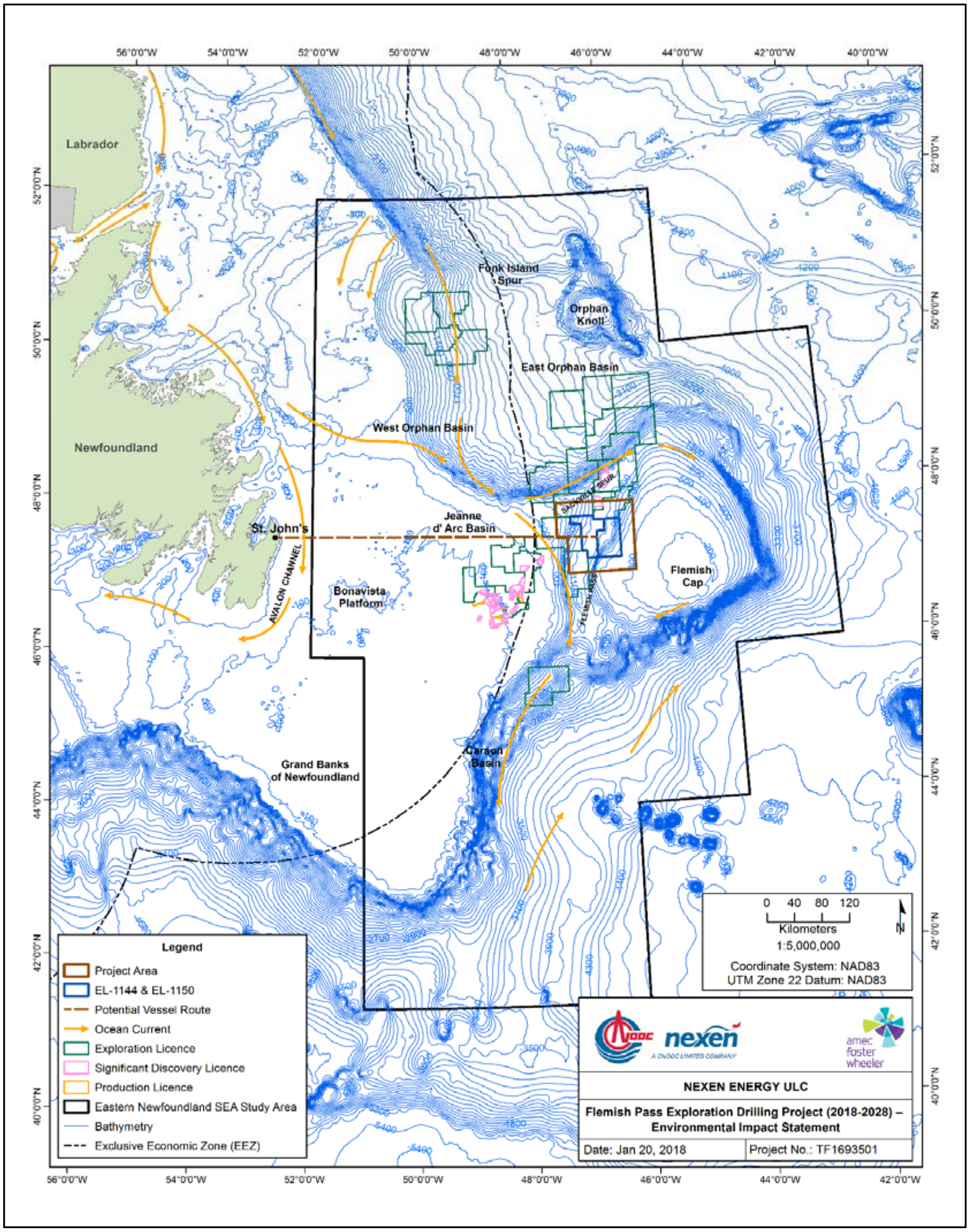
[1] Based on 53 years of MSC50 hourly wind data from 1962–2015.
[2] Averages of wind data from single grid point in Project Area.
[3] Direction from which winds are blowing.
[4] Averages of wave data from single grid point in Project Area.
[5] Direction from which waves are propagating.

Source: Nexen (2018).

2.2.2 Currents

The cold Labrador Current dominates the general circulation over the eastern Newfoundland offshore area. The Labrador Current is divided into two streams: 1) an inshore branch that flows along the coast on the continental shelf; and 2) an offshore branch that flows along the outer edge of the Grand Banks (Figure 2-2).

The Labrador Current's inshore branch tends to flow mainly in the Avalon Channel along the coast of the Avalon Peninsula but may sometimes also spread farther out on the Grand Banks.



Source: Nexen (2018).

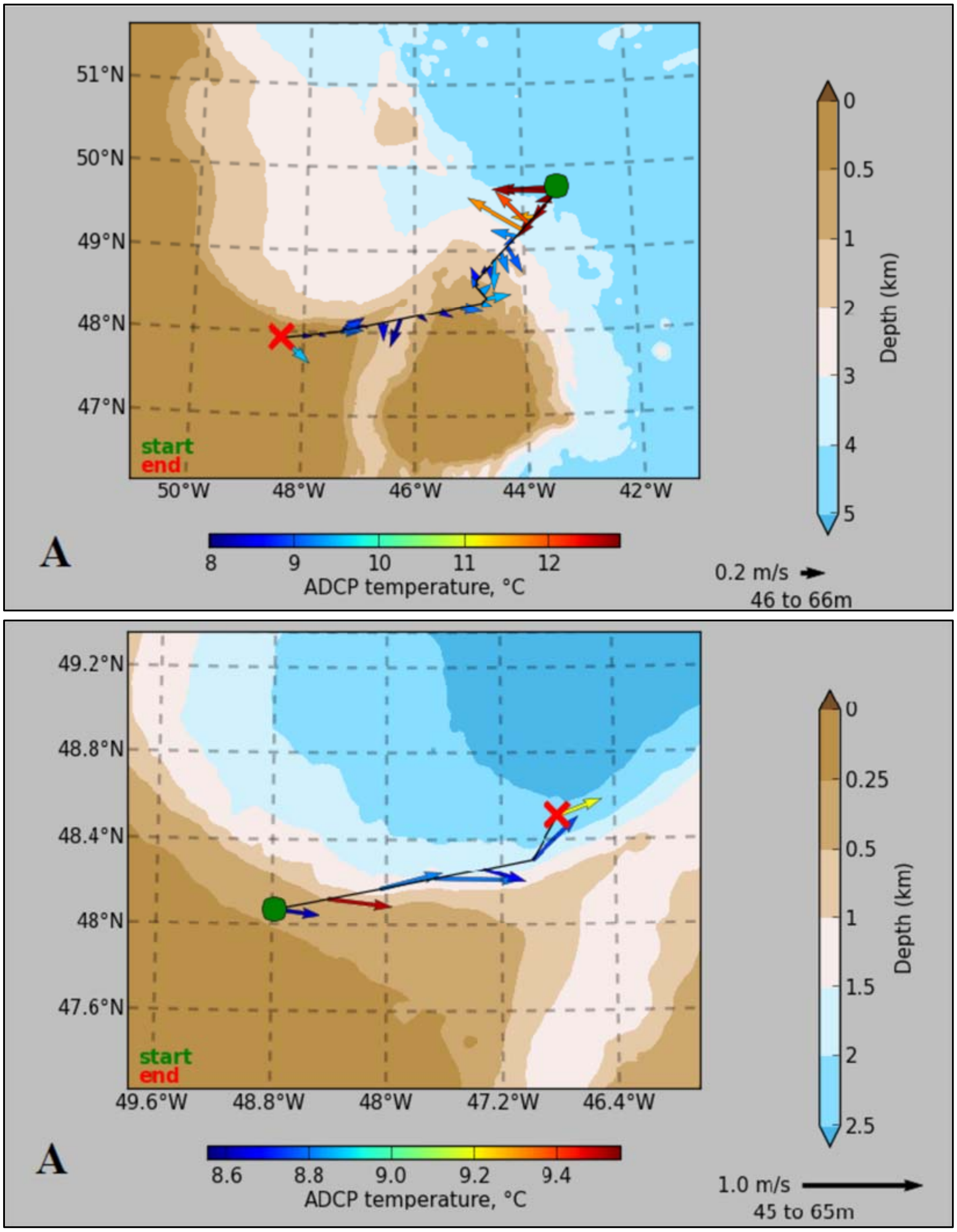
Figure 2-2. Ocean currents in the eastern Newfoundland offshore area.

The offshore branch flows over the upper Continental Slope at depth, and through the 1,300 m deep Flemish Pass. The offshore Labrador Current (which remains bathymetrically trapped over the upper Continental Slope) has average speeds of about 40 cm/s carrying approximately 85 percent of the total transport, mainly between the 400 and 1,200 m isobaths (Lazier and Wright 1993). Over areas of the Grand Banks with water depths less than 100 m, the mean currents are generally weak (less than 10 cm/s) and flow southward, dominated by wind-induced and tidal current variability (Seaconsult Ltd. 1988).

Near the EIS Project Area, in the vicinity of the Flemish Pass, the Labrador Current divides into two branches with the main branch flowing southwards as Slope Water Current and the side branch flowing up to the east-northeast clockwise past the Sackville Spur and north-eastward around the Flemish Cap. The cores of these currents are located at an average depth of 100 m. This is well-illustrated in Figures 2-3 and 2-4 which show current transects (currents at depth approximately 45–65 m) from a recent Fisheries and Oceans Canada (DFO) oceanographic program in the Sackville Spur and Flemish Pass regions in 2013–2014. This field program, with funding from the Environmental Studies Research Fund (ESRF), had the objective of studying ocean current variability and dispersion in the vicinity of the Sackville Spur as well as to characterize some of the benthic habitat for assessment of vulnerable marine ecosystems (Greenan et al. 2016).

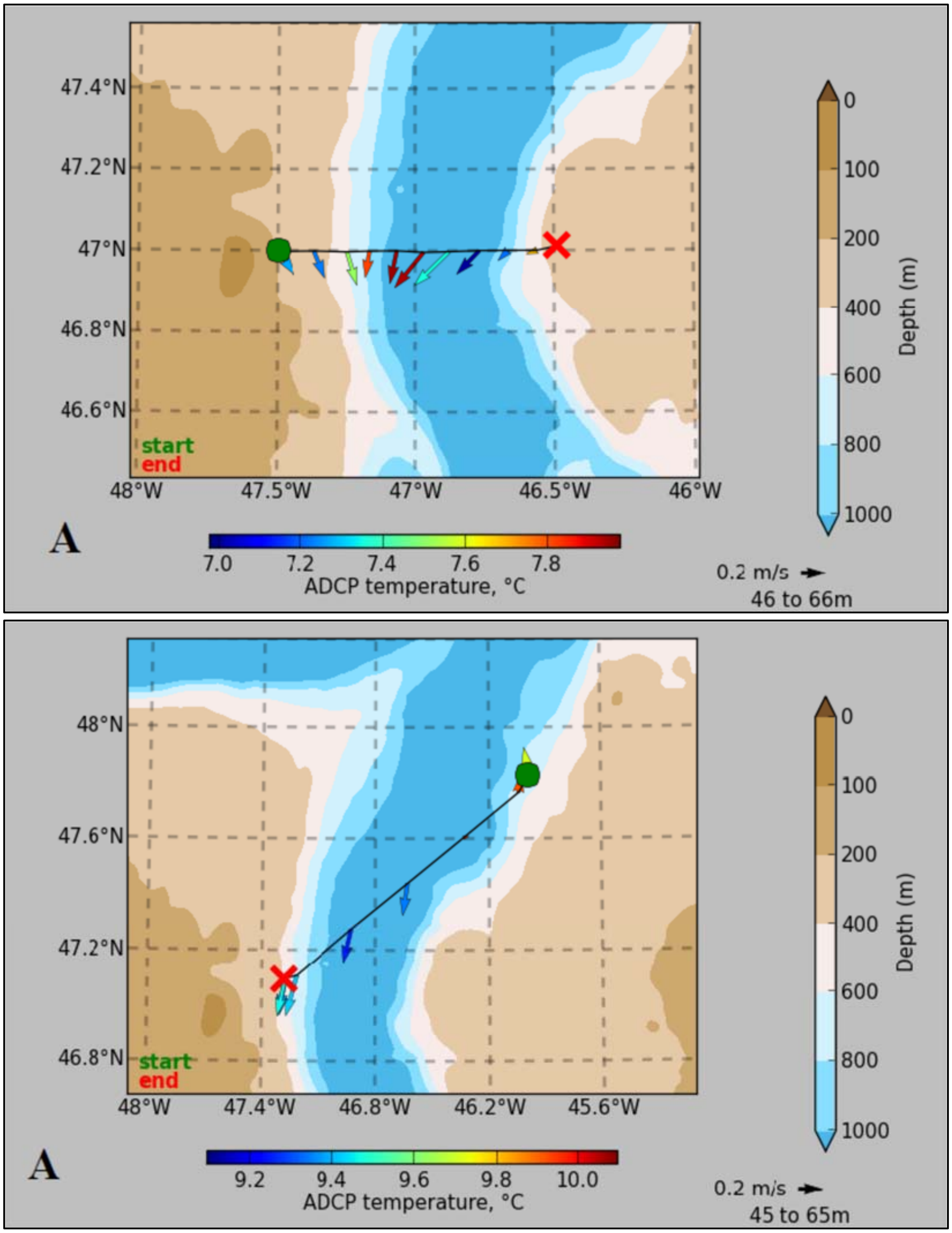
The oceanographic data from the DFO (Greenan et al. 2016) program includes shipboard conductivity, temperature and dissolved oxygen (CTD), lowered Acoustic Doppler Current Profiler (ADCP), vessel-mounted ADCP and water samples during two cruises in July 2013 and 2014. Moorings were deployed at three locations (Figures 5.19 and 5.20 *in* Greenan et al. 2016) including one (Sackville Spur West, 1841) 45 km to the north of Project Area and one 16 km west of the southwest corner of the Project Area (Flemish Pass, 1842). A third mooring (Sackville Spur East, 1840) was located about 92 km to the northeast of the Project Area. The Ocean Data Inventory (ODI) current statistics reported below include measurements from 12 single-point current meters (RCM11) from the two Sackville Spur moorings (six RCM11s at each location).

For the purposes of this overview, statistics for both actual current meter data near the Project Area and modelled currents in the Project Area are reported. The primary modelling data source is the Bedford Institute of Oceanography (BIO) ODI database (Gregory 2004). The database consists of all current meter records that have a record length of at least five days within a given month.



Source: Nexen (2018).

Figure 2-3. Sackville Spur Region, ADCP depth-averaged current speed; (top) July 2013, (bottom) July 2014.



Source: Nexen (2018).

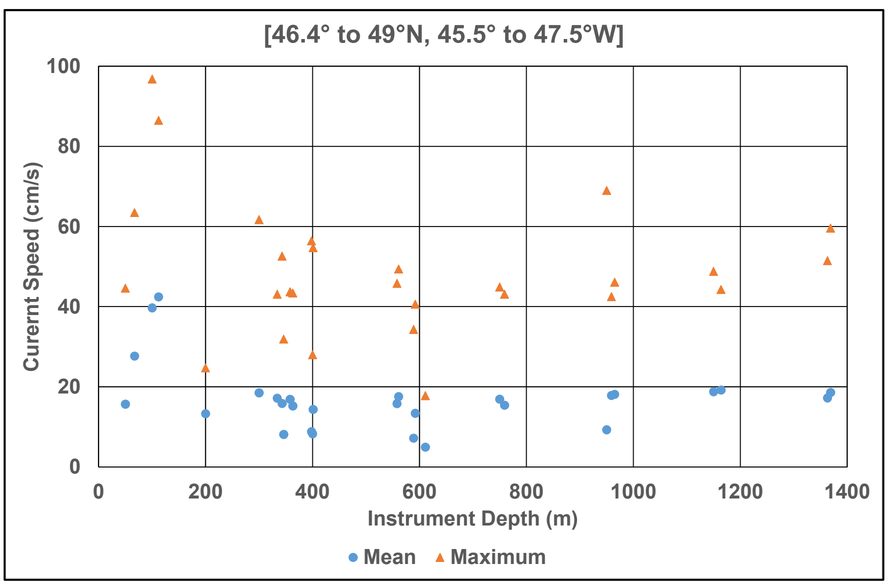
Figure 2-4. Flemish Pass Region, ADCP depth-averaged current speed; (top) July 2013, (bottom) July 2014.

In anticipation that measurements may be relatively limited within the Project Area boundaries, the ODI database was queried for a surrounding area extending from 46.4°N to 49°N, 45.5°W to 47.5°W (DFO 2017). While there are no measurements directly within the Project Area, there are a total of 228 monthly current statistic records from 33 deployments at 28 depths at 11 locations. These are located solely to the west and southwest of the Project Area on the eastern slopes of the Grand Banks and Flemish Pass, and north of the Project Area along the Sackville Spur. A summary of these data by depth, noting the number of instrument records, data duration, and mean and maximum current speed is presented in Table 2-2. The mean and maximum currents for all 28 depths near the Project Area are presented in Figure 2-5.

Table 2-2. ODI ocean current statistics summary (46.4° to 49°N, 45.5° to 47.5°W) near the Project Area.

Water Depth	Number of Instrument Records	Number of Data Months	Mean Current Speed (cm/s)	Maximum Current Speed (cm/s)
0 to 100 m	7	5.1	22.5	63.5
100 to 200 m	14	9.9	40.5	96.8
200 to 500 m	61	51.7	14.7	61.7
500 to 1,000 m	94	84.7	15.3	69.0
> 1,000 m	52	49.3	18.5	59.6
Total	228	200.7	17.6	96.8

Source: Nexen (2018).



Source: Nexen (2018).

Figure 2-5. Mean and maximum current speed at locations near the Project Area.

These current measurements have average speeds (for each of the various depth ranges shown in Figure 2-5) that range from 8 cm/s to 42 cm/s for depths up to 400 m and range from 5 cm/s to 19 cm/s at depths of 558 m and above. Maximum current speeds of 97 cm/s were recorded in

February 1986, along the slope, 8 km southwest of the Project Area boundary, at location 46.9835°N, 47.13885°W, at an instrument depth of 100 m. The deepest maximum current speeds are 60 cm/s measured near-bottom (1,369 m) located along the Sackville Spur at a mooring water depth of 1,400 m.

2.2.3 Ice Conditions

Portions of the GAI are subject to seasonal abundance of icebergs and sea ice, which are variable in numbers and location each year. Iceberg and sea ice conditions are influenced by colder or milder winter conditions over Newfoundland and the surrounding waters, in addition to seasonal wind patterns. Ice can be moved offshore by cold and dry winds from the west through to the north, and inshore by north-easterly winds (Nexen 2018).

The iceberg season in Newfoundland generally lasts from January through to August, with 85% of first iceberg sightings occurring from March to June. The highest probability of icebergs within the GAI is during the months of March through to May (Nexen 2018). There is considerable variability in the abundance, size, and location of icebergs that may occur within the GAI.

Sea ice may be present with the GAI with ice that drifts southwards from Labrador and from the northeast of Newfoundland pushing out towards the Orphan Basin and Flemish Pass. There is, however, large variability in sea ice conditions that may be experienced temporally from year to year, and within any given year, on time scales of days to weeks, and spatially over relatively small geographic scales to tens of kilometers (Nexen 2018). Further details on icebergs and sea ice are presented in Section 5.0 of the EIS.

2.3 Potential Oil Spill Scenarios

Two spill modelling reports (RPS 2018, 2019) provide hypothetical oil spill scenarios developed for a subsea blowout at two locations in the northern Flemish Pass, specifically within ELs 1144 and 1150, during two seasons (winter and summer). While the modelling in RPS (2018) used 30-day blowout durations and 60-day simulations to represent the time required to cap the well, RPS (2019) modelling used 120-day blowout durations and 160-day simulations to represent the time required to drill a relief well. As noted earlier, this SIMA focuses on the RPS (2019) modelling given it is considered a 'worst-case scenario' compared to the RPS (2018) modelling. The EL 1144 modelling scenarios are characterized by a crude oil release rate of 184,000 bpd at a depth of 1,137 m (floor of Flemish Pass; Figure 2-6), while the EL 1150 modelling scenarios are characterized by a release rate of 44,291 bpd at a depth of 378 m (upper western slope of Flemish Pass). The total release volumes over the 120-day blowout scenarios for EL 1144 and EL 1150 are 22,080,000 bbl and 5,314,920 bbl, respectively. While the exact locations for exploration wells have yet to be determined, these hypothetical scenarios encompass the range of the anticipated locations and potential crude release volumes of an actual well. General parameters for a source control blowout are summarized in Table 2-3 and discussed in greater detail in Section 5.0, Oil

Spill Modelling. The Bay du Nord (BdN) crude oil is the reference oil type for the spill modeling in EL 1144 and EL 1150. Since these large-scale releases would require the broadest range of oil spill response options, they form the basis for the risk analysis conducted in Section 6.0.

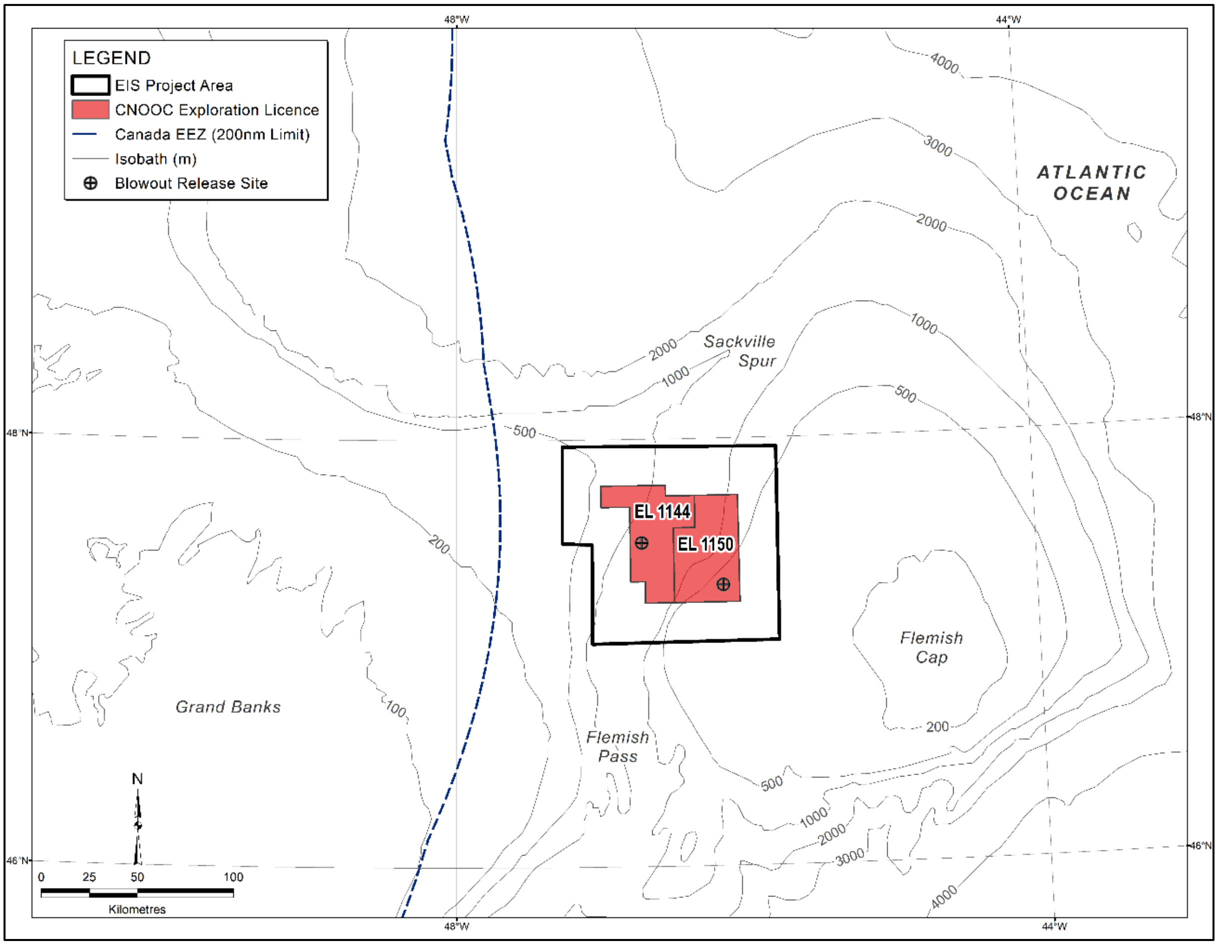


Figure 2-6. Locations of hydrocarbon blowout release sites within EL 1144 and EL 1150.

Table 2-3. General parameters for Tier 3 hypothetical source control blowouts at the two release locations within ELs 1144 and 1150.

Parameter	**Exploration Licence**	
	EL 1144	**EL 1150**
Source of Spill	Blowout at Seafloor	Blowout at Seafloor
Crude Oil Type (API gravity)	Bay du Nord (35.8)	Bay du Nord (35.8)
Release Location Coordinates	47° 31' 1.2194'' N, 46° 43' 9.1987'' W	47° 18' 54.757'' N, 46° 9' 40.394'' W
Water Depth	1,137 m	378 m
Timing of Release	Summer; Winter	Summer; Winter
Duration of Release	120-day continuous	120-day continuous
Rate of Release	184,000 bpd	44,291 bpd
Model Duration	160 d	160 d

Note:'bpd' denotes barrels per day.

For the purposes of this SIMA, the Worst Credible Case Discharge (WCCD) refers to the worst credible consequence that could occur over a 160-day modelled time period, from an environmental impact and emergency response perspective. The WCCD oil spill modelling was used to generate both stochastic and deterministic simulations for summer and winter scenarios. Stochastic (or probabilistic) modelling predicts the probability of sea surface, shoreline, or water column contact that could occur for a given spill event. The model runs numerous individual spill trajectory simulations using a range of hydrodynamic (MetOcean) and historical meteorological data, such as wind and currents. When combined, these trajectories produce statistical outputs that predict the probability of where oil may travel or occur. Stochastic model outputs do not represent the extent of any one spill event but instead provide a summary of the total individual simulations for a given spill scenario. In contrast, deterministic (single run) modelling predicts the fate (i.e., surface oil thickness, in-water oil concentration) and transport (i.e., migration path, time to shoreline) of oil resulting from a single hypothetical spill event using predefined MetOcean data. Therefore, the use of both stochastic and deterministic modelling provides an indication of the likelihood and magnitude of the potential effects of the spill scenarios considered for this SIMA.

The analysis of the trajectories of Tier 3 scenarios in both summer and winter has two objectives:

(1) to evaluate the differences in reasonable response operational effectiveness across the two modelled seasons; and
(2) to evaluate the impact of the response operations to the regional resources of concern across two seasons.

For the stochastic modelling described in the EIS, 'Summer' and 'Winter' seasons represent two periods of time. For the purposes of this SIMA, summer is defined as the May–October period, and winter is defined as the November–April period (RPS 2019). Deterministic modelling was derived from stochastic simulations that predicted the worst environmental impacts from an emergency response point of view and which were assessed in the EIS as an unmitigated spill result. For the SIMA, these resulting deterministic simulations represent unmitigated spill scenarios with natural attenuation for both the summer and winter seasons.

3.0 Response Options

The six spill response options considered in this SIMA are as follow (RPS 2019):

- Natural attenuation (i.e., no intervention);
- Shoreline protection and recovery;
- On-water mechanical recovery;
- In-situ burning;
- Surface dispersant application (SDA); and
- Surface dispersant application in combination with subsea dispersant injection (SSDI).

An overview for each response option, including operational benefits and limitations, is provided to ensure a common framework of understanding for the SIMA analysis. Since every response option has benefits and limitations, a full discussion of response options and tactics are provided in the CNOOC Offshore Spill Response Plan (AS-ATC-PRA-0031) and associated Emergency Response Plan (AS-ATC-PRA-0028). These documents have been integrated into the CNOOC Atlantic Canada Management System and submitted to the C-NLOPB.

Factors considered while assessing the efficacy of potential response methods include MetOcean data, oil characteristics, the nature and location of the release, and regulatory and logistical considerations. For most spill events, optimal response actions vary depending on many factors. During any given event, several response methods are likely to be used concurrently.

3.1 Natural Attenuation

Natural attenuation (i.e., 'no intervention') is the baseline to which all other potential response options are compared to in this SIMA risk analysis. With no intervention, oil from a spill will be transported via winds and oceans currents gradually weathering until it evaporates, dissolves, and disperses into the water column where it could possibly strand on a shoreline. If stranding of the oil does occur, it will continue to weather, and will gradually biodegrade or be incorporated into the sediments. The stranded oil may also re-mobilize into the water column from the shoreline several times until it is finally degraded, consumed by organisms, or buried through natural tidal processes.

The option of natural attenuation may be appropriate for open ocean spills that do not threaten worker health and safety, marine species of importance, shorelines and/or potentially sensitive environmental areas. Remote sensing, real time modelling and monitoring at sea and on potentially affected shorelines would be conducted to track the fate of naturally weathering oil slicks or stranded oil.

Benefits: Natural attenuation may be appropriate for an offshore spill event that does not pose a threat to the shoreline, protected habitats, or sensitive marine species. It may also be beneficial if the spill occurs during periods of high sea state such as during winter months or storm events, that facilitate natural oil dispersion but prevent safe deployment of other response options. Natural attenuation may also be appropriate for certain sensitive shoreline habitats where intrusion by people and equipment may cause more environmental damage than naturally degrading oil.

Limitations: By allowing the oil to naturally attenuate, oil slicks may remain on the surface of the water, which may range from hours in duration for light oil in high seas, to months for heavier or emulsified oils in relatively calm conditions. This response option may also lead to shoreline oiling. Heavy reliance on the natural attenuation option could affect emergency response capabilities at the blowout site given the higher potential for exposure of surface vessels and personnel to the volatile organic compounds (VOCs) of crude oil, thereby creating a health and safety risk.

3.2 Shoreline Protection and Recovery

Shoreline protection (e.g., through diversion and deflection booming of oil) and recovery (i.e., manual retrieval of oil) are two response techniques that are typically used in combination, so they are addressed together in this section. The trajectory modelling conducted for both EL 1144 and EL 1150 demonstrates that there is limited probability of spilled oil reaching the shoreline of Newfoundland and Labrador. When spilled oil cannot be effectively treated or collected at sea before reaching the shoreline, protection and recovery are essential.

In order to implement shoreline protection and recovery strategies, large numbers of responders must be trained, transported, housed, and managed. Therefore, the associated logistics can be complex, particularly if they are to occur in remote, topographically challenging areas or under adverse weather conditions such as those that may be experienced in coastal areas of Newfoundland and Labrador. Additionally, proper worker personal protective equipment, hand tools, washing equipment, protective and containment booms, and any other appropriate mechanical equipment must be provided, stored, transported, and maintained. Gaining access to oiled shorelines can make this response option operationally difficult.

The strategies for protective booming may vary depending on tides, currents and weather conditions. These strategies require relatively calm waters due to the likelihood of failure in sea states above 1–2 m and vulnerability to high winds, tides, and currents. For the specific spill location considered, the options listed below are the most typical shoreline recovery options that may be utilized if oil does reach Newfoundland shorelines. Operations would be prioritized based on the varying sensitivity of the affected shoreline.

- Manual removal – removal of surface oil from the shoreline by manual means (e.g., hands, rakes, shovels, buckets, scrappers, sorbents, etc.);

- Debris removal – manual or mechanical removal of debris (oiled and unoiled) from the shore or water surface to prevent additional sources of contamination;
- Low-pressure cold-water flushing; and
- Limited use of mechanical recovery equipment in accessible areas, if justified by the contamination level.

Benefits: Since booming can only protect relatively short stretches of the shoreline, it should be used strategically in selected areas requiring protection of ecologically or socially important areas. The equipment required for shoreline recovery is readily available and can be easily deployed under favourable conditions. This response option can be effective for recovering a wide range of spilled products and is not just limited to crude oil (IPIECA et al. 2017). The use of strategic protective booming should be based on the forecasted spill trajectory, the environmental context, and conditions at the time of the incident. Once oil reaches the shoreline, the potential benefits of shoreline recovery options relative to natural attenuation include the following:

- Reduction in shoreline oiling;
- Physical removal of oil from the environment with minimal environmental impact during on-water clean-up;
- Recycling or proper disposal of recovered oil; and
- Mitigation of impacts to culturally, environmentally or economically important areas.

Limitations: There is a risk of collateral damage due to physical disturbance caused by clean-up personnel installing, maintaining, and dismantling the boom during this response. Additionally, there may be potential of disturbance from anchoring the materials to soils, sediments, or plants, along with increased shoreline and sediment erosion while the boom moves in place. However, this is considered minor when compared to the damage likely to result from the oil if no response was made. Weather, shoreline topography, and hydrographic conditions are all determining factors in boom deployment.

Oil usually remains on the surface of the sediments during recovery, and in combination with the placement of sorbents at the edge of the water line to passively collect any oil that re-floats, shoreline recovery tends to be more intrusive than any of the on-water response option. Shoreline recovery can only be conducted during daylight hours when weather conditions are conducive to worker safety. Given the logistical challenges and limitations, on-water cleanup with the goal of preventing the oil from reaching the shoreline will almost always be environmentally preferable to on-shore recovery. The time required for an oiled shoreline to recover may take weeks to years, depending on oil type and different environmental variables (e.g., wave energy, amount of solar exposure, rainfall, shoreline type, and erosion processes).

3.3 On-Water Mechanical Recovery

On-water mechanical recovery usually entails the use skimming vessels, support vessels, storage barges, spotter aircraft, booms, and skimmers to redirect, contain and remove oil from the ocean's surface. The success rate of oil removal by means of on-water mechanical recovery depends on various factors including wind, waves, and daylight. The encounter rate of oil can be relatively low during on-water mechanical recovery due to slow speeds of the skimmer pulling vessels, usually around one knot. Once oil has been removed from the ocean's surface, it must be stored in either tanks on vessels or in floating temporary storage devices such as towable bladders. Once full they must be returned to an onshore operational base for offloading and either recycling or disposal. On-water mechanical recovery is typically conducted only during the day in conditions with relatively good visibility despite the availability of night-vision technologies. Monitoring to determine the effectiveness of on-water mechanical recovery is limited to visual observations from surveillance aircraft or satellite imagery.

Benefits: The primary benefit of on-water mechanical recovery is that the recovered oil is physically removed from the environment with minimal impact. Therefore, the public acceptance for use of on-water mechanical recovery is relatively high. Since oil can still be recovered after some weathering has occurred, there is usually a larger window of opportunity compared to other on-water response methods (IPIECA et al. 2017). Generally, this response option would be implemented if it is safe to do so.

Limitations: The deployment of on-water mechanical recovery is limited by the weather and to daylight hours. The mobilization time required for deployment in the Flemish Pass would take approximately 48–72 hours. This reduces the window of opportunity to conduct larger-scale on-water mechanical recovery. The low oil encounter rate and the need to dispose of captured oil also limits the effectiveness of this response option. Beyond the encounter rate limitations, typical wave heights are a key consideration in the SIMA GAI. For example, open water booming associated with oil skimming operations begins to fail in sea states with wave heights exceeding 2 m. However, equipment capable of functioning in high sea states will also be available during an actual spill. In the CNOOC Project Area, wave heights typically exceed this operational limit during the September–May period (see Table 2-1). Even when sea states are favourable for on-water mechanical recovery operations, these techniques typically recover less than 10% of the oil spilled in open ocean environments. During the DWH response period when wave height was seldom restrictive, it was estimated that less than 5% of the oil released was removed (Federal Interagency Solutions Group 2010). Despite the logistical and operational limitations on the effectiveness of on-water mechanical recovery, this response option remains advantageous since it is the only method that physically removes oil from the environment.

3.4 *In Situ* Burning

In situ burning (ISB) is similar to on-water mechanical recovery in that it involves collection and concentration of oil on the surface using vessels and booms. However, the few key differences are as follows:

- the booms used to collect the oil must be fire resistant;
- while herding agents (i.e., chemical oil-collecting agents that herd oil spilled on a sea surface into thickened slicks) may be used to aid in the containment or thickening of the oil, none of the available herding agents are currently approved for use in Canada; and
- heavy oils and highly weathered oils are less amenable to burning.

The first step in using ISB as a spill response option is to conduct a test burn on spilled oil. Once oil is collected with booms and concentrated to a thickness (2-5 mm) that will support combustion, it is ignited using flares, torches, or improvised ignition devices (IPIECA and IOGP 2016). ISB produces dense black smoke plumes that consist primarily of small carbon particles which disperse into the atmosphere, and an oily residue will typically remain on the surface after burning, however its volume is too low for collection. In the SIMA GAI, the only likely human exposures to smoke plumes would be to response workers as these plumes would dissipate before reaching any populated land mass.

Benefits: ISB rapidly reduces the amount of oil that remains in the aquatic environment, and since oil is not collected for disposal, there is no need to transfer oil to shore. Under optimal sea state conditions, ISB can reduce more oil from the water surface than on-water mechanical collection and disposal and has an efficiency rate of up to 99% (IPIECA et al. 2017). For offshore deep-water spill responses, the considerable distance from shore means that the ISB smoke plume would not typically affect humans on shore.

Limitations: Environmental conditions at the time of an incident is the most relevant factor when determining to use ISB. In some areas (but not in the SIMA GAI), reduction in air quality due to gases and particulate material produced during burning may be a concern because of potential exposure to populated areas.

ISB also creates limited by-product burn residues that can potentially sink into the water column and not be recovered. This response option has many of the same limitations that on-water mechanical recovery has with respect to operational speed, weather, and daylight. The effectiveness of this response option also diminishes for heavier oils and as oil becomes weathered. Oil must first be collected using vessels and booms, possibly resulting in a relatively low oil encounter rate, depending on sea state. In addition, fire resistant booms designed for ISB operations (i.e., specialized 'fire booms') must be used. While public perception can be negative due to the physical appearance of a black smoke plumes, and the localized reduction of air quality, it is unlikely to become an issue due to the considerable distance between the CNOOC Project Area and mainland Newfoundland.

Wave height is also a substantial limitation affecting ISB, as this response option is more sensitive to wave height than on-water mechanical recovery. The booms must concentrate oil to a greater thickness for burning purposes, and wave action is disruptive to combustion. Effective ISB typically requires wave heights <1 m and wind speeds <10 knots (5.1 m/s) (IPIECA and IOGP 2016), conditions that rarely exist in the CNOOC Project Area (see Table 2-1). Although ISB was used as a response method during the DWH incident while sea states were essentially flat, a recovery rate of only about 5% was reported (Federal Interagency Solutions Group 2010).

3.5 Overview of Dispersants and Dispersed Oil

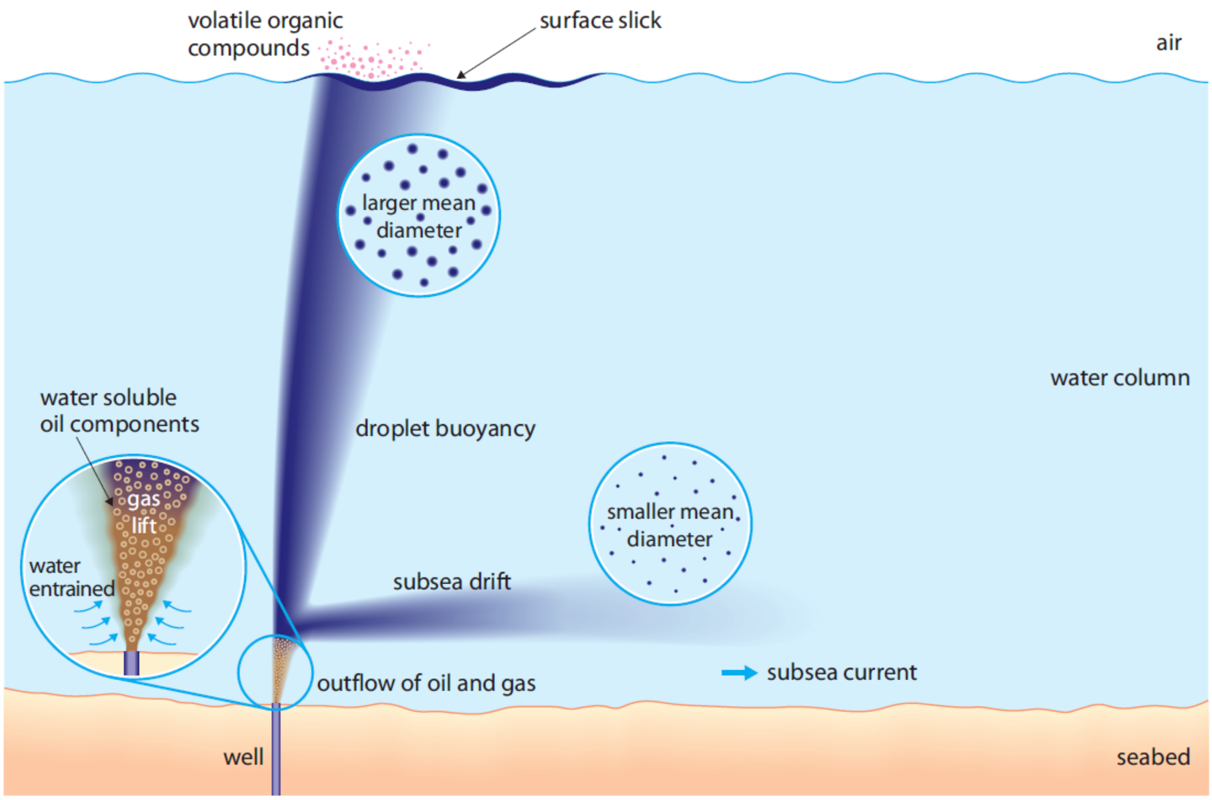
Section 16.6 of the updated EIS Section 16.0 (CNOOC 2019; Appendix C) provides a detailed discussion of the potential effects of an unmitigated oil spill in its Project Area. Introductory information on dispersants and dispersed oil are provided here as background for the reader.

The use of dispersants, whether applied at the ocean's surface (SDA) or through subsea injection (SSDI) at the hydrocarbon release location, will change the fate of the oil. For surface dispersant operations, past studies (ocean field trials conducted in the North Sea in 1994 (AEA Technology 1994), in 1995 (AEA Technology 1995; Jones and Petch 1995), and in 1996 (Strøm-Kristiansen et al. 1997; Coelho et al. 1998) and spills (Deep Water Horizon [DWH] - Operational Science Advisory Team [OSAT] 2010)) have indicated that surface dispersant application will result in dispersed oil concentrations in the upper few metres of the water column ranging from 10–50 parts per million (ppm) for the first hour after dispersant application. Over the following few hours, rapid horizontal and vertical mixing will quickly reduce those concentrations to below 10 ppm.

The only available information related to dispersed oil concentrations resulting from subsea dispersant injection operations is from the DWH incident. Due to potential conflicts with response operations and safety concerns, most of the subsea monitoring during the DWH response was conducted outside an exclusion zone extending 1 km from the wellhead. Beyond the 1 km exclusion zone, an existent subsea dispersed oil plume was typically narrow, trended away from the site in the direction of very slight subsea currents, and was bounded by water depths ranging from 900–1,200 m. Of the 2,779 individual samples collected in that area, only 33 samples had total petroleum hydrocarbon (TPH) concentrations higher than 10 parts per billion (ppb) (Coelho et al. 2011; Lee et al. 2015).

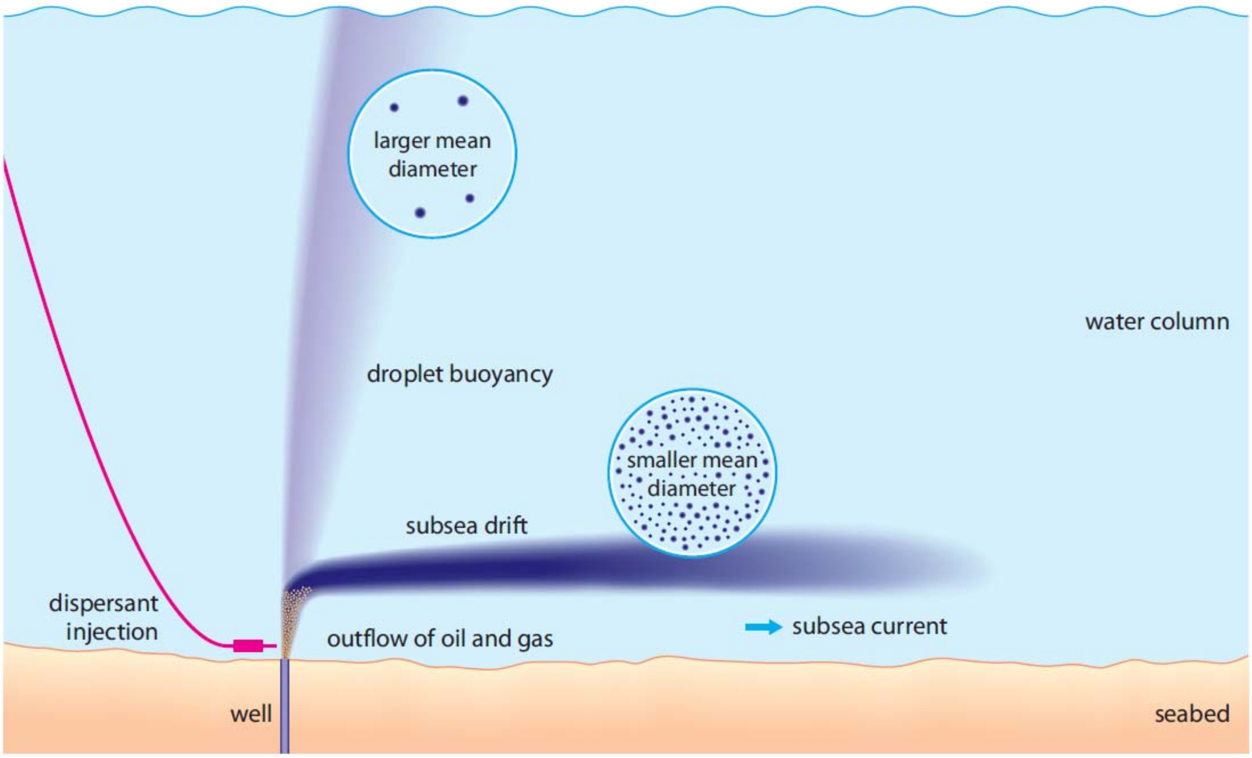
Cross-section illustrations of oil behaviour from a hypothetical subsea release are provided for an unmitigated release (Figure 3-1) and a SSDI-treated release (Figure 3-2). Estimated oil concentrations in the vicinity of the spill are provided using measured concentrations reported from the 2010 DWH incident (Coelho et al. 2011; National Oceanic and Atmospheric Administration [NOAA] 2012).

Slaughter et al. (2017) provides an in-depth discussion on the role of dispersants in oil spill response, including the basic principles of chemical dispersion and factors that affect dispersant efficacy.



Source: IPIECA and IOGP (2015a).

Figure 3-1. Cross section of an unmitigated subsea release (vertical scale exaggerated for illustrative purposes).



Source: IPIECA and IOGP (2015a).

Figure 3-2. Cross-section of an unmitigated subsea release treated with SSDI (vertical scale exaggerated for illustrative purposes).

3.5.1 Surface Dispersant Application

Surface dispersant application involves the use of aircraft and/or spray-boom fitted vessels to apply dispersants on the water surface after a spill. The dispersants function as surfactants and break the oil down into small droplets approximately 10–200+ µm in diameter that will disperse into the water column (Slaughter et al. 2017). In an ideal scenario, the oil particles will remain in the top few metres of the water column rather than sinking to the lower water column. By breaking floating oil into small, dispersed droplets, the surface area to volume ratio increases, thereby increasing the rate of dissolution of oil constituents, dilution, weathering, and microbial degradation. Biodegradation is discussed in more detail in Section 6.2.2.

The surface oil encounter rate is higher than those associated with other surface response methods, as the dispersants can be applied from aircraft and/or relatively fast vessels. Additionally, floating oil should disperse into the upper 10 m of the water column rapidly as high wave action is frequently observed in the Project Area.

For surface applications, dispersants are typically applied at a dispersant to oil ratio (DOR) of about 1:20. This ratio, however, can vary depending on the composition of the oil and the degree of weathering. Therefore, the DOR is monitored and adjusted accordingly to optimize the efficacy of the surface application. Due to the considerable transit distances from St. John's airport to the CNOOC Project Area, large aircraft such as a C-130 equipped with a 5,280-gallon (20 m^3) Airborne Dispersant Delivery System (ADDS Pack) or the new OSRL 727 aircraft must be used. These large aircraft can treat up to 400 m^3 (400,000 L) of oil in one sortie (Slaughter et al. 2017). Spotter aircraft are used to assist in targeting dispersible surface slicks for the dispersant spraying aircraft. Dispersant-carrying aircraft would be on site within 24 hours of spill notification, and ready for operation by Day 2 of a spill.

As seen in Table 2-3 in Section 2.3, the daily rate of release in EL 1144 scenario amounts to 184,000 bpd, which is the equivalent of 29,000 m^3 of oil, and the spill scenario in EL 1150 would result in a release of 44,000 bpd or 7,000 m^3. If spotter aircraft were able to treat oil to their maximum capacity of 400 m^3, one sortie could treat approximately 1.4% of the oil released daily at EL 1144 and 5.7% at EL 1150.

The application of surface dispersant requires daylight and good visibility in order to visually track and target thick oil, to allow detection of human activity (e.g., vessels) and relevant megafauna within the spray area, and to visually observe the effectiveness of the application (e.g., colour change). Wave-action is also a limiting factor to SDA as wave heights of approximately 0.5 m or less will allow for successful application, however the maximum treatable wave heights are approximately 4 m (IPIECA et al. 2017; Slaughter et al. 2017). Dispersants can typically be applied in high wind and wave conditions as long as aircraft can be operated safely.

The application of dispersants can also be done via the use of vessels, either deployed from shore or already in the vicinity of the spill (e.g., Standby Vessel and Platform Supply Vessel). Although the oil encounter rate is lower using the vessel approach, the targeting of the oil can be more accurate. Vessels were used during the DWH spill response to treat surface oil in the vicinity of well containment in order to reduce the risk of exposure to the workers (Slaughter et al. 2017).

Dispersants are more efficient when treating fresh oil compared to weathered oil. Where a one-time batch spill occurs, there is a limited time period in which surface dispersant application will be effective and it depends on the oil characteristics and environmental conditions (IPIECA et al. 2017). For continuous releases, such as a subsea blow out, surface dispersant application could continue until the source is contained.

Determination of the effectiveness of the dispersant application is typically done during a post-spill environmental effects monitoring (EEM) program. The EEM program would include aerial observational flights to estimate the amount of oil remaining at surface, *in situ* water sampling at surface and near-surface, and bird surveys. Additionally, the operational effectiveness of dispersant application can be done in real time to provide feedback to determine the continued use in the field.

Benefits: The application of surface dispersants reduces the oil at the water surface, thereby reducing levels of VOCs and increasing the safety of workers. This response option can be deployed at a much faster rate compared to other options and has a relatively high oil encounter rate.

Limitations: The limitations on the efficacy of surface dispersant application in the CNOOC Project Area are related primarily to environmental conditions in which aircraft or spray-vessels can be used safely. Daylight hours and good visibility are required for aerial application of surface dispersant and vessel-mounted spray brooms require a suitable sea state. High wind and wave conditions not only affect the safety of surface dispersant operations, they also affect the efficacy of dispersants. At wave heights above 3-4 m, breaking waves entrain oil in the water column and prevent appropriate interaction between the oil and the dispersant (NOAA 2010; Slaughter et al. 2017). From a commercial fisheries perspective, the use of dispersants may not be as favourable as other response options because of public perception related to taint.

Although CNOOC has supply vessels that could be equipped to carry and apply dispersants, it does not currently have a stock of dispersants in Newfoundland and Labrador, neither onshore nor on its supply vessels.

3.5.2 Subsea Dispersant Injection

SSDI is used to inject dispersant directly into the flow of subsea oil released from a fixed location. This response option was first conducted during the DWH incident in 2010. Dispersants were applied almost continuously at the well head opening near the sea floor. Vessels were used to deliver dispersants at the release point via tubing. Remotely operated vehicles (ROVs) are typically used to oversee the operation, deploy injection equipment to the release point, and assist in monitoring to ensure dispersant efficacy. Although configuring and loading a vessel to support SSDI takes several days, SSDI operations are less sensitive to weather than other response methods and can therefore continue 24 hours a day. In the SIMA GAI, it is assumed that SSDI operations could be deployed by Day 10 of a subsea spill.

Chemical dispersion principles discussed for surface application generally apply to SSDI, with some key differences. For example, SSDI increases the oil encounter rate due to the method of application being at the location of the source, compared to at the sea surface (see Figures 3-1 and 3-2). This high encounter rate does allow for a decrease in DOR from 1:20 seen in SDA to 1:100 (Brandvik et al. 2014; IPIECA and IOGP 2015b; API 2017). As the dispersant will be injected to the source location near the sea floor, the dispersed oil will dilute vertically and horizontally in a much greater volume of water. This rapid dilution of the oil at the source would result in lower concentrations of dispersed oil entering the marine environment compared to those associated with SDA, in which the dispersed oil is typically limited to 10 m of vertical dilution. During the DWH incident, dispersed oil concentrations at 1 km from the well head and at a depth of 1,200 m were consistently below 1 ppm (IPIECA and IOGP 2015a; Slaughter et al. 2017).

The efficacy of SSDI use can be monitored via visual and sensor techniques at the subsea injection site by ROVs (e.g., underwater camera and particle size detector) and by aircraft observations or satellite imagery at the surface. Since effective SSDI operations reduce VOC levels at the water surface, air monitoring near the release point can also provide an indication of dispersant efficacy. Ideally, adjustments to the initial 1:100 DOR, in conjunction with monitoring, should allow optimization of the dispersant injection rate for a particular oil type and flow rate (IPIECA and IOGP 2015b; API 2017).

Benefits: The principal benefits of SSDI include improved worker safety, higher oil encounter rates, lower DORs, lower sensitivity to weather conditions, lack of daylight restrictions, and the ability to operate continuously.

SSDI reduced the size and thickness of surface slicks during the DWH spill response and reduced VOC levels at the surface. VOC reduction lowers the risk to workers in the immediate release area by reducing the potential for fire, explosions, and inhalation. Ultimately, SSDI allows workers to more effectively engage in well capping and source control operations. As SSDI operations are conducted by ROVs at the sea floor, the potential for worker exposure to oil, dispersants, and dispersed oil is lower compared to other response options (IPIECA et al. 2017). Once SSDI vessels and equipment are in place, dispersant injection operations can run continuously in much higher sea states than either ISB (limited to <1 m) or mechanical recovery (limited to <2 m). In the CNOOC Project Area, MetOcean conditions could hamper SSDI logistics when sea states are above 5 m.

Limitations: The acquisition and transport of vessels, equipment and dispersant supplies to conduct SSDI operations at the response site can take considerable time–approximately 10 days. After the dispersant and ROV operation vessels are deployed to the well location and a dispersant manifold is positioned on the dispersant supply vessel, coiled tubing is deployed to the seafloor via ROVs. A minimum of two ROVs are needed for this operation, one for dispersant injection into the oil release point, and the other for observation and the determination of dispersant efficacy.

Public perception of SSDI is often negative due to misunderstandings about dispersed oil fate and transport, and the role that it may play in the marine environment. Since dispersed oil occurs in the water column and cannot be readily seen, the public may incorrectly assume that the oil is sinking rather than dispersing and will subsequently surface in the future. However, during the DWH response, continuous sampling and monitoring at thousands of locations failed to detect the presence of undispersed subsea oil slicks (OSAT 2010).

4.0 Resources of Concern

The framework for identifying Resources of Concern (ROC) for the CNOOC Flemish Pass SIMA requires understanding of the ecosystem health, human safety, and socioeconomic concerns in the Project Area and GAI. Within this framework, key resources are identified using physical, biological, and socio-economic data related to the Project Area and GAI presented in the EIS (Nexen 2018) and the three relevant SEAs (C-NLOPB 2008, 2010, 2014).

In addition, key resources have been identified through CNOOC's engagement with various government regulators, Indigenous Groups (IGs), and stakeholders during development of the EIS (Nexen 2018). The engagement process also provides a forum for understanding stakeholders' concerns and priorities, which are taken into consideration and incorporated in the SIMA's ROCs.

In addition to the information provided in the EIS, the fate and behaviour of oil in the Project Area and GAI are examined to identify resources that may be more vulnerable due to species type, age class, sensitivity to oil, etc. These resources are taken into consideration during the risk assessment phase of the SIMA (Section 6.0).

Under the framework described above, the following ecological and socio-economic ROCs were identified for the CNOOC Flemish Pass SIMA.

1. Fish and Fish Habitat;
2. Marine and Migratory Birds;
3. Marine Mammals;
4. Sea Turtles; and
5. Fisheries.

The constituents of ROCs 1, 2 and 5 include:

- Fish and Fish Habitat ROC includes algae, phytoplankton, zooplankton, ichthyoplankton (i.e., fish eggs and larvae), invertebrate eggs and larvae, juvenile and adult stages of fishes, and invertebrates;
- Marine and Migratory Bird ROC includes seabirds, shorebirds, and waterfowl; and
- Fisheries ROC includes commercial fisheries, Indigenous fisheries, recreational fisheries, and aquaculture.

The selected ROCs/ROC constituents encompass the following Valued Components (VCs) defined, described and assessed in the EIS (Nexen 2018):

- Marine Fish and Fish Habitat (including Species at Risk);
- Marine and Migratory Birds (including Species at Risk);

- Marine Mammals and Sea Turtles (including Species at Risk);
- Sensitive Areas;
- Indigenous Peoples; and
- Fisheries and Other Ocean Uses.

A geographic area, habitat, and brief description of each environmental compartment are included in Table 4-1. They are provided to emphasize the differences between offshore and inshore habitats. The assessment is based on the generalized ecological communities and/or habitat types present in the potentially affected area since this SIMA is intended to consider a holistic protection of the environment, not the protection of individuals or specific species.

Supporting information required to identify species present in the GAI, including seasonal distribution and life stages of wildlife, are summarized in the EIS (Nexen 2018). The EIS also lists species occurring in the area that are designated as *Threatened* or *Endangered* under either the *Species at Risk Act* (SARA) or the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). For ease of use, these tables, which have been updated, are provided in the below sections. Although some of these protected species are rare in the Project Area, they are still considered in the analysis due to their designated status in Canada and elsewhere. Additional areas of potential environmental sensitivity are identified in the EIS. These Sensitive Areas, including Ecologically and Biologically Significant Areas (EBSAs), have been designated because of their biodiversity and ecological importance in Canada's oceans, and the need to proactively conserve and protect marine ecosystem functions for future generations. However, specific Species at Risk (SAR) and Sensitive Areas are not included in the ROC (Table 4-1) or in the Comparative Risk Matrix in Section 6.0 because the components of these areas are already captured under the broader areas, habitats and environmental compartments listed in the ROC Table. Similarly, SAR are already considered when evaluating its broader resource category (e.g., marine and migratory birds) for each habitat being evaluated. Section 6.3 provides more information on how SAR and Sensitive Areas are considered in the SIMA process and the rationale behind it.

In addition to ecological ROCs/ROC constituents, Table 4-1 includes the socio-economic Fisheries ROC since a high level of importance is attached to the constituents of this ROC, as outlined in the EIS. As indicated above, commercial fisheries, indigenous fisheries, recreational fisheries, and aquaculture are included in the Fisheries ROC.

The following sections provide more detail on the ROCs/ROC constituents being considered in this SIMA. Note that the sections for the Fish and Fish Habitat, Marine and Migratory Bird, and Fisheries ROCs are longer and more detailed than those for the Marine Mammal and Sea Turtle ROCs. New data that were not available during the preparation of the EIS (Nexen 2018) and the three supporting SEAs are presented in this document for fish and fish habitat, marine and migratory birds, and fisheries, thereby resulting in longer, more detailed sections.

Table 4-1. Resources of Concern developed for the CNOOC SIMA Geographic Area of Interest.

Habitat Compartment	Specific Habitat	Description of Specific Habitat	Ecological and Socio-Economic Resources of Concern
Shoreline	Intertidal zone and shallow subtidal zone (i.e., <20 m depth) of Newfoundland mainland and island shoreline with some probability of contact with crude	Marine intertidal zone is defined as the area of the foreshore and seabed that is exposed during low tide and submerged during high tide	Fish and Fish Habitat Marine and Migratory Birds Marine Mammals Fisheries
Continental Shelf (subtidal zone to shelf break)	Sea surface	The sea surface microlayer (SML) is the upper 1 mm of the ocean's surface where exchanges occur between the atmosphere and the ocean	Marine and Migratory Birds Marine Mammals Sea Turtles Fisheries
	Water column (≤20 m depth)	The oceanic mixed layer pelagic environment	Fish and Fish Habitat Marine and Migratory Birds Marine Mammals Sea Turtles Fisheries
	Water column (>20 m depth)	The marine pelagic environment from the mixed layer to the seabed	Fish and Fish Habitat Marine and Migratory Birds Marine Mammals Sea Turtles Fisheries
	Seabed (benthic)	Surficial sediment surface and sub-surface	Fish and Fish Habitat Fisheries
Continental Slope (offshore of shelf break)	Sea surface	The sea surface microlayer (SML) is the upper 1 mm of the ocean's surface where exchanges occur between the atmosphere and the ocean	Marine and Migratory Birds Marine Mammals Sea Turtles Fisheries
	Water column (≤20 m depth)	The oceanic mixed layer pelagic environment	Fish and Fish Habitat Marine and Migratory Birds Marine Mammals Sea Turtles Fisheries
	Water column (>20 m depth)	The marine pelagic environment from the mixed layer to the seabed	Fish and Fish Habitat Marine and Migratory Birds Marine Mammals Sea Turtles Fisheries
	Seabed	Surficial sediment surface and sub-surface	Fish and Fish Habitat Fisheries

4.1 Fish and Fish Habitat

Fish and Fish Habitat has been selected as a ROC due to the ecological and economic importance of its constituents (i.e., fishes, invertebrates, algae, phytoplankton, zooplankton, ichthyoplankton, invertebrate eggs and larvae) within the GAI, and the potential interactions between its constituents and the hypothetical oil release scenario. Fish and fish habitats within the GAI are summarized in Sections 4.1.1–4.1.4.

4.1.1 Pelagic Fish and Fish Habitat

The pelagic environment within the GAI is made up of open ocean waters, including the Flemish Cap and Pass, Orphan Basin (including the Orphan Knoll), Labrador and Grand Banks shelves and slopes, and other oceanic waters beyond the continental shelf. Water depths within the GAI range from the intertidal zone to 5,000+ m. The Flemish Cap, which is characterized by a relatively distinct ecosystem, is separated from the Grand Banks by the Flemish Pass. It is an area of nutrient-rich, highly oxygenated waters that are influenced by the Labrador Current, and it is characterized by high biodiversity relative to nearby shelf habitats (Barrio Frojàn et al. 2012, and Altuna et al. 2013 *in* Nexen 2018). The Grand Banks is also considered an area of high productivity due to mixing from shelf waters, the Labrador Current, and the Gulf Stream, resulting in nutrient rich waters (Bundy et al. 2000, Templeman 2010, and Murilla et al. 2016 *in* Nexen 2018).

Marine plankton is comprised of microscopic marine plants (phytoplankton), invertebrates (zooplankton and invertebrate eggs and larvae), fish eggs and larvae (ichthyoplankton), bacteria, fungi, and viruses (Legendre and Rassoulzadegan 1995, and Suttle 2005 *in* Nexen 2018). Plankton levels near the Flemish Cap are relatively high because the associated anticyclonic gyre contributes to higher temperatures and inorganic nutrients, resulting in higher levels of primary and secondary production (Maillet et al. 2004 *in* Nexen 2018). High concentrations of plankton have also been recorded along shelf systems within the GAI (i.e., the Newfoundland and Labrador Shelves; Pepin et al. 2011; Harrison et al. 2013) and in embayments along the coast of the Avalon Peninsula (e.g., Trinity Bay) (Guillermo et al. 1997; Hudson et al. 2001) and Conception Bay (Parrish et al. 2005). The spring plankton bloom peaks in May on the Flemish Cap, late-March/April on the Grand Banks, and late-spring off Labrador (Fuentes-Yaco et al. 2007 *in* Nexen 2018).While zooplankton abundance mirrors that of phytoplankton, zooplankton communities decline after the peak bloom due to continual predation by other zooplankton, fish, and marine mammals, and the depletion of the phytoplankton food base. Copepods constitute over 80% of the zooplankton assemblage within the GAI (Dalley et al. 2001 and Pepin et al. 2011, 2015 *in* Nexen 2018). Although ichthyoplankton communities are dominated by capelin, sand lance, lanternfish, and Artic cod along the Northeastern Newfoundland Shelf and Grand Banks, survey tows also indicate the presence of commercial species such as Atlantic cod, redfish, and American plaice (Dalley and Anderson 1998, and Dalley et al. 2000 *in* Nexen 2018). Commercially important species, including larval and adult male northern shrimp and larval redfish, depend on copepod availability as a main food source (Fuentes-Yaco et al. 2007 *in* Nexen 2018).

Key pelagic invertebrate species in the GAI are described in Section 6.1.6.4 of the EIS (Nexen 2018). Northern shrimp *(Pandalus borealis)*, a valuable commercial fishery target species, are highly abundant in the Flemish Pass and on the Northeastern Grand Banks (Dawe et al. 2012 *in* Nexen 2018). Trawl catches by the *RV Investigator* on the Grand Banks indicate that squid (*Illex illecebrosus)* have been found in high abundance during their seasonal migration in early May (Squires 1957), at which time they are an important opportunistic food source for adult Atlantic cod off the Flemish Cap (Casas and Paz 1996). Jellyfish have been found in abundance on the Newfoundland Shelf (Brotz et al. 2012) and are primary prey for leatherback sea turtles (*Dermochelys coriacea*) (DFO 2016a).

Sections 6.1.7 of the EIS (Nexen 2018), 4.2.1.6 of the Eastern Newfoundland SEA (C-NLOPB 2014), 4.2, 4.3, and 4.8 of the Labrador Shelf SEA (C-NLOPB 2008), and 3.2 of the Southern Newfoundland SEA (C-NLOPB 2010) describe the key marine finfish species that occur within the GAI. Predominant pelagic finfishes that occur in the GAI are provided in Table 4-2. While capelin are typically residents within the GAI, larger-bodied predators, such as swordfish, tunas, and sharks, and smaller-bodied fishes, such as salmon, eels, mackerel, and herring, are migratory species and therefore transients within the GAI (C-NLOPB 2014; Nexen 2018).

Table 4-2. Predominant pelagic finfishes within the GAI.

Common Name	Scientific Name
Albacore tuna	*Thunnus alalonga*
Atlantic bluefin tuna	*Thunnus thynnus*
Bigeye tuna	*Thunnus obesus*
American eel	*Anguilla rostrata*
Atlantic herring	*Clupea harengus*
Atlantic mackerel	*Scomber scombrus*
Atlantic salmon	*Salmo salar*
Capelin	*Mallotus villosus*
Basking shark	*Cetorhinus maximus*
Blue shark	*Prionace glauca*
Porbeagle shark	*Lamna nasus*
Greenland shark	*Somniosus microcephalus*
Shortfin mako shark	*Somniosus microcephalus*
White shark	*Carcharodon Carcharias*
Lanternfish	Myctophidae
Swordfish	*Xiphias gladius*

4.1.1.1 Pelagic Fish Species at Risk

Pelagic fishes in the GAI that are considered species at risk are listed in Table 4-3.

Table 4-3. Pelagic fishes that may occur within the GAI and are identified as species at risk under the SARA, COSEWIC, NL *Endangered Species Act* (ESA), and/or International Union for the Conservation of Nature (IUCN).

Species	SARA			COSEWIC			ESA			IUCN				
	E	T	SC	E	T	SC	E	T	V	CE	E	V	NT	LC
American eel (*Anguilla rostrata*)					X				X		X			
Atlantic Sturgeon (*Acipenser oxyrinchus*) St. Lawrence populations					X									
Maritimes populations					X									
Lanternfish (Myctophidae)														X
Basking shark (*Cetorhinus maximus*) Atlantic population						X						X		
Porbeagle shark (*Lamna nasus*)				X								X		
White shark (*Carcharodon carcharias*) Atlantic population	S1			X								X		
Shortfin mako shark (*Isurus oxyrinchus*) Atlantic population				X							X			
Atlantic bluefin tuna (*Thunnus thynnus*)				X							X			
Albacore tuna (*Thunnus alalonga*)													X	
Bigeye tuna (*Thunnus obesus*)												X		
Skipjack tuna (*Katsuwonus pelamis*)														X
Atlantic salmon (*Salmo salar*) Inner Bay of Fundy population	S1			X										X
South Newfoundland population					X									X
Quebec Eastern North Shore population						X								X
Quebec Western North Shore population						X								X
Anticosti Island population				X										X
Inner St. Lawrence population						X								X
Gaspe-Southern Gulf of St. Lawrence population						X								X
Eastern Cape Breton population				X										X
Nova Scotia Southern Upland population				X										X
Outer Bay of Fundy population				X										X

Note: E = Endangered; T = Threatened; SC = Special Concern; V = Vulnerable; CE = Critically Endangered; NT = Near Threatened; LC = Least Concern; S = Schedule.

Source: COSEWIC (2019); IUCN (2019); GNL (2019); SARA (2019).

4.1.2 Demersal Fish and Fish Habitat

4.1.2.1 Coastal Demersal Fish Habitat

The coastline of Newfoundland and Labrador that occurs within the GAI is quite variable. It features fjords and fjord-like bays (e.g., Trinity, Bonavista, and Placentia Bays), cliffs, rocky outcrops, lagoons (e.g., Burin Peninsula), tidal inlets (e.g., Gilbert Bay), and beaches mainly comprised of muddy gravels and sands (e.g., Fortune Bay), pebbles, cobbles, and boulders (Forbes 1984; Wroblewski et al. 2007). Macroalgae and eelgrass beds are important ecosystem features in coastal areas given how they enhance productivity and provide areas of refuge (Amec 2014 *in* C-NLOPB 2014). Generally, macroalgae and seagrasses are limited to water depths of ≤50 m due to their need for adequate light to photosynthesize (Anderson et al. 2002 *in* Nexen 2018). The eastern Newfoundland shore has a wave-exposed rocky coast where fleshy algae is abundant (Keats et al. 1987). The macroalgal canopy provides benthic fishes, most notably juvenile cod *(Gadus morhua)*, with protective cover from predation (Keats et al. 1987). Eelgrasses *(Zostera marina)* also provide refuge for many commercially important benthic species (e.g., juvenile cod and American lobster [*Homarus americanus*]*)* larvae (Karnofsky et al. 1989; Matheson et al. 2016), as well as feeding grounds and resting areas for some marine fishes (e.g., Atlantic salmon (Catto et al. 1999). Due to their intricate root systems, eelgrasses have also been found to stabilize sandy sediments erosion (Catto et al. 1999). These habitats are at risk due to the invasive green crab *(Carcinus maenas)* which has been found to uproot seagrasses when foraging for in-faunal prey (Matheson et al. 2016).

4.1.2.2 Offshore Demersal Fish Habitat

Offshore, the Flemish Pass is a north-east – south-west trending mid-slope sedimentary basin that separates the Grand Banks from the Flemish Cap (Nexen 2018). The Flemish Pass is characterized by depths of up to 1,300 m and is bounded by the Flemish Cap to the east and the Grand Banks to the west. The Grand Banks extend northwards to the Northeast Newfoundland Shelf where depths reach 300 m, and to the Labrador Shelf and Orphan Basin with depths of over 4,000 m (C-NLOPB 2014). South of the Grand Banks lies the Newfoundland Basin, where depths within the GAI exceed 5,000 m. Substrates within the GAI range from exposed bedrock and boulders on the Avalon Peninsula and around the Flemish Cap to gravel around the coasts of Newfoundland and Labrador, and coarser-grained sediments throughout the central and western sides of the Flemish Pass (Marshall et al. 2014 *in* Nexen 2018). The western portion of the Flemish Pass is comprised of muds and detritus (Piper and Campbell 2005 *in* Nexen 2018) and muddy-sands and sandy-muds are found on the seabed around the Flemish Cap and Orphan Basin. The Grand Banks substrate is mainly comprised of sand and muddy-sand (Nexen 2018).

4.1.2.3 Benthic Invertebrates and Demersal Fishes

Benthic invertebrates found within the GAI are described in Section 6.1.6 of the EIS (Nexen 2018). The distribution of benthic invertebrates is highly dependent on oceanographic parameters (e.g., water depth, substrate type, temperature, currents) and biological conditions (e.g., suitable habitat and community assemblages) (Baker et al. 2012, Beazley and Kenchington 2015, Guijarro et al. 2016, Knudby et al. 2013, and Murillo et al. 2016 *in* Nexen 2018). Benthic invertebrates in the GAI that are important for commercial fisheries include snow crab and northern shrimp (Dawe et al. 2012 *in* Nexen 2018). Species found in deep-sea ecosystems typically have lower metabolic and recruitment rates, later maturity, slower growth rates, and experience greater longevity compared to those found in shallower waters, making them less resilient to environmental change and anthropogenic disturbance (Smith et al. 1994, Beazley et al. 2013a, McClain and Schalcher 2005, and Murillo et al. 2016 *in* Nexen 2018). Predominant benthic invertebrate and demersal finfish species and/or groups that occur within the offshore region of the GAI are provided in Tables 4-4 and 4-5.

Table 4-4. Predominant offshore benthic invertebrates occurring within various regions of the GAI.

Region	Subregion	Invertebrate Species/ Group
Grand Banks	Shelf / Slope Edge (70–100 m)	Infauna: Polychaetes (*Prionospio steenstrupi, Chaetozone setosa, Spio filicornis, Nothria conchylega*); Amphipods (*Priscillina armata*); Bivalves (*Macoma calcarea*); Gastropods; Crustaceans; Isopods; Echinoderms (*Echinarachnius parma*) Epifauna: Polychaetes (Sabellidae); Bivalves (*Chlamys islandica*); Gastropods (*Buccinidae*); Crustaceans (Majidae, *Chionoecetes opilio*); Echinoderms (Ophiuroidea, Asteroidea, *Echinarachnius parma, Strongylocentrotus pallidus*)
	Shelf / Slope Edge (120–146 m)	Infauna: Bivalves (*Cyrtodaria siliqua, Macoma calcarea*); Echinoderms (*Echinarachnius parma, Strongylocentrotus pallidus*)
	Shelf / Slope Edge (120–250 m)	Epifauna: Echinoderms (*Echinarachnius parma, Ophiura sarsi, Strongylocentrotus pallidus*); Bivalves (*Astarte borealis*); Crustaceans (*Chionoecetes opilio, Pandalus borealis, Atlantopandalus propinqvus*); Cnidaria (*Gersemia* sp.)
Flemish Cap	Shelf / Slope Edge (200–340 m)	Epifauna: Echinoderms (*Ceramaster granularis*); Cnidaria (*Hormathia digitata*)
	Shelf / Slope Edge (300–500 m)	Epifauna: Echinoderms (*Brisaster fragilis, Ctenodiscus crispatus*)
Flemish Pass	Middle Slope (500–900 m)	Epifauna: Cnidaria (*Flabellum alabastrum, Heteropolypus sol* sp.*, Funiculina quadrangularis, Acanella arbuscula, Stauropathes artica*)
	Middle-Deep Slope (800–1,200 m)	Epifauna: Annelids; Sponges; Arthropods; Chordates; Echinoderms (*Phormosoma placenta, Bathybiaster vexillifer, Zoroaster fulgens*, cnidaria; *Anthoptilum grandiflorum, Halipteris finmarchica, Funiculina quadrangularis, Pennatula aculeata*
	Middle-Deep Slope (700–1,400 m)	Epifauna: Sponges (*Stryphnus fortis, Geodia parva-phlegraei, Craniella cranium, Geodia barretti, Stelletta normani*)
Orphan Basin	Upper Slope (300–700 m)	Infauna: Polychaetes; Bivalves Epifauna: Echinoderms (Ophiuroids); Sponges; Bryozoans; Brachiopods (on cobbles/boulders)
	Middle Slope (700–2,000 m)	Infauna: Polychaetes

Region	Subregion	Invertebrate Species/ Group
		Epifauna: Cnidarians; Echinoderms (Ophiuroids)
	Lower Slope (2,000–2,500 m)	Infauna: Polychaetes Epifauna: Echinoderms (Ophiuroids); Molluscs

Source: Nexen (2018).

Table 4-5. Predominant demersal finfish occurring within various regions of the GAI.

Finfish Species/ Group	Predominant Region within GAI
Atlantic cod (*Gadus morhua*)	Coastal, Grand Banks Shelf, Flemish Cap, Southeast Shoal and the Tail of the Banks, Virgin Rocks, Burgeo Banks EBSAs (spring-fall); <500 m
Acadian redfish (*Sebastes fasciatus*)	Grand Banks Shelf, Flemish Cap, Southwest Shelf Edge and Slope EBSA (spring); 250–600 m
Deepwater redfish (*Sebastes mentella*)	Grand Banks Shelf, Flemish Pass, Flemish Cap, Southwest Shelf Edge and Slope EBSA (spring); 250–1000 m
Golden redfish (*Sebastes norvegicus*)	Grand Banks Shelf, Flemish Cap, Southwest Shelf Edge and Slope EBSA (spring); 250–600 m
Common grenadier (*Nezumia bairdii*)	Grand Banks Shelf, Flemish Pass, Flemish Cap; 250–1000+ m
Roughhead grenadier (*Macrourus berglax*)	Grand Banks Shelf, Flemish Pass, Flemish Cap; 250–1000+ m
Roundnose grenadier (*Coryphaenoides rupestris*)	Grand Banks Shelf, Flemish Pass, Flemish Cap; 600–1000+ m
Longnose eel (*Synaphobranchus kaupii*)	Grand Banks Shelf, Flemish Pass, Flemish Cap; 250–1000+ m
Spotted wolffish (*Anarhichas minor*)	Flemish Cap; 250–600 m
Greenland halibut (*Reinhardtius hippoglossoides*)	Grand Banks Shelf, Flemish Pass, Flemish Cap, Northeast Shelf and Slope EBSA (spring); 250–1000+ m
White hake (*Urophycis tenuis*)	Grand Banks Shelf, Flemish Pass, Flemish Cap, Laurentian Channel (spring), Southwest Shelf Edge and Slope EBSA (spring); 250–600 m
Blue hake (*Antimora rostrata*)	Grand Banks Shelf, Flemish Pass, Flemish Cap; 600–1000+ m
Smalleyed rabbitfish (*Hydrolagus affinis*)	Grand Banks Shelf, Flemish Pass; 600–1000+ m
Thorny skate (*Amblyraja radiata*)	Flemish Cap; 250–600 m
Black dogfish (*Centroscyllium fabricii*)	Grand Banks Shelf, Flemish Pass, Flemish Cap; 600–1000+ m
Demon catshark (*Apristurus* sp.)	Flemish Cap; >600 m

Source: C-NLOPB (2014); Nexen (2018).

4.1.2.4 Demersal Fish Species at Risk

Demersal fish species at risk that occur in the GAI are provided in Table 4-6.

Table 4-6. Demersal fishes that occur within the GAI and are identified as species at risk under the SARA, COSEWIC, NL ESA, and/or IUCN.

Species	SARA			COSEWIC			ESA			IUCN				
	E	T	SC	E	T	SC	E	T	V	CE	E	V	NT	LC
Banded killifish (*Fundulus diaphanus*) Newfoundland populations			S1			X			X					X
White hake (*Urophycis tenuis*) Atlantic and Northern Gulf of St. Lawrence population					X									
American plaice (*Hippoglossoides platessoides*) Newfoundland and Labrador population					X									
Atlantic halibut (*Hippoglossus hippoglossus*)											X			
Lumpfish (*Cyclopterus lumpus*)					X									
Barndoor skate (*Dipturus laevis*)											X			
Smooth skate (*Malacoraja senta*) Funk Island Deep population				X							X			
Laurentian-Scotian population						X					X			
Thorny skate (*Amblyraja radiata*)						X						X		
Winter skate (*Leucoraja ocellata*) Eastern Scotian Shelf – Newfoundland population				X							X			
Spinytail skate (*Bathyraja spinicauda*)													X	
Greenland shark (*Somniosus microcephalus*)													X	
Acadian redfish (*Sebastes fasciatus*) Atlantic population					X						X			
Bonne Bay population						X					X			
Deepwater redfish (*Sebastes mentella*) Northern population					X									X
Gulf of St. Lawrence – Laurentian Channel population				X										X
Spiny dogfish (*Squalus acanthias*) Atlantic population						X						X		
Black dogfish (*Centroscyllium fabricii*)														X
Portuguese dogfish (*Centroscymnus coelolepis*)													X	
Striped (Atlantic) wolffish (*Anarhichas lupus*)			S1			X								
Northern wolffish (*Anarhichas denticulatus*)		S1			X									

Species	SARA			COSEWIC			ESA			IUCN				
	E	T	SC	E	T	SC	E	T	V	CE	E	V	NT	LC
Spotted wolffish (*Anarhichas minor*)		S1			X									
Atlantic cod (*Gadus morhua*) Newfoundland and Labrador population				X								X		
Haddock (*Melanogrammus aeglefinus*)												X		
Cusk (*Brosme brosme)*				X										
Roundnose grenadier *(Coryphaenoides rupestris)*				X						X				
American lobster *(Homarus americanus)*														X

Note: E = Endangered; T = Threatened; SC = Special Concern; V = Vulnerable; CE = Critically Endangered; NT = Near Threatened; LC = Least Concern; S = Schedule.

Source: COSEWIC (2019); IUCN (2019); GNL (2019); SARA (2019).

4.1.3 Corals and Sponges

Deep-sea corals and sponges are benthic, slow-growing, immobile invertebrates that inhabit stable environments. Therefore, they are particularly sensitive to anthropogenic stresses (Murillo et al. 2011, and Beazley el. 2013a *in* Nexen 2018), such as trawling and infrastructure development for oil and gas, which can have long-lasting effects on recovery (Campbell and Simms 2009, Watanabe et al. 2009, Barrio Frojàn et al. 2012, Bell et al. 2015, and Clark et al. 2016 *in* Nexen 2018). Corals, sea pens, and sponges can serve as important habitats for fishes and invertebrates, can provide structural integrity to the deep-sea environment, and can act as refuge and foraging areas (Watanabe et al. 2009). High biodiversity has been associated with these areas (Beazley et al. 2013; Buhl-Mortensen et al. 2015).

Corals inhabiting the slopes of the Flemish Pass, Flemish Cap, and Grand Banks are most abundant at the 600–1300 m depth range (Guijarro et al. 2016 *in* Nexen 2018). Slopes on the western side of the Flemish Pass and eastern side of the Flemish Cap are important habitats for large gorgonians, and all slopes associated with the Flemish Cap are important for black corals (Knudby et al. 2013).

Soft corals, particularly *Duva florida* and *Anthomastus* spp., are the most common by-catch-deep-water corals within the GAI (Nexen 2018). At least 56 species of corals and sea pens have been identified within the GAI (Gilkinson and Edinger 2009, Wareham 2009, Beazley et al. 2013a, Murillo et al. 2013, Vàzquez et al. 2013, Baillon et al. 2014a,b, and Beazley and Kenchington 2015 *in* Nexen 2018). Commonly occurring coral and sponge species within the GAI are described in Section 6.1.6.5 of the EIS (Nexen 2018).

4.1.4 Sensitive Fish Habitat

Sensitive fish and invertebrate habitats within the GAI are described in Section 6.1.1.10, Identified Important and Sensitive Ecological Environments, and Section 6.4, Special Areas, of the CNOOC EIS (Nexen 2018). Additional information is provided in Section 4.11 of the Labrador Shelf SEA (C-NLOPB 2008), Section 4.2.4 of the Eastern Newfoundland SEA (C-NLOPB 2014), and Section 3.8 of the Southern Newfoundland SEA (C-NLOPB 2010). Sensitive fish habitat is considered in this SIMA due to its ecological, historical, socio-cultural and/or conservation importance, and the potential for it to be affected by the hypothetical release scenario. Sensitive fish habitats within the GAI are provided below.

4.1.4.1 Sensitive Coastal Fish Habitat

Sensitive coastal fish habitats within the GAI are provided in Table 4-7 and Figure 4-1.

Table 4-7. Sensitive coastal fish habitat within the GAI.

Sensitive Habitat	Governing Body	Name	Source
Ecologically and Biologically Significant Areas (EBSAs)	Government of Canada	[I] Hamilton Inlet[1] [II] Gilbert Bay[1] [III] Grey Islands [IV] Fogo Shelf[1,2] [1] Bonavista Bay[a] [2] Baccalieu Island[a] [3] Smith Sound[1,3] [4] Eastern Avalon [5] St. Mary's Bay[a] [6] Placentia Bay[1,3]	1, 2
Provincial Protected Areas	Government of Newfoundland and Labrador	[A] Burnt Cape Ecological Reserve [B] Pistolet Bay Provincial Park [C] Hare Bay Islands Ecological Reserve [D] Dildo Run Provincial Park [E] Funk Island Ecological Reserve [F] Deadman's Bay Provincial Park [G] Windmill Bight Provincial Park [H] Dungeon Provincial Park [I] Bellevue Beach Provincial Park [J] Baccalieu Island Ecological Reserve [K] Marine Drive Provincial Park [L] Witless Bay Ecological Reserve [M] La Manche Provincial Park [N] Chance Cove Provincial Park [O] Mistaken Point Ecological Reserve [P] Cape St. Mary's Ecological Reserve [Q] Gooseberry Cove Provincial Park [R] Jack's Pond Provincial Park [S] Lawn Bay Ecological Reserve	3
National Park	Government of Canada	Terra Nova National Park	4
Marine Protected Areas (MPAs)	Government of Canada	Gilbert Bay Marine Protected Area[1,2,3] Eastport Marine Protected Area[1,2,3]	5
Marine Refuges	Government of Canada	[a] Glover's Harbour Lobster Closure[1] [b] Mouse Island Lobster Closure[1]	5

Sensitive Habitat	Governing Body	Name	Source
		[c] Gander Bay Lobster Closure[1] [d] Gooseberry Island Lobster Closure[1]	
Federal Fishing Closure Area	Government of Canada	Eastport Peninsula Lobster Management Area (EPLMA) [1,2,3]	6
Candidate National Marine Conservation Areas (NMCAs)[b]	Government of Canada	Labrador Coast (B) (Proposed NMCA) Unknown 17 (Preliminary Region Without Studies [RWS])	7
Preliminary Representative Marine Areas (RMAs)	Government of Canada	[i] Northwestern Conception Bay[1] [ii] Southern Coast of Burin Peninsula	7

Notes:

[1] Important reproduction area; [2] important feeding area; [3] important nursery area.

[a] Canadian Science Advisory Secretariat document describing EBSA not yet released.

[b] Supporting documentation not yet released by Parks Canada describing candidate NMCAs.

Source: [1] Wells et al. (2017a); [2] N. Wells, Biologist, Aquatic Resources Division, DFO, pers. comm., 4 February 2019; [3] GNL (2018); [4] GoC (2018); [5] GoC (2019); [6] DFO (2013); [7] C. Pierce, Ecosystems Geomatics Technician, Protected Areas Establishment Branch, Parks Canada, pers. comm., 28 September 2018.

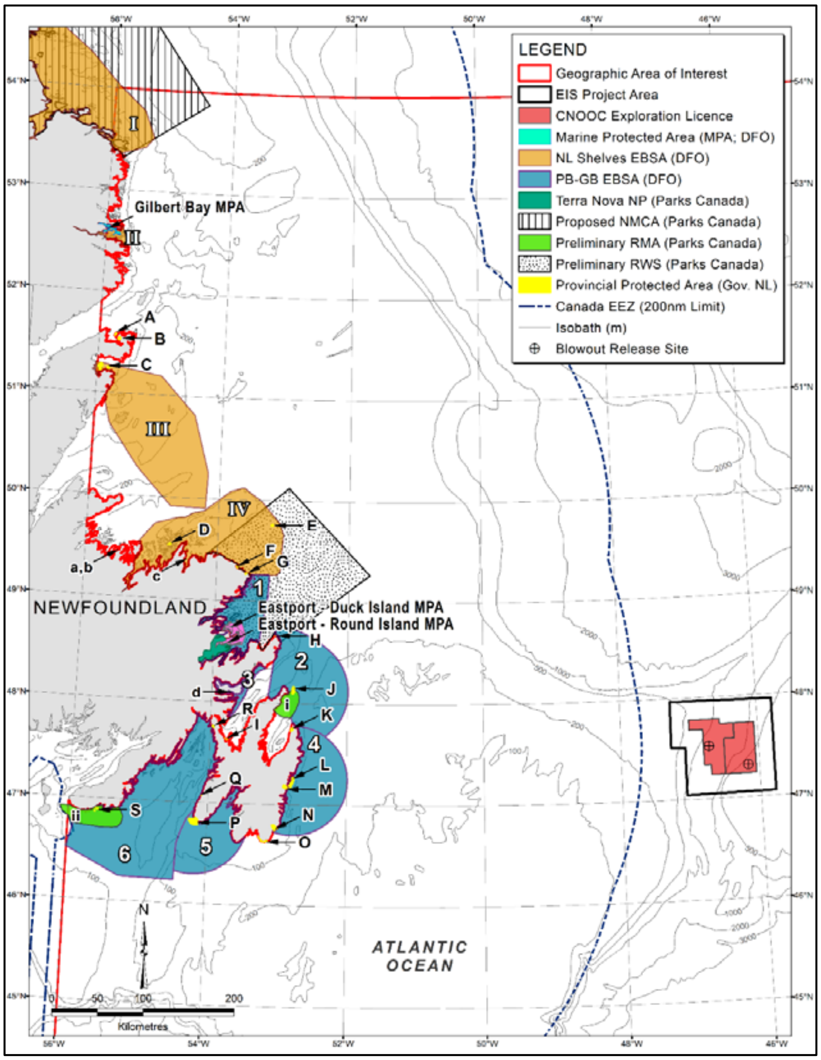


Figure 4-1. Sensitive coastal fish habitat within the GAI (alpha/numeric labels are shown in brackets in Table 4-7).

4.1.4.2 Sensitive Offshore Fish Habitat

Sensitive offshore fish habitats within the GAI that could be affected by an oil spill are provided in Table 4-8 and Figures 4-2 and 4-3.

Table 4-8. Sensitive offshore fish habitat within the GAI.

Sensitive Habitat	Governing Body	Name	Source
Ecologically and Biologically Significant Areas (EBSAs)[a]	Government of Canada	[1] Hamilton Inlet[1] [2] Labrador Marginal Trough [3] Labrador Slope [4] Grey Islands [5] Fogo Shelf[1,2] [6] Notre Dame Channel [7] Orphan Spur [A] Bonavista Bay[b] [B] Northeast Slope[2] [C] Baccalieu Island[b] [D] Eastern Avalon [E] St. Mary's Bay[b] [F] Placentia Bay[1,3] [G] Virgin Rocks[1] [H] Haddock Channel Sponges[b] [I] Lilly Canyon-Carson Canyon[1,2] [J] Southwest Slope[1,2] [K] Southeast Shoal[1,2,3]	1, 2
EBSAs	Convention on Biological Diversity	[I] Orphan Knoll[1,2,3] [II] Slopes of the Flemish Cap and Grand Bank [III] Southeast Shoal and Adjacent Areas on the Tail of the Grand Bank[1,3]	3
Marine Refuges / Federal Fishing Closure Areas	Government of Canada	Hawke Channel Closure Funk Island Deep Closure Northeast Newfoundland Slope Closure Division 3O Closure	4, 5
Voluntary Industry Closure Area	Fishing Industry	Bonavista Cod Box[1,3]	6
Candidate National Marine Conservation Areas (NMCAs)[c]	Government of Canada	Labrador Coast (B) (Proposed NMCA) Unknown 17 (Preliminary Region Without Studies [RWS])	7
Preliminary Representative Marine Areas (RMAs)	Government of Canada	[a] Virgin Rocks[1] [b] South Grand Bank Area	7
Seasonal Shrimp Closure Area[d]	NAFO	Within NAFO Division 3M (also includes a portion of 3L)	8
Vulnerable Marine Ecosystem (VME) Closures: Seamount Closures	NAFO	Orphan Knoll Newfoundland Seamounts Fogo Seamounts 1 Fogo Seamounts 2	9
VME Closures: Sponge, Coral and Sea Pen Closures	NAFO	Tail of the Bank (1) Flemish Pass / Eastern Canyon (2) Beothuk Knoll (3) Eastern Flemish Cap (4) Northeast Flemish Cap (5) Sackville Spur (6) Northern Flemish Cap (7) Northern Flemish Cap (8)	9

Sensitive Habitat	Governing Body	Name	Source
		Northern Flemish Cap (9) Northwest Flemish Cap (10) Northwest Flemish Cap (11) Northwest Flemish Cap (12) Beothuk Knoll (13) 3O Coral Closure	
Critical Habitat	Government of Canada	Northern Wolffish (proposed) [1,2,3] Spotted Wolffish (proposed) [1,2,3]	10

[1] Important reproduction area; [2] important feeding area; [3] important nursery area.
[a] Some EBSAs are also listed under Coastal Sensitive Fish Habitat (see Table 4-7), as they include coastal and offshore elements.
[b] Canadian Science Advisory Secretariat document describing EBSA not yet released.
[c] Supporting documentation not yet released by Parks Canada describing candidate NMCAs.
[d] No vessel is permitted to fish for shrimp within Closure Area between 1 June and 31 December.
Source: [1] Wells et al. (2017a); [2] N. Wells, Biologist, Aquatic Resources Division, DFO, pers. comm., 4 February 2019; [3] CBD (2015); [4] GoC (2019); [5] DFO (2019); [6] C-NLOPB (2014); [7] C. Pierce, Ecosystems Geomatics Technician, Protected Areas Establishment Branch, Parks Canada, pers. comm., 28 September 2018; [8] NAFO (2019a); [9] NAFO (2019b); [10] DFO (2018a).

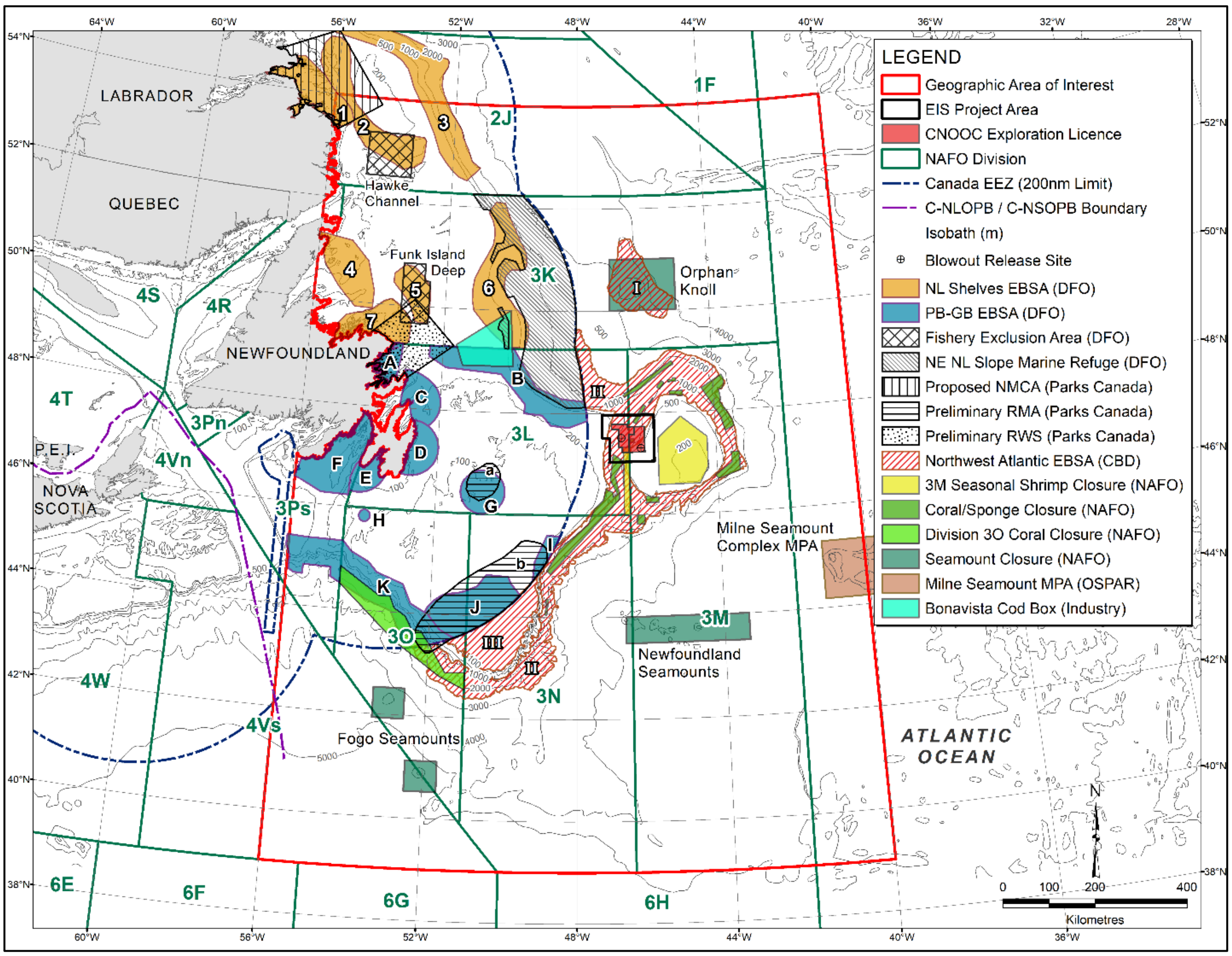


Figure 4-2. Sensitive offshore fish habitat within the GAI (alpha/numeric labels are shown in brackets in Table 4-8).

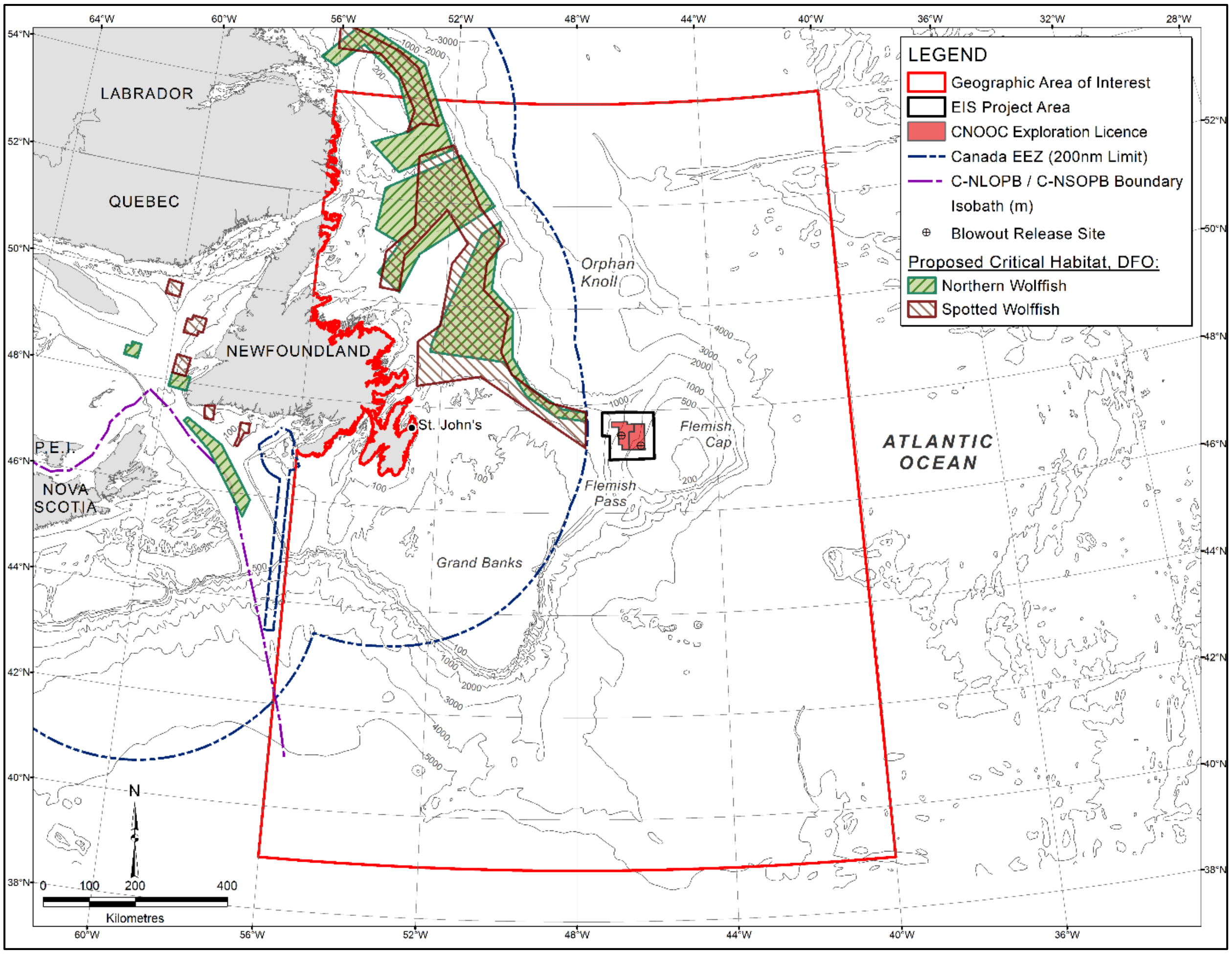


Figure 4-3. Proposed northern and spotted wolffish critical habitat within the GAI.

4.2 Fisheries

Fisheries within the GAI are described in Sections 7.2 of the EIS (Nexen 2018), 4.3.4 of the Eastern Newfoundland SEA (C-NLOPB 2014), 3.3.1 of the Southern Newfoundland SEA (C-NLOPB 2010), and 4.10 of the Labrador Shelf SEA (C-NLOPB 2008). The federal *Fisheries Act* has jurisdiction over Canada's inland and coastal fisheries and protects fish and fish habitat from destructive activities in inland and marine waters out to the 200-nm Economic Exclusive Zone (EEZ). The NAFO Convention Area beyond the EEZ regulates the groundfish, shrimp, and pelagic squid fisheries. There is currently a moratorium on fisheries for cod in NAFO Divisions (Div.) 3LNO, redfish in Sub-area 2 and Div. 1F3K, American plaice in Div. 3LMNO, witch flounder in Div. 3L, capelin in Div. 3NO, and shrimp in Div. 3LNO (NAFO 2019c). Due to the socio-economic importance of fishing activities within the GAI and their potential interaction with oil from a spill scenario, they are included as a ROC.

The GAI overlaps NAFO Div. 1F, 2J, 3KLMNOPs, 4R, and 4RVs, which are further subdivided into Unit Areas (UAs; Table 4-9; Figure 4-4). Inshore UAs include those with coastal components, as inshore fishing occurs near land, with most activity typically within ~25 km from shore (e.g., DFO 2018b). While numerous fisheries are conducted year-round within the GAI, some are only conducted during specific seasons, such as the snow crab fishery which typically occurs between April and July (DFO 2018c; NAFO 2019a). Within the GAI, most fisheries are conducted during the spring and summer months (see Section 7.2.4.5 of the EIS [Nexen 2018]). Domestic demersal and pelagic commercial fisheries conducted within the GAI during 2016 and 2017 are summarized in Sections 4.2.1 and 4.2.2. Indigenous fisheries and aquaculture are discussed in Sections 4.2.3 and 4.2.4, respectively.

Table 4-9. NAFO Divisions and Unit Areas entirely or partially within the GAI.

Division	Unit Area
1F	1F
2J	2Jd, 2Je, 2Jf, 2Jg, 2Ji, 2Jj, 2Jl, **2Jm,** 2Jn
3K	**3Ka**, 3Kb, 3Kc, **3Kd**, 3Ke, 3Kf, 3Kg, **3Kh**, **3Ki**, 3Kk
3L	**3La**, **3Lb**, 3Lc, 3Ld, 3Le, **3Lf**, 3Lg, 3Lh, 3Li, **3Lj, 3Lq**, 3Lr, 3Ls, 3Lt
3M	3Ma, 3Mb, 3Mc, 3Md, 3Mm
3N	3Na, 3Nb, 3Nc, 3Nd, 3Ne, 3Nf, 3Nn
3O	3Oa, 3Ob, 3Oc, 3Od, 3Oe, 3Of
3Ps	**3Psb**, **3Psc**, 3Psf, 3Psh
4R	**4Ra**
4Vs	4Vsc, 4Vse, 4Vsv

Note: Emboldened Unit Areas include coastal components within the GAI.

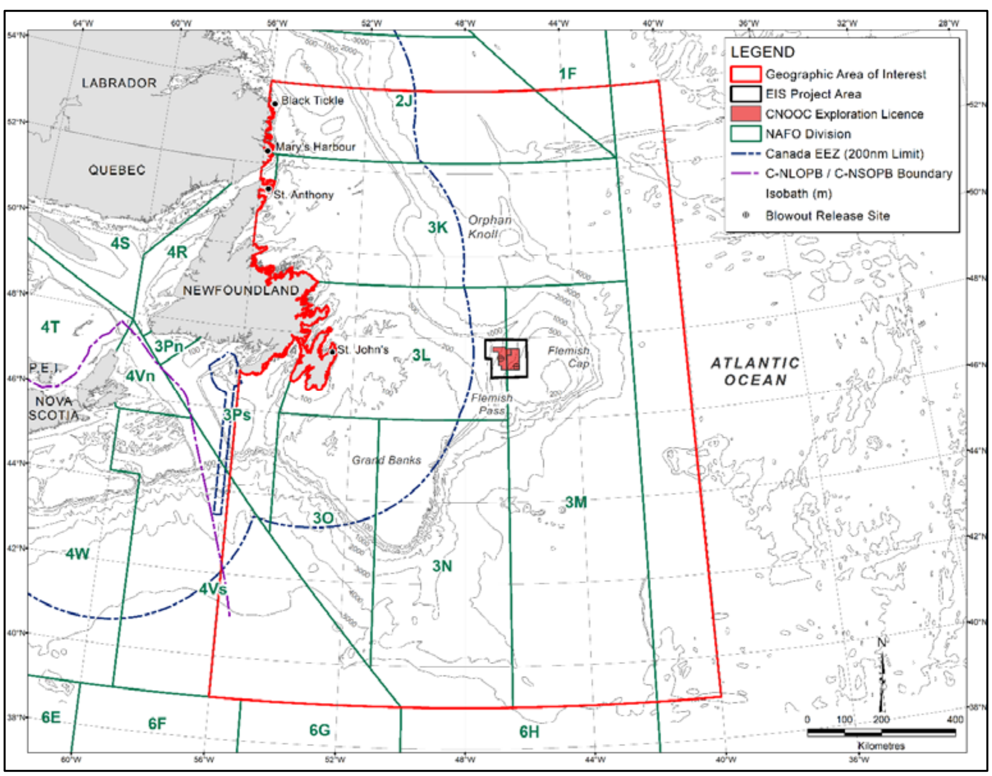
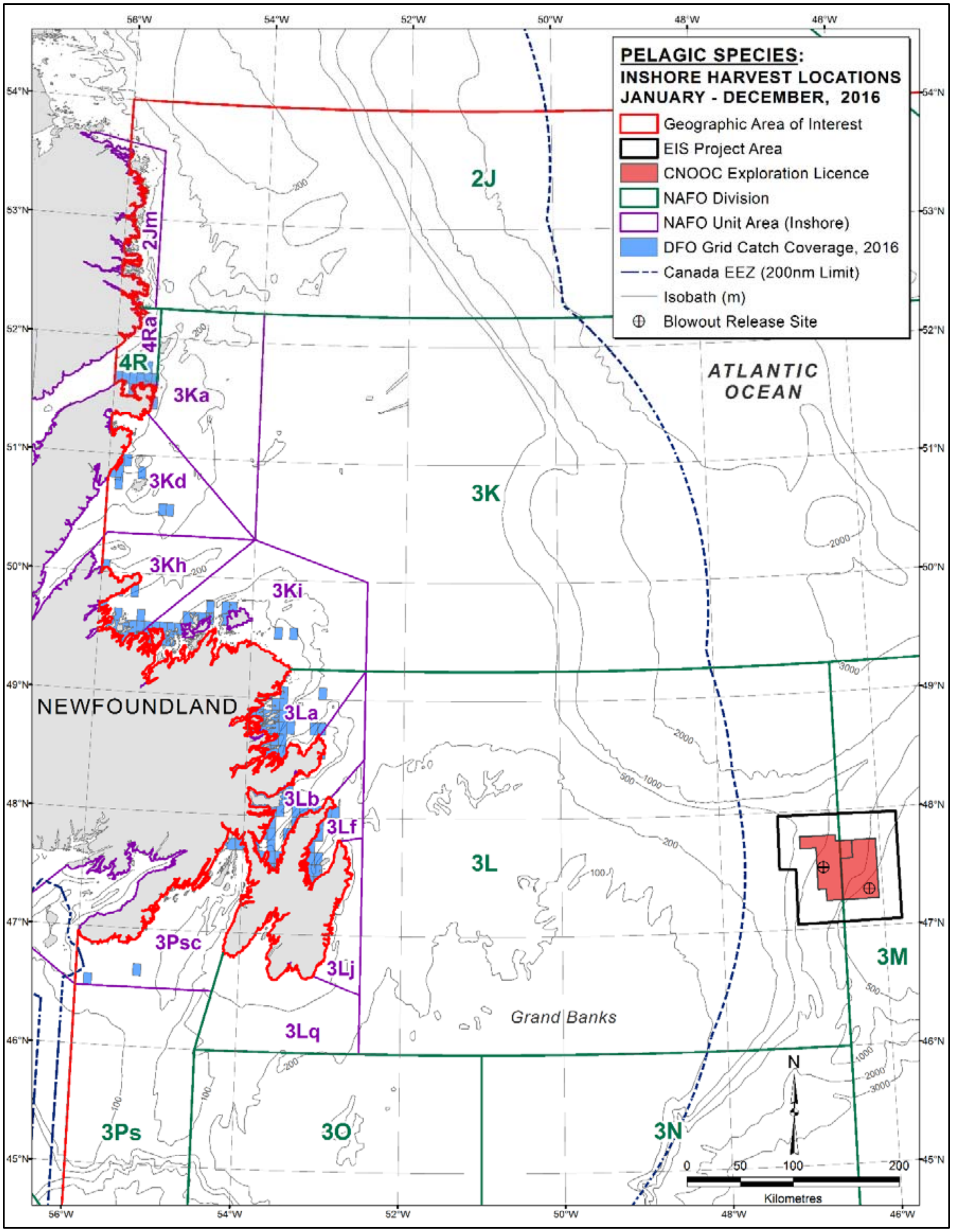


Figure 4-4. NAFO Divisions relevant to the GAI.

4.2.1 Domestic Pelagic Commercial Fisheries

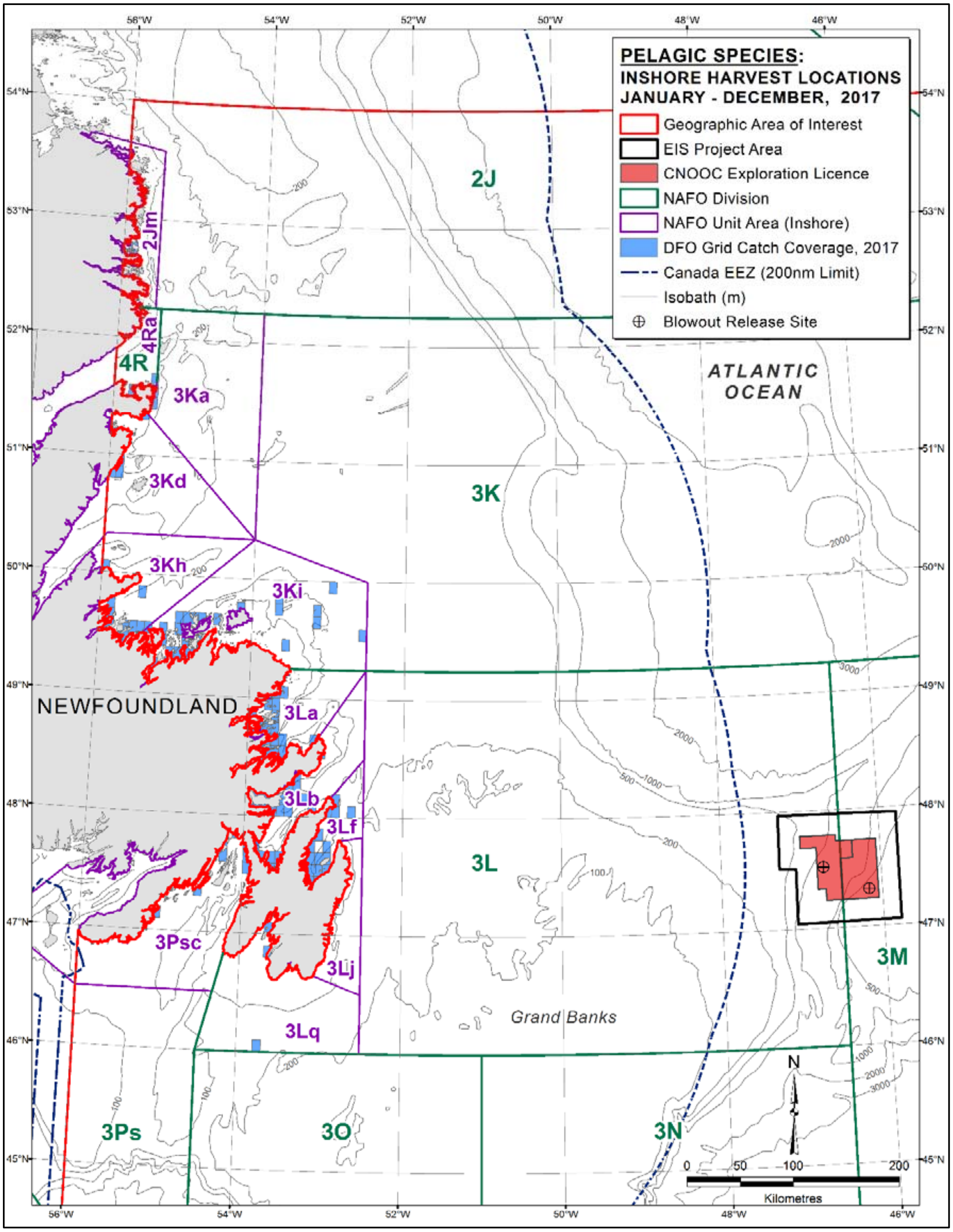
Inshore domestic pelagic commercial fisheries harvest locations within the GAI included NAFO UAs 3Kadhi, 3Labf, 3PSc, and 4Ra during 2016 (Figure 4-5), and 2Jm, 3Kadhi, 3Labfq, 3PSc, and 4Ra during 2017 (Figure 4-6). In order of descending catch weight, pelagic species harvested during 2016 and 2017 included capelin, Atlantic herring, mackerel, and bluefin tuna. Capelin accounted for the majority of inshore commercial catch value during 2016 and 2017. Most inshore pelagic commercial catches occurred during July and August (primarily capelin) in 2016 and 2017, and to a lesser extent during the fall (mainly Atlantic herring and mackerel). Inshore pelagics were primarily harvested using mobile fishing gears (~98% of total catch), including seines for capelin, herring and mackerel, and rod & reel for tuna. Capelin were also caught using trap nets, a fixed gear. Tuna were also captured via electric harpoon during 2016, and herring were also caught in fixed gillnets and trap nets during 2017. All of the inshore domestic pelagic catch was harvested by fishers from Newfoundland and Labrador (NL).

Offshore domestic pelagic commercial fisheries occurred within NAFO UAs 3Kf, 3Lc, 3Ocde, 3PSfh, and 4VSe within the GAI during 2016 (see Figure 4-7), and 2Jj, 3Kbfg, 3Lg, 3Oacde, and 3PSfh during 2017 (see Figure 4-8). In order of descending catch weight and value, offshore commercial pelagic species included swordfish, mako shark, bluefin tuna, bigeye tuna, albacore tuna, Atlantic herring, shark sp., dolphinfish (mahi mahi), and mackerel during 2016. Similarly, swordfish, mako shark, bluefin tuna, albacore tuna, bigeye tuna, Atlantic herring, mackerel, capelin, dolphinfish, and unidentified pelagics were harvested during 2017. Offshore commercial pelagic catches primarily occurred during July–October, with the highest catches during late-summer and early fall. Most of the offshore domestic pelagic commercial harvest was conducted using fixed gear (~82-88% of total catch), primarily fixed longlines for swordfish, mako shark, dolphinfish, and unspecified pelagics and, to a lesser extent, gillnets for sharks. Mobile trolling lines, rod & reel, and electric harpoon were used to catch bluefin tuna, and along with seines for Atlantic herring, mackerel, and capelin. The offshore domestic pelagic catch was harvested by fishers from Nova Scotia (NS; ~88% of total catch in 2016 and 62% in 2017) and NL (~12% of total catch in 2016 and 38% in 2017).



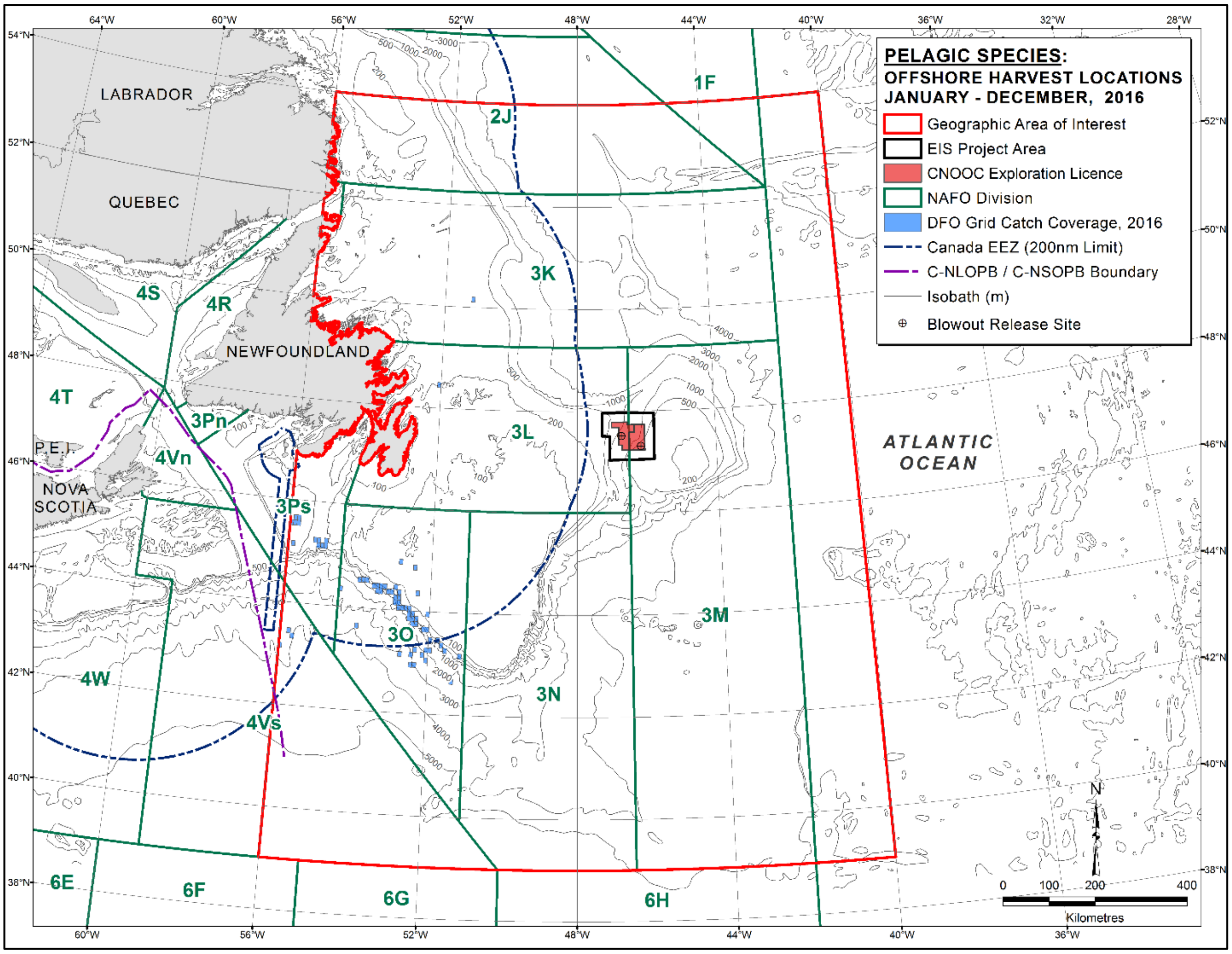
Source: DFO commercial landings database, 2016.

Figure 4-5. Inshore domestic pelagic commercial fisheries catch locations of all species within the GAI during 2016.



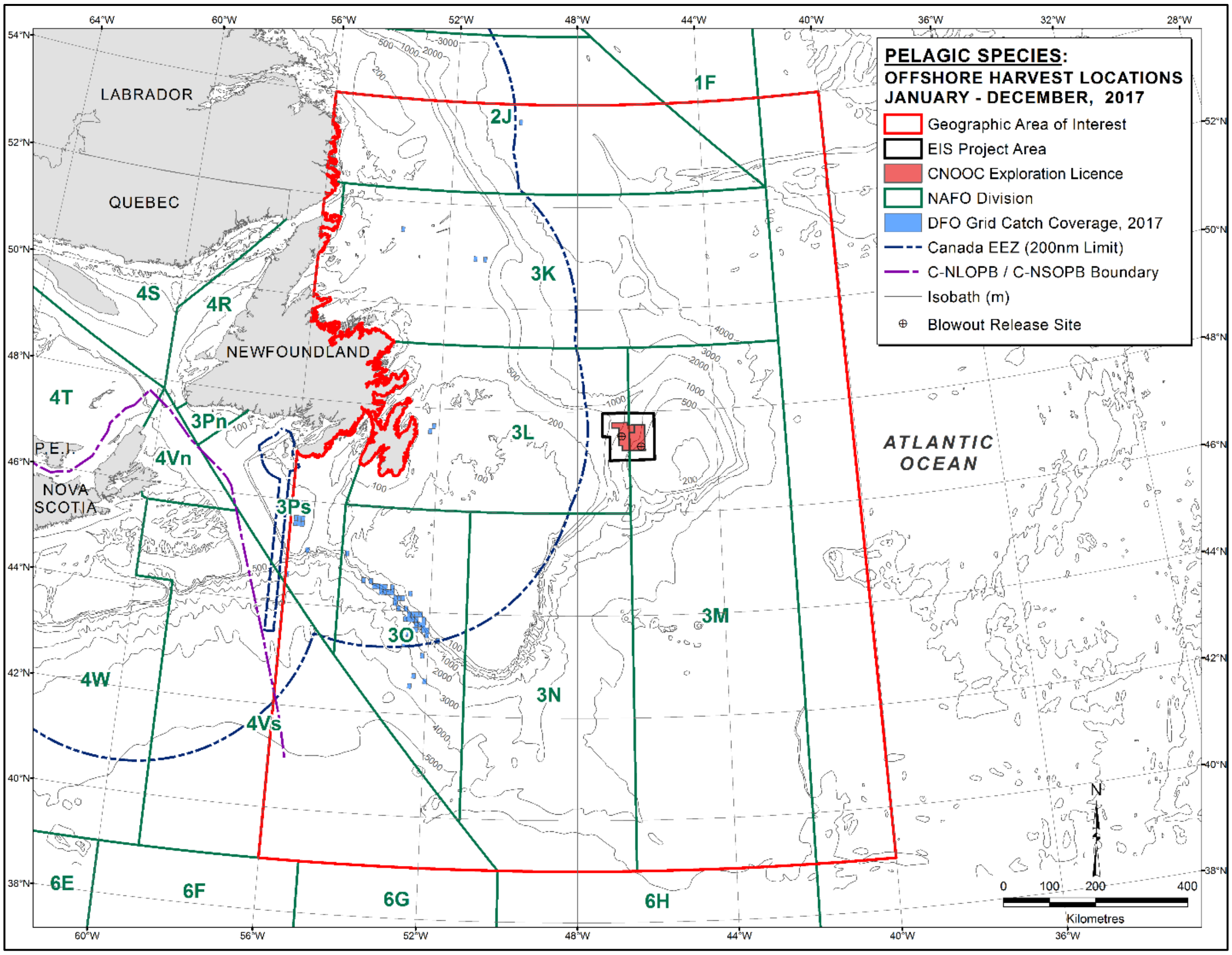
Source: DFO commercial landings database, 2017.

Figure 4-6. Inshore domestic pelagic commercial fisheries catch locations of all species within the GAI during 2017.



Source: DFO commercial landings database, 2016.

Figure 4-7. Offshore domestic pelagic commercial fisheries catch locations of all species within the GAI during 2016.



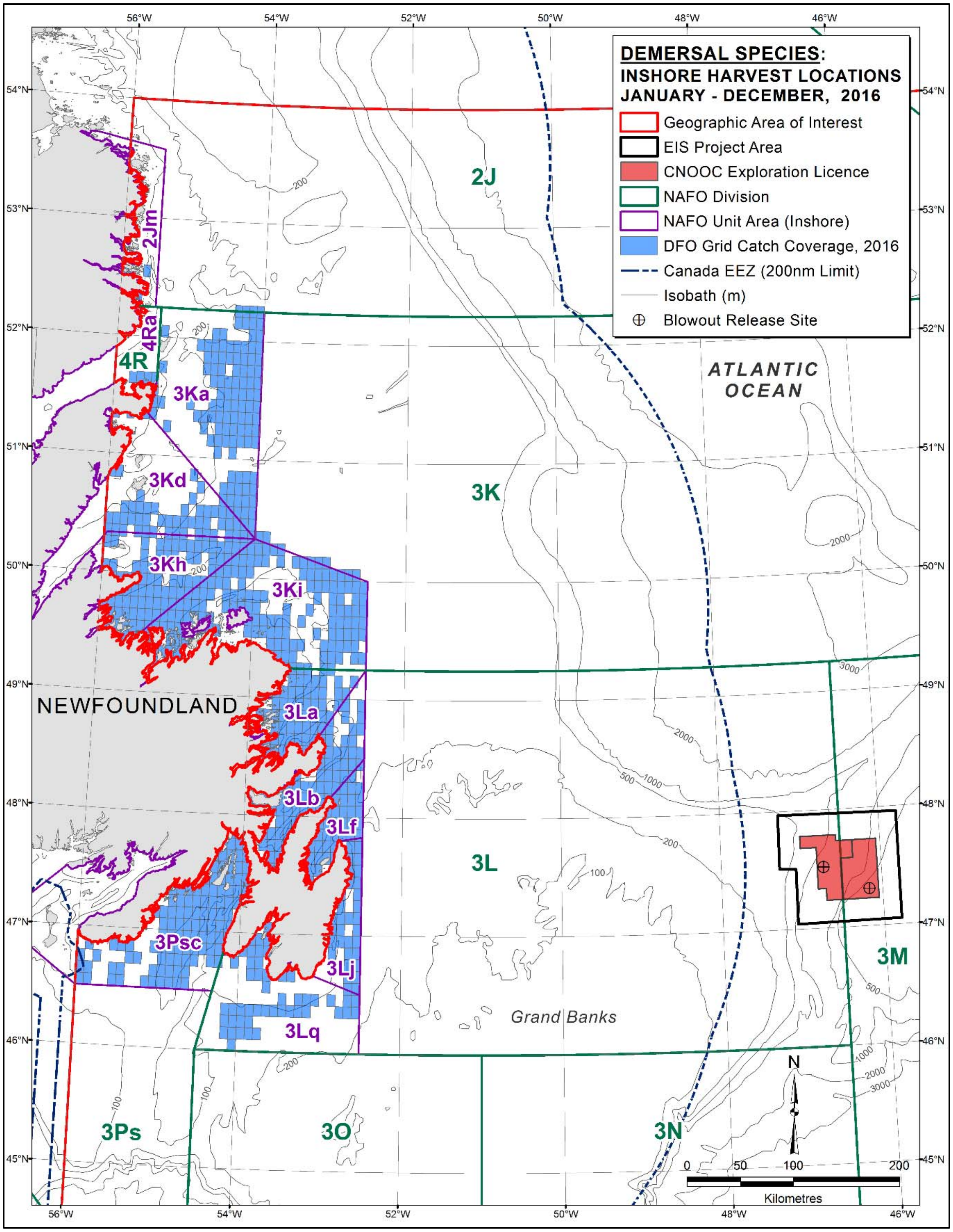
Source: DFO commercial landings database, 2017.

Figure 4-8. Offshore domestic pelagic commercial fisheries catch locations of all species within the GAI during 2017.

No offshore domestic pelagic commercial fisheries occurred within the EIS Project Area (Nexen 2018) during 2016 or 2017.

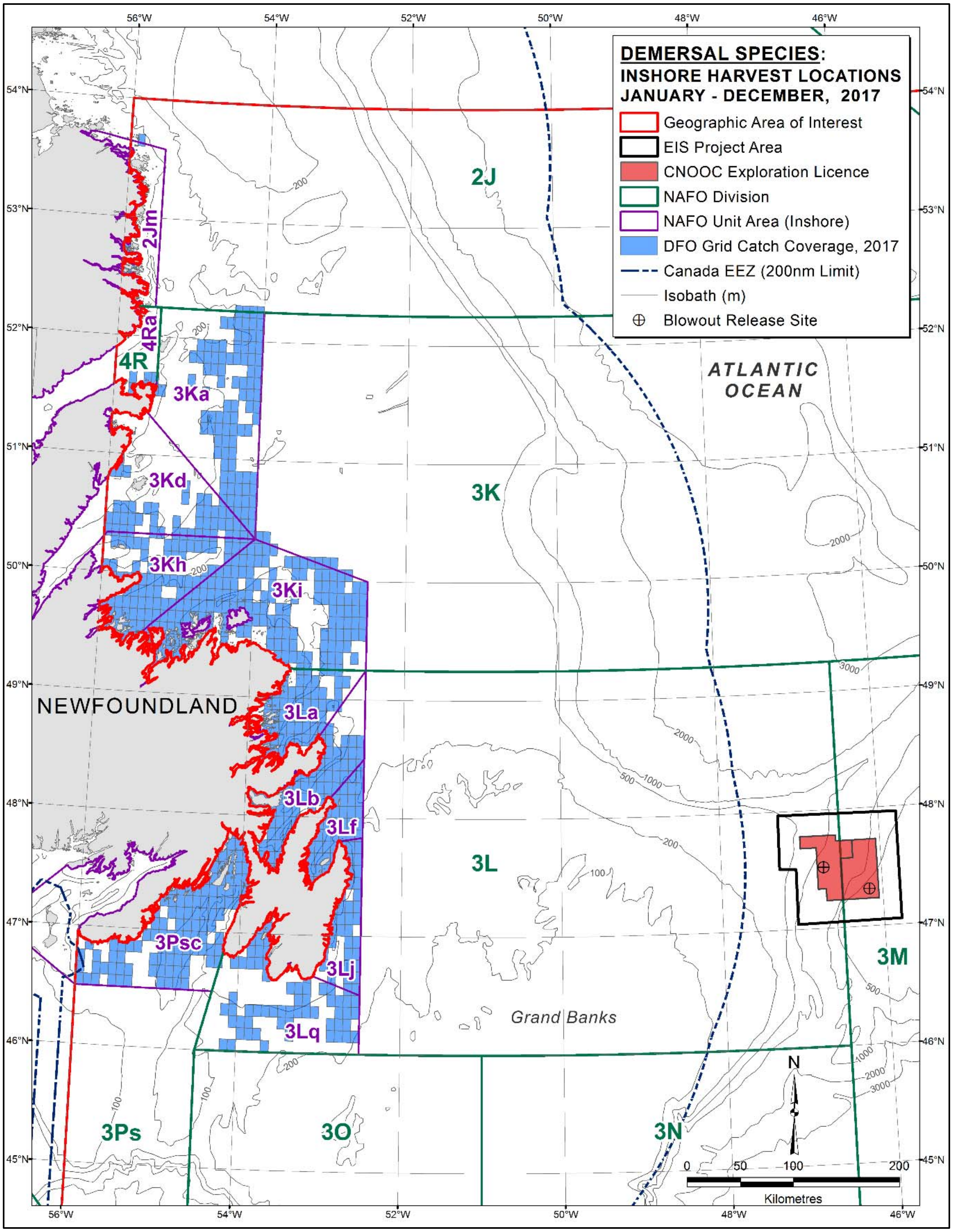
4.2.2 Domestic Demersal Commercial Fisheries

Inshore domestic demersal commercial fisheries within the GAI occurred in NAFO UAs 2Jm, 3Kadhi, 3Labfjq, 3PSbc, and 4Ra during 2016 and 2017 (Figures 4-9 and 4-10). In order of descending catch weight, species harvested include snow crab, Atlantic cod, northern shrimp, American plaice, sea scallop, Greenland halibut, Iceland scallop, Atlantic halibut, whelk, toad crab, skate, winter founder, redfish, Atlantic haddock, and striped shrimp during 2016. Snow crab, Atlantic cod, American plaice, northern shrimp, Greenland halibut, redfish, whelk, winter flounder, skate, Atlantic halibut, sea scallop, sea cucumber, Iceland scallop, and white hake were harvested during 2017. Snow crab and Atlantic cod were the most valuable species harvested during 2016 and 2017, followed by northern shrimp, sea scallop, American plaice, and Greenland



Source: DFO commercial landings database, 2016.

Figure 4-9. Inshore domestic demersal commercial fisheries catch locations of all species within the GAI during 2016.



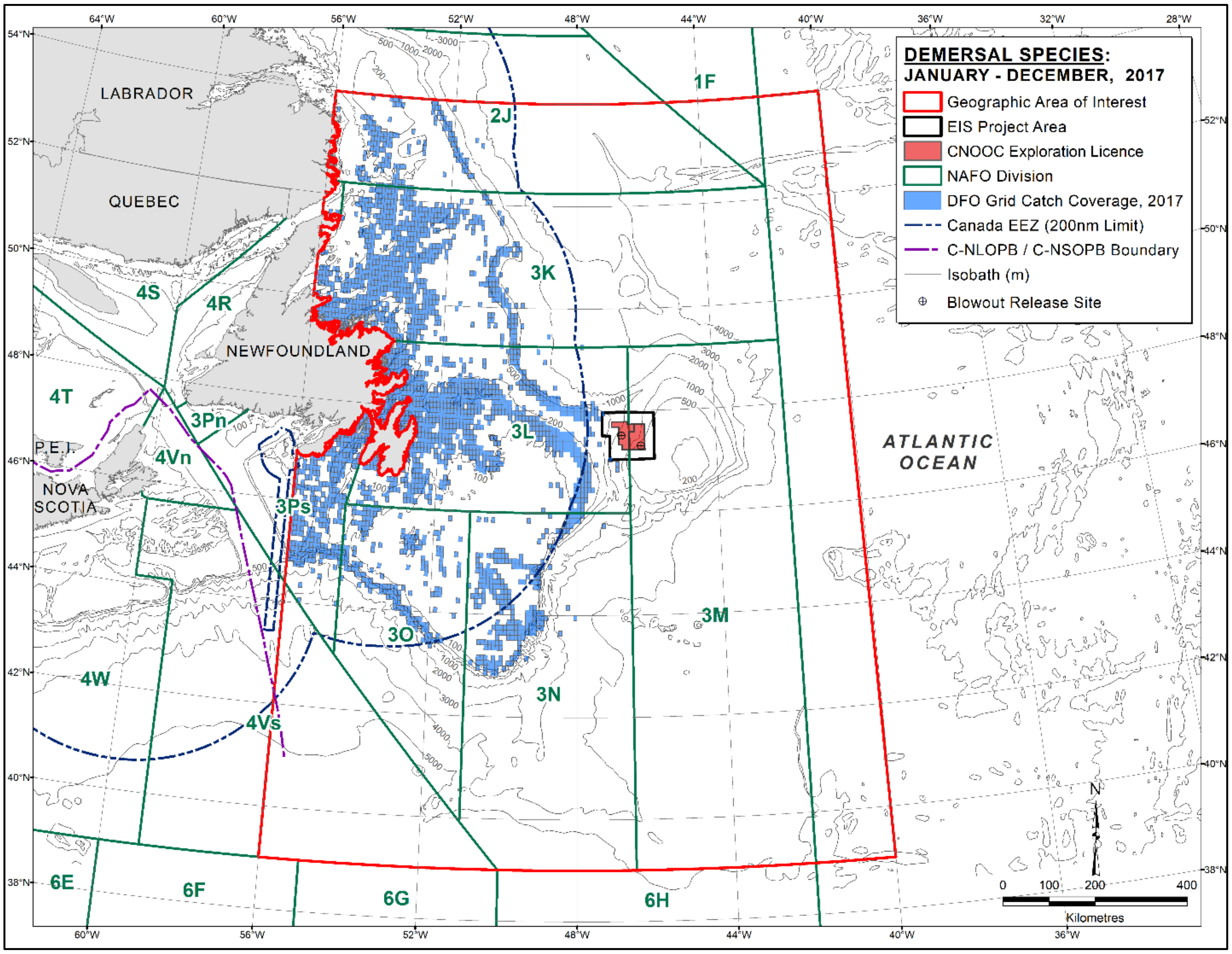
Source: DFO commercial landings database, 2017.

Figure 4-10. Inshore domestic demersal commercial fisheries catch locations of all species within the GAI during 2017.

halibut in 2016 and American plaice, northern shrimp, Greenland halibut, and redfish in 2017. The majority of inshore domestic demersal fisheries occurred during April–June followed by July–September during 2016. Most harvest occurred during May–July during 2017. Harvests were primarily taken using fixed fishing gears (~88-94% of total catch), namely pots followed by gillnets, longlines, cod pot traps, and trap nets. Mobile baited hand lines were used to catch cod, plaice, halibut, and haddock, trawls for shrimp, and dredges for scallops. Sea cucumbers were caught using sea cucumber drags during 2017. Nearly all (>99%) of the inshore domestic demersal commercial catch was harvested by fishers from NL during 2016 and 2017, while <0.1% (Atlantic cod, northern shrimp, and/or Atlantic halibut) was taken by Nova Scotian fishers.

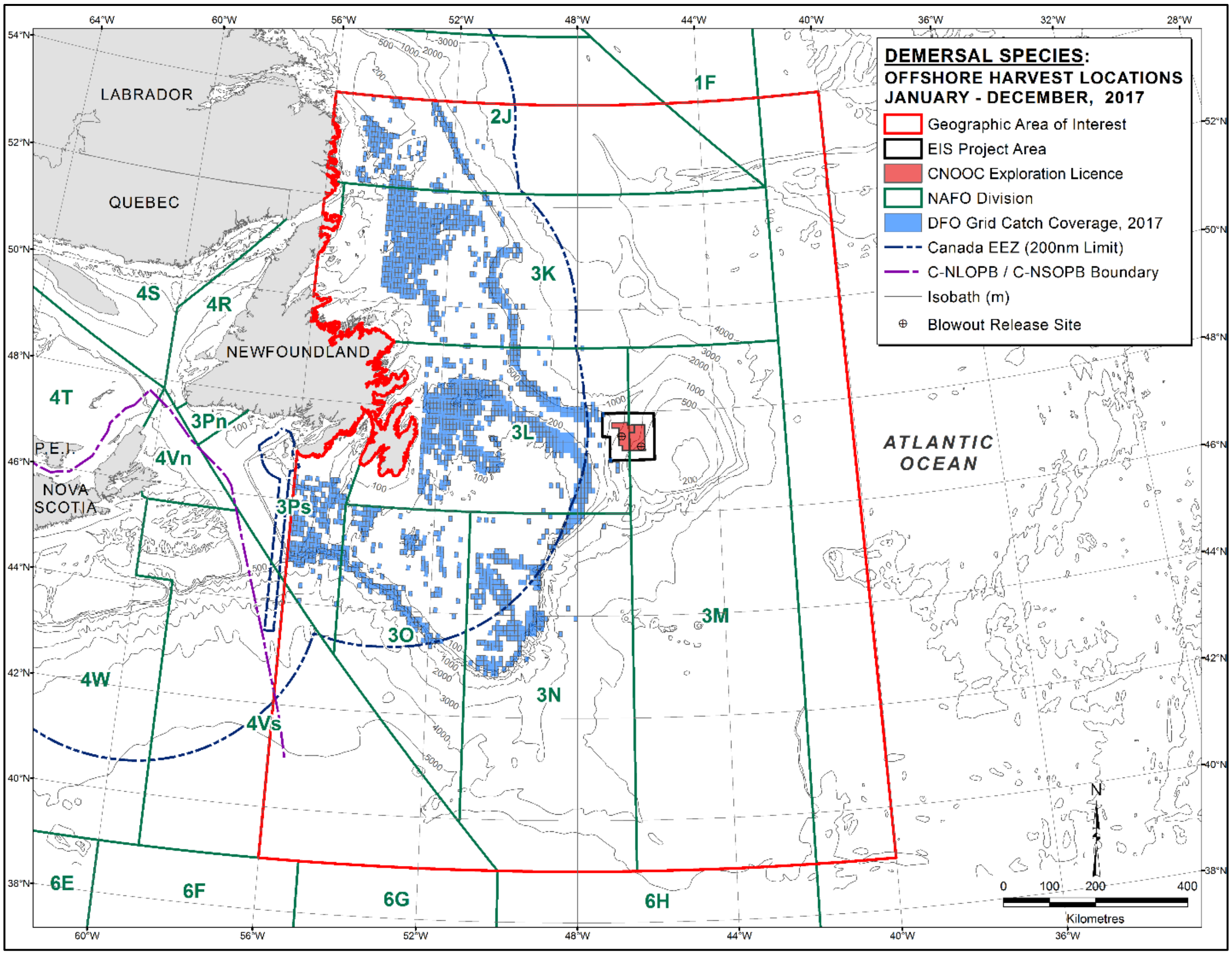
Offshore domestic demersal commercial fisheries were conducted in NAFO UAs 2Jefgiln, 3Kbcefg, 3Lcdeghirst, 3Nabcdef, 3Oabcde, 3PSefgh, and 4VSe during 2016 (Figure 4-11). Catch locations were within the same UAs during 2017, except no catches occurred within 3PSeg and 4VSe (Figure 4-12). Snow crab comprised most of the harvest catch weight and value during 2016 and 2017, followed by, in order of descending catch weight, northern shrimp, Atlantic halibut, Atlantic cod, Greenland halibut, American plaice, yellowtail flounder, redfish, witch flounder, white hake, Atlantic haddock, monkfish, pollock, Stimpson's surf clam, cockle, whelk, propeller clam, cusk, skate, sea scallop, roughhead grenadier, silver hake, wolffish, Iceland scallop, and dogfish during 2016. Northern shrimp, Atlantic halibut, Greenland halibut, Atlantic cod, redfish, American plaice, yellowtail flounder, witch flounder, white hake, Atlantic haddock, monkfish, pollock, Stimpson's surf clam, cockle, cusk, whelk, skate, pink shrimp, sea scallop, sea cucumber, roughhead grenadier, Iceland scallop, toad crab, and wolffish were also caught during 2017. Most of the year-round offshore demersal harvests occurred during April–August during 2016 and 2017. Harvests were essentially equally partitioned between fixed and mobile gears, predominantly pots (fixed) for crab and whelk and trawls (mobile) for shrimps and finfishes. Finfishes were also harvested using fixed gillnets and longlines, boat dredges were used to catch bivalves, and sea cucumber drags were used to harvest sea cucumbers. Offshore demersal commercial catches were harvested by fishers from NL (~90% of total catch) and NS (~10%).

Offshore domestic demersal commercial fisheries within the EIS Project Area (Nexen 2018) accounted for 0.1% and 0.02% of the total catch within the GAI during 2016 and 2017, respectively. In order of descending catch weight and value, harvested species included redfish, Atlantic halibut, witch flounder, and snow crab during 2016, and redfish and snow crab during 2017. Redfish, halibut, and flounder were harvested during October and November 2016, while snow crab were caught during May in 2016 and 2017. During 2017, redfish were taken during September. Finfishes were caught using mobile trawls, accounting for 86% and 50% of total catch during 2016 and 2017, respectively. Snow crab were harvested using fixed pots. All demersal commercial catches within the CNOOC EIS Project Area were harvested by fishers from NL during 2016 and 2017.



Source: DFO commercial landings database, 2016.

Figure 4-11. Offshore domestic demersal commercial fisheries catch locations of all species within the GAI during 2016.



Source: DFO commercial landings database, 2017.

Figure 4-12. Offshore domestic demersal commercial fisheries catch locations of all species within the GAI during 2017.

4.2.3 Indigenous Fisheries

Two types of fisheries are associated with the Indigenous groups who were consulted during the preparation of the Nexen EIS: (1) Food, Social and Ceremonial (FSC) fishing; and (2) Commercial-Communal fishing. FSC fishing usually involves harvesting various freshwater, estuarine, and coastal species, such as Atlantic salmon and American eel, and Commercial-Communal fishing typically involves the harvesting of offshore species, such as snow crab, shrimp, and groundfish. As indicated in the EIS Addendum (CNOOC 2019), three fish species that are very important in Indigenous culture include Atlantic salmon, swordfish, and bluefin tuna. Within the NL Region under consideration, depending on location and seasonality, other species of Indigenous importance may also include lobster, crab, mussels, various pelagic and/or groundfish species, and seals.

The NunatuKavut Community Council (NCC, formerly the Labrador Métis Nation), the Nunatsiavut Government, Innu Nation, Qalipu Mi'kmaq First Nation Band, Miawpukek First Nation from the NL Region, and Mi'kmaq Alsumk Mowimsikik Koqoey Association (MAMKA) have been all issued licenses by DFO that give them access to various fisheries resources within several NAFO Divisions that overlap the GAI (see Section 7.4 *in* Nexen 2018). There are also Indigenous organizations located in the Maritimes, Gulf, and possibly the Quebec Region that have access to this area.

4.2.4 Aquaculture

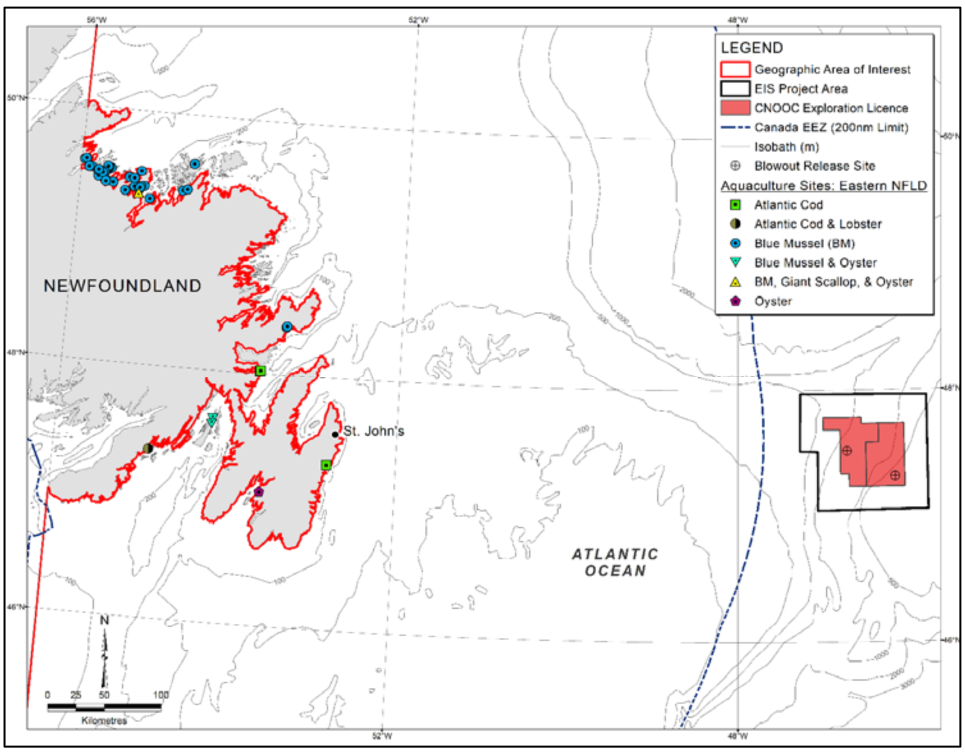
Aquaculture within the GAI is summarized in Section 7.2.12 of the EIS (Nexen 2018) and Section 4.3.4.3 of the Eastern Newfoundland SEA (C-NLOPB 2014). There are no approved aquaculture sites within the Labrador Shelf SEA (C-NLOPB 2008). The main species farmed in NL include blue mussel *(Mytilus edulis)*, Atlantic salmon, oyster, and Atlantic cod. Aquaculture production in Newfoundland reached its peak in 2016 but declined by 24% in 2017 from 28,622 mt (valued at $276 million) to 21,712 mt ($221 million), mainly due to decreased salmonid production (DFLR 2018). Aquaculture production and value decreased in 2018 (21,712 mt and $204 million, respectively) (DFLR 2019). Production is expected to rebound by 2020 due to progressive growth in salmonid aquaculture, and by 2022, salmonid production is anticipated to exceed 50,000 t (DFLR 2019). Shellfish production is expected to increase to over 10,000 t by 2022 (DFLR 2019). Table 4-10 and Figure 4-13 indicate the currently licensed aquaculture sites within the GAI that could potentially interact with an accidental oil spill. Grieg NL are currently in the process of establishing salmon aquaculture sites in Placentia Bay. There are currently no offshore aquaculture sites within the GAI.

Table 4-10. Newfoundland aquaculture operations within the GAI.

Operator	Location		Species Farmed
Allister Roberts	Gull Island Tickle, Badger Bay	Notre Dame Bay	Blue mussel
Atlantic Ocean Farms Ltd.	Winter Tickle, Saltwater Pond, Northwest Arm, Fortune Harbour	Notre Dame Bay	Blue mussel
B & B Farms Ltd.	Bear Cove, Moorey Cove	Notre Dame Bay	Blue mussel
Badger Bay Mussel Farms Ltd.	Pretty Island, Big Island, No Good Island, Long Arm, Pilley's Tickle, East Hare Island, Northern Arm, West Arm, Triton Island, Hussey's Cove, Sop's Arm, Badger Bay, Tommy's Arm, Pigeon Island, Stuckey Cove, Budgell's Harbour, Osmonton Arm, Side Harbour, Seal Bay, Little Northwest Arm, New Bay, Beaver Bight	Notre Dame Bay	Blue mussel
Big Blue Seafood Products	Coal All Island, Reach Run	Notre Dame Bay	Blue mussel
Black Gold Inc.	South Arm, Tea Arm-Mouse Island	Notre Dame Bay	Blue mussel, oyster, giant scallop
International Enterprises Ltd.	Burnt Arm North, Goshen's Arm	Notre Dame Bay	Blue mussel
LBA Enterprises Ltd.	Shoal Harbour, Little Bay Arm	Notre Dame Bay	Blue mussel
Notre Dame Bay Mussel Farms Inc.	Strong Island Sound, Big Indian Cove, Little Indian Cove	Notre Dame Bay	Blue mussel

Operator	Location		Species Farmed
Sunrise Fish Farms Inc.	Woodford's Arm, Flat Rock, Pilley's, Raft Tickle, Shoal Arm, Green Bay	Notre Dame Bay	Blue mussel
Terry Mills	Charles Arm	Notre Dame Bay	Blue mussel, oyster, giant scallop
Thwart Island Mussel Farm Inc.	Thwart Island	Notre Dame Bay	Blue mussel
Claude Seward	Ship Cove, Square Cliff, Heart's Ease Inlet	Trinity Bay	Atlantic cod
Shells & Fins Inc.	Cap Cove, Lockston, Northwest Arm	Trinity Bay	Blue mussel
Sapphire Sea Farms Ltd.	Bay Bulls	Witless Bay	Atlantic cod
Merasheen Oyster Farms	O'Donnell's	St. Mary's Bay	Oyster
Bernard Norman	Jerseyman Island	Placentia Bay	Atlantic cod, lobster
Merasheen Mussel Farms Inc.	Big South West Cove, Merasheen Island	Placentia Bay	Blue mussel, oyster

Source: C. Lang, Registrar of Aquaculture, Aquaculture Licensing Administrator, Department of Fisheries and Land Resources, pers. comm., 26 March 2019.



Source: C. Lang, Registrar of Aquaculture, Aquaculture Licensing Administrator, Department of Fisheries and Land Resources, pers. comm., 26 March 2019

Figure 4-13. Licenced aquaculture sites within the GAI.

4.3 Marine and Migratory Birds

The CNOOC SIMA GAI includes the highly productive shelf waters of the Grand Banks, the Flemish Cap, and areas well beyond the shelf break. It also includes coastal areas of the Burin and Avalon Peninsulas, extending northwards to Notre Dame Bay, the eastern tip of the Great Northern Peninsula and south coast of Labrador. The GAI includes a number of different habitats that might be used by marine birds for breeding, foraging, moulting, migratory staging, and wintering. Avian taxa and species descriptions presented below supplement biological information provided in Section 4.2.2.1 of the Eastern Newfoundland SEA (C-NLOPB 2014) and Section 6.2 of the EIS (Nexen 2018).

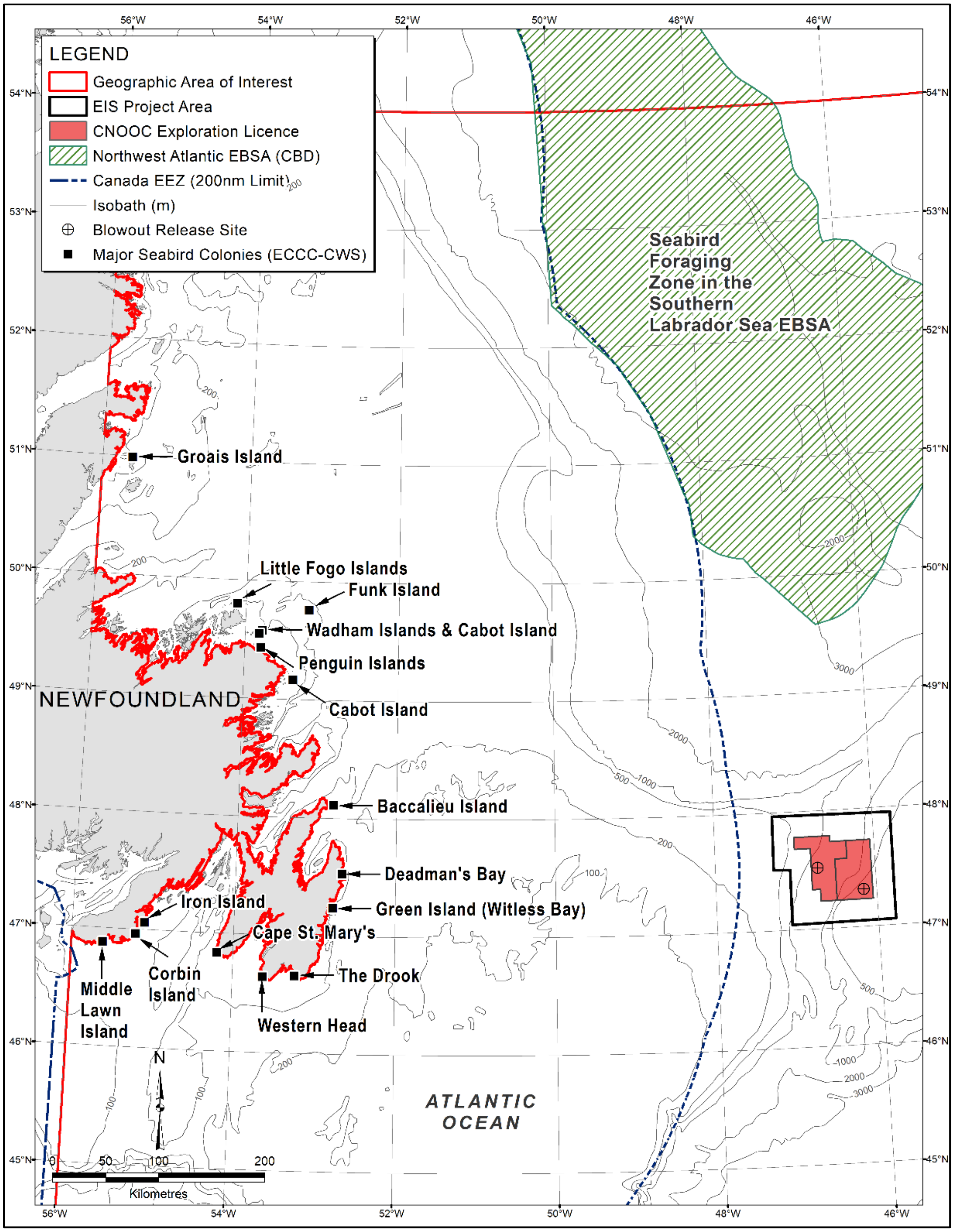
4.3.1 Seabirds

This section provides relevant information for various seabird species that typically occur in the offshore of the GAI.

4.3.1.1 Northern Gannet

In North America, Northern Gannet breed at six main colonies, three of which are on the coast of Newfoundland. The Newfoundland colonies are at Cape St. Mary's (25,972 individuals), Funk Island (19,674 individuals), and Baccalieu Island (3,424 individuals), all of which are within the GAI (ECCC-CWS 2018) (Figure 4-14). Gannets are found in low densities around the coastline of the GAI and offshore over the tail of the Grand Banks from April–July. In August–November, Gannets within the GAI are primarily adjacent to the coastlines of the Burin Peninsula, Avalon Peninsula, and the Strait of Belle Isle. They are almost entirely absent from the GAI during December–March (Bolduc et al. 2018).

Gannets feed primarily on shoaling fish by making dramatic plunge dives from the air (Mowbray 2002). Two types of dives have been observed: (1) short, shallow dives; and (2) long, deep, "U-shaped" dives. Most dives are short and shallow, generally less than 8 seconds in duration with a mean depth of 3.5 m. Only 10% of dives were deeper than 10 m, up to 22 m in depth and 38 seconds in duration (Garthe et al. 2000). Gannets also spend time on the surface of the water after their dives, bathing or preening.



Source: Bolduc et al. (2018).

Figure 4-14. Locations of major seabird colonies within the GAI.

4.3.1.2 Northern Fulmar

Northern Fulmar breed in small numbers (300 birds total) at seven colonies along the coast of Newfoundland and Labrador, five of which are within the GAI (ECCC-CWS 2018) (see Figure 4-14). Birds from these colonies, along with non-breeders, are present during the summer months. In autumn, these birds are joined by large numbers of fulmars from the breeding colonies in the eastern Canadian Arctic, where roughly 200,000 pairs breed in ten colonies (Gaston et al. 2006). Birds return to the high north colonies in late-April or early-May and leave by mid-October (Mallory et al. 2012). The densities are highest in late summer (August–November) when densities of 48–399.4 birds per km^2 are typical along the continental slope from the Flemish Pass north to Baffin Island (Bolduc et al. 2018).

Fulmars are seldom encountered over the shelf, but concentrations are found throughout the year over the shelf break and slope along the Labrador coast, the Orphan Basin, and the Flemish Cap (Bolduc et al. 2018).

Fulmars feed from the water, either by picking up prey from the surface or by diving short distances (up to 3 m). They are evidently unable to feed from the air (Mallory et al. 2012).

4.3.1.3 Shearwaters – Great, Sooty, Manx

Shearwaters are present in the GAI, primarily in the Summer period (June–November), although small numbers return to the area in late-May, and a few Great Shearwaters are still present in early-December (Bolduc et al. 2018). Great Shearwater and Sooty Shearwater both breed in the southern hemisphere and travel to the North Atlantic during the austral winter (northern summer) to take advantage of the rich feeding grounds during their annual moult (Brown 1986; BirdLife International 2019). Most of the world's population of Great Shearwater and thousands of Sooty Shearwaters use offshore Newfoundland waters, accounting for the largest share of fish consumed on the Grand Banks in summer (Brown 1986; Hedd et al. 2012). Most of the sooty shearwaters moult in the deep, warm waters between Flemish Cap and the Mid-Atlantic Ridge from April to early-June before moving into the cooler waters of the Grand Banks for the June–October period (Hedd et al. 2012). Great Shearwater is by far the most abundant species of shearwater present in the GAI, reaching densities of up to 33.6–59.5 birds per km^2 during the late summer months of August–November. Sooty Shearwater by contrast is found at densities of 1.6–12.5 birds per km^2 primarily on the southern Grand Banks in April–July and at lower densities of 1.3–6.4 birds per km^2 in August–November, by which time they have moved into the area of the Flemish Cap in greater numbers (Bolduc et al. 2018).

There is only one known breeding location for Manx Shearwaters in Canada, Middle Lawn Island, off the Burin Peninsula, Newfoundland (Figure 4-14; ECCC-CWS 2018). This colony is estimated at ~200 individuals, is designated a provincial Ecological Reserve, and is located within the GAI. Research surveys have documented consistently low colony productivity over the past 30 years primarily due to a low incidence of breeding success with increasing predation pressure (Robertson 2002; Fraser et al. 2013). There are scattered records of Manx Shearwater across the Grand Banks during the summer months, most in May–July (Bolduc et al. 2018). The highest densities of this species 1.4–2.2 birds per km^2, are mostly south of the Grand Banks (Bolduc et al. 2018).

While shearwaters spend most of their time either in flight or on the waters' surface, they are capable of diving into the water column. A study of Sooty Shearwaters in New Zealand found that they regularly dive to depths of 40–60 m (Weimerskirch and Sagar 1996). When Great Shearwaters are moulting in North Atlantic waters, they spend more time on the water and may therefore be more susceptible to oil spills.

4.3.1.4 Storm-Petrels – Leach's & Wilson's

Leach's Storm-Petrels breed in large numbers in colonies on the coast of Newfoundland, especially between the Bonavista Peninsula and Fogo Island, at Baccalieu Island, and the southern extent of the Burin Peninsula (see Figure 4-14). The largest Leach's Storm-Petrel colony in the world is found at Baccalieu Island (in the GAI) which numbers 1,970,000 pairs or roughly 30% of the world's population (Wilhelm et al. 2019). Two other large nesting colonies are located on Gull and Great Islands in the Witless Bay Ecological Reserve on the east coast of the Avalon Peninsula. Gull Island had a colony of 180,000 pairs in 2012 (ECCC-CWS, unpublished data). The Great Island colony numbered 134,000 pairs in 2011 (Wilhelm et al. 2015). Between the GAI coastal segment of Bonavista Peninsula and Fogo Island, large colonies include Little Fogo Islands (76,000 birds), Coleman Island (10,000 birds), Wadham Islands (23,876 birds), and the Penguin Islands (18,000 birds). Major colonies along the Burin Peninsula (in the GAI) include Iron Island (20,000 birds), Corbin Island (200,000 birds) and Middle Lawn Island (52,626) (ECCC-CWS 2018) (see Figure 4-14). A tracking study found that foraging ranges of individuals nesting at the three largest colonies in the world, Baccalieu, Gull, and Middle Lawn islands, lie primarily within the GAI (Hedd et al. 2018). During the breeding season (June–October) birds feed within 200 km of the colonies (Huntington et al. 1996). In April–July, Leach's Storm-Petrel densities are highest (5.9–25.9 birds per km^2) northeast of the main colonies and out to the Orphan Basin. From August–October the area of highest density (5.5–31.7 birds per km^2) shifts south to the shelf break around the tail of the Grand Banks (Bolduc et al. 2018). They are largely absent from the GAI during the winter months.

While Wilson's Storm-Petrels breed in Antarctica and on sub-Antarctic islands they migrate north, including to the North Atlantic, during their non-breeding season (Birdlife International 2019). They are present in the GAI in small numbers from April–October (Bolduc et al. 2018).

Leach's Storm-Petrels feed on plankton and small fish picked off the water surface while hovering or while sitting on the water but there are no reports of diving (Huntington et al. 1996).

4.3.1.5 Gulls – Herring, Great Black-backed, Ring-billed, & Black-legged Kittiwake

Herring, Great Black-backed and Ring-billed Gulls occur within the GAI year-round. Colonies are usually situated on remote, coastal islands with selected habitat dependent on predator accessibility. They frequently nest on rocky high elevation cliffs with turf-covered ledges. Ring-billed gulls nest almost exclusively at rocky, cobble sites near sea level. Gull colonies are abundant along the GAI coastline with number of identified colonies totaling 406, 324, and 68 for Herring, Great Black-backed and Ring-billed Gulls, respectively (ECCC-CWS 2018). Glaucous, Iceland, Sabine's, and Ivory Gulls nest in the Arctic and are only found in the GAI outside the breeding season. Other species that infrequently occur in the GAI include Lesser Black-backed, Black-headed, and Laughing Gulls (Nexen 2018). Considering all gulls together, densities are highest for the EIS Project Area during the winter months at 17.3–40.1 birds per km^2 (Bolduc et al. 2018).

Black-legged Kittiwake is present over shelf and deeper waters and is the most pelagic species of gull found in the GAI, occurring far offshore. They nest in colonies on inaccessible cliffs around the coast. Over 130,000 breed in colonies around Newfoundland, some with just a few pairs and others with over 20,000 birds (ECCC-CWS 2018). The largest colonies in the GAI include Cape St. Mary's (20,000 birds), Western Head (2,200 birds), The Drook (3,600 birds), Green Island in Witless Bay (20,000 birds), Deadman's Bay (3,500 birds), Baccalieu Island (25,950 birds), and Groais Island (4,000 birds) (ECCC-CWS 2018) (see Figure 4-14). Kittiwakes are widespread offshore throughout the GAI, reaching the highest densities in the winter months (Bolduc et al. 2018). Tracking of kittiwakes suggests that 80% of the 4.5 million adult kittiwakes that nest in the Atlantic Ocean, including most European colonies, winter along the shelf edges off Newfoundland and deeper areas extending from the Labrador Sea to the Mid-Atlantic Ridge (Frederiksen et al. 2012). They feed primarily at the surface, occasionally making short dives of 0.5–1 m depth (Hatch et al. 2009).

4.3.1.6 Terns – Arctic, Common, Caspian

The three tern species found in the GAI are migratory and are present only during the breeding season. They typically remain coastal, with the exception of Arctic Tern which tend to be highly pelagic during migration, occurring at very low densities offshore during the April to November period (Bolduc et al. 2018). Colonies are typically situated near expansive marine shorelines on sandy, gravel, or cobble substrates. Major colonies for Arctic Tern are located between the Bay of Exploits and Cape Freels (6 colonies; 2,230 total birds) (see Figure 4-14). Common Terns breed at 23 known colonies within the GAI; 14 are concentrated near the coastal boundary of Terra Nova National Park (2,245 birds). The main Caspian Tern colonies within the GAI are limited to two locations near Penguin Islands (total of 216 birds) (ECCC-CWS 2018).

4.3.1.7 Alcids – Atlantic Puffin, Common Murre, Thick-billed Murre, Razorbill, Black Guillemot, Dovekie

Five species of alcids (Atlantic Puffin, Common Murre, Thick-billed Murre, Razorbill and Black Guillemot) breed in the GAI and one species (Dovekie) is a winter resident. Alcids are stocky seabirds that are excellent divers which spend much of their time in the water column.

Atlantic Puffin breed at 21 known colonies in the GAI, the largest of which are found at Great Island, Witless Bay (175,000 breeding pairs), Wadham Islands (50,236 birds), Baccalieu Island (60,000 birds) and Green Island in Witless Bay (40,000 birds) (Wilhelm et al. 2015; ECCC-CWS 2018) (see Figure 4-14). The Witless Bay Ecological reserve also includes three other puffin colonies: Gull Island (118,000 pairs), Green Island (9,000 pairs), and Pee (1800 pairs). Puffins are found closer to shore while at their breeding colonies from April–July but during the rest of the year may be found further offshore including the Flemish Pass (Bolduc et al. 2018). Common Murres breed at five large colonies in the GAI: Funk Island (825,048 birds), Cabot Island (7,465 birds), Baccalieu Island (8,000 birds), Green Island in Witless Bay (148,000 birds) and Cape St. Mary's (20,000 birds) (ECCC-CWS 2018). The colony at Funk Island represents approximately 4% of the global population and two thirds of the eastern North American population (IBA Canada 2019). The core wintering area of the common murres breeding at nesting colonies in North America lie in offshore Newfoundland waters (Hedd et al. 2011; McFarlane Tranquilla et al. 2015). Four Newfoundland colonies are also used by smaller numbers of Thick-billed Murres (Funk Island - 500 birds; Baccalieu Island - 362 birds; Witless Bay - 1,200 birds and Cape St. Mary's - 2,000 birds) (ECCC-CWS 2018). Wintering Thick-billed Murres from nesting colonies on Baffin Bay and Hudson Bay, with a minority from Spitsbergen have their core wintering range on the Grand Banks and Labrador Sea, making the GAI part of one of the most important wintering areas for North Atlantic thick-billed murre breeding populations (Frederiksen et al. 2016). Razorbills breed at 10 colonies in the GAI, ranging in size from as few as 10 birds at the Drook to 546 birds in the Wadham Islands (ECCC-CWS 2018).

Black Guillemots nest in scattered small colonies, typically of less than 100 individuals, around the coast of Newfoundland. At least 46 of these small colonies are found in the GAI comprising an estimated total of 3,350 birds (ECCC-CWS 2018). Black Guillemots are typically found close to shore and prefer inshore waters less than 35 m deep (Butler and Buckley 2002).

Dovekies nest in small numbers on Baffin Island but more importantly, a population of up to 20 million pairs nest in northwest Greenland (Montevecchi and Stenhouse 2002). The core winter distribution of 30 million dovekies that nest along the west and east coasts of Greenland lies off eastern Newfoundland (Fort et al. 2013). Densities in the GAI are highest from December–March, in the range of 9.0–32.6 birds per km^2 (Bolduc et al. 2018).

Murres and Razorbills are the strongest divers of the alcids and have been recorded diving to maximum depths of 180 m and 120 m respectively (Piatt and Nettleship 1985). Puffins generally forage at depths of less than 60 m but have been recorded as diving up to 68 m (Burger and Simpson 1986). Black Guillemots were recorded diving to 50 m (Piatt and Nettleship 1985). Maximum dive depths for Dovekies were recorded as 19–35 m (Falk et al. 2000).

4.3.1.8 Seabird Distribution and Densities within the GAI

Seabird distribution and densities within the GAI during 2006–2016 are shown in Figures 4-15–4-18. The data are presented in three four-month time periods; December–March, April–July, and August–November.

4.3.2 Shorebirds and Waterfowl

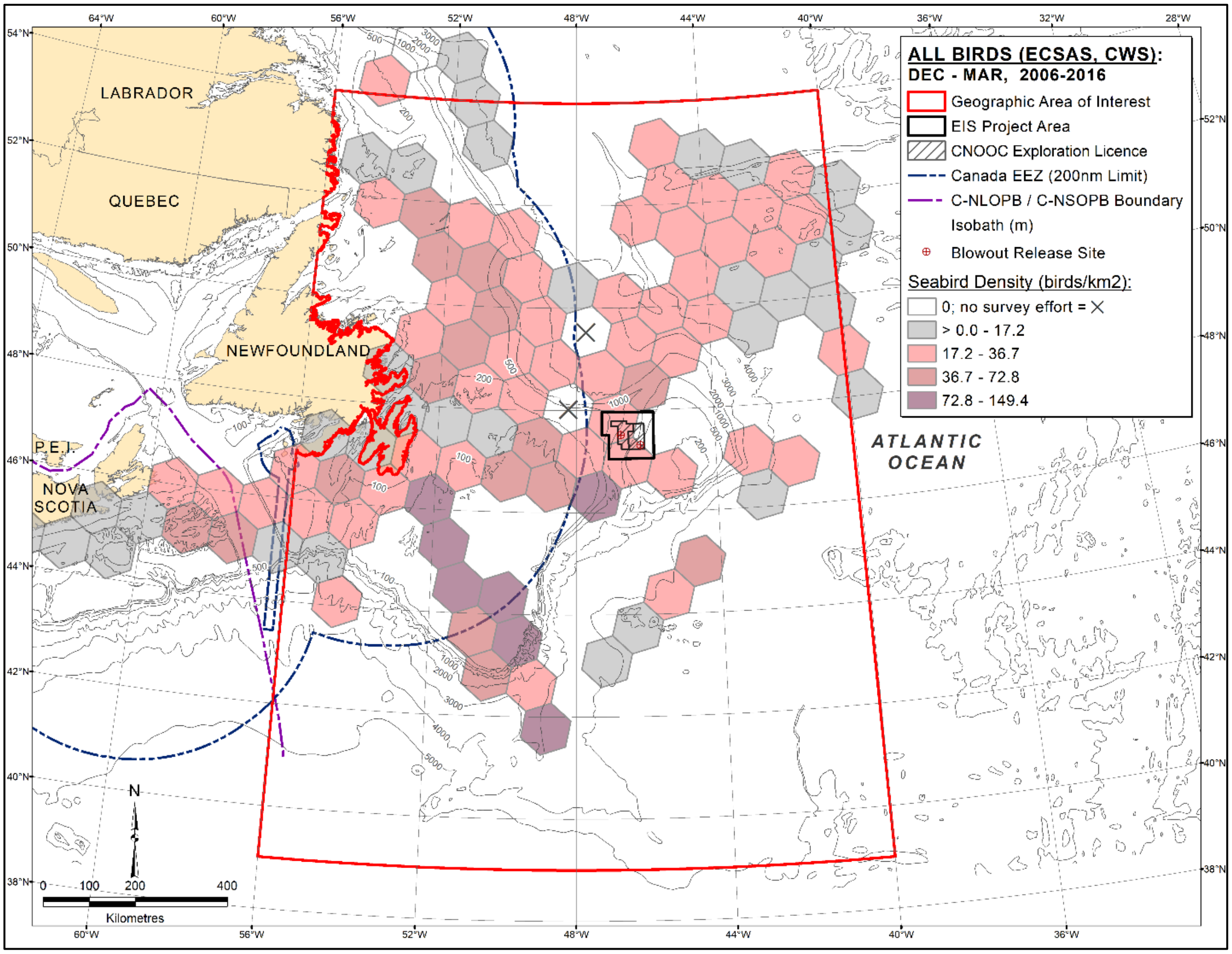
Many species of shorebird pass through the GAI during migration (especially during the protracted fall migration from July–October) and Purple Sandpipers and small numbers of Ruddy Turnstones are present in the winter months (C-NLOPB 2014). During migration, shorebirds are widespread in appropriate habitat along the coastline. Some portions of the shoreline are particularly attractive to wintering Purple Sandpipers, such as the Mistaken Point area which has consistently held roughly 1% of the North American population (IBA Canada 2019).

Various waterfowl also occur along the Newfoundland shoreline section occurring within the GAI (e.g., Common Eider [*Somateria mollissima*], Harlequin Duck [*Histrionicus histrionicus*]).

4.3.3 Important Bird Areas

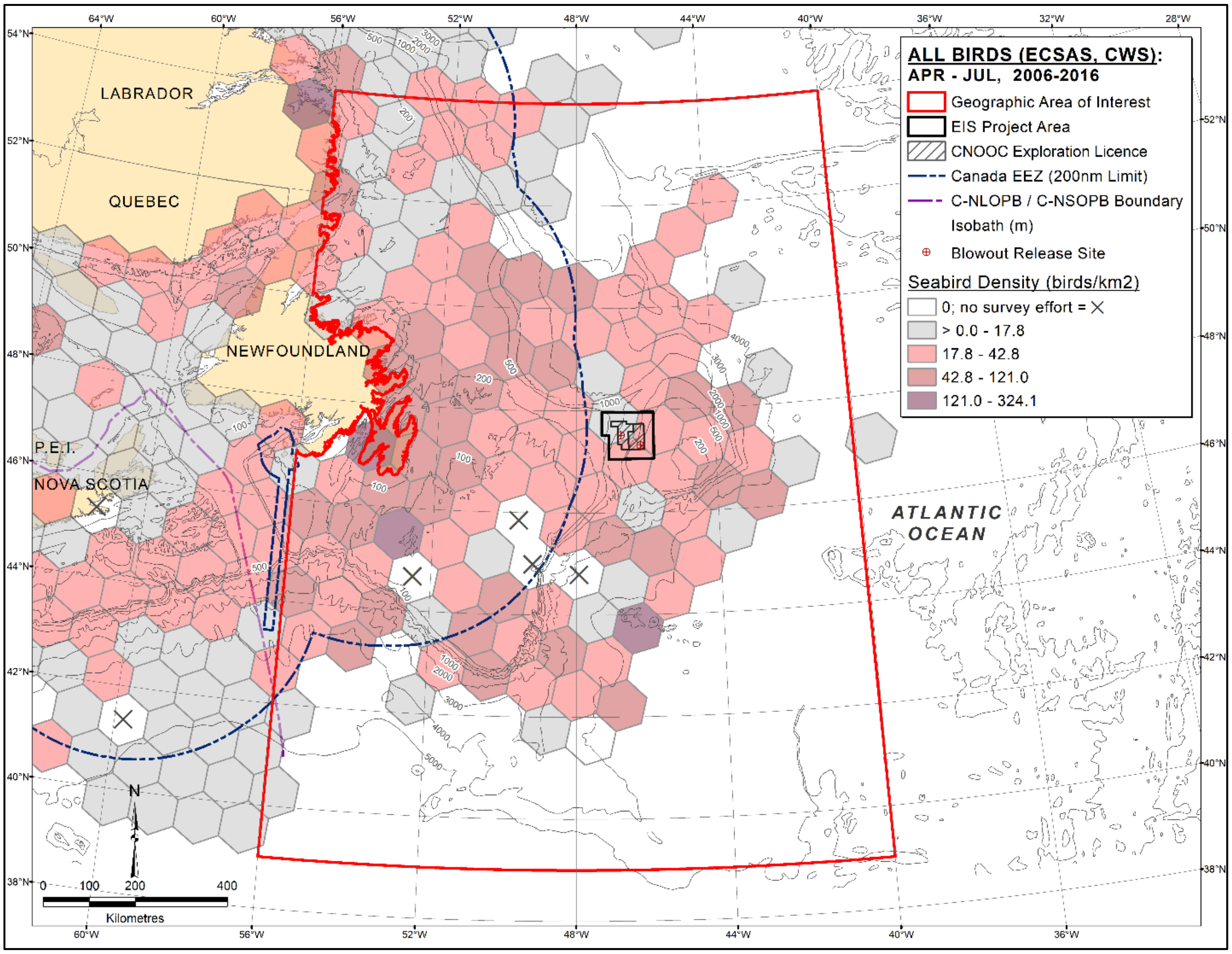
Important Bird Areas (IBAs) are sites of international significance to birds either because they support large congregations of birds, threatened species or species that are range or habitat restricted (IBA Canada 2019). They are designated according to internationally agreed upon standards, but the sites are not necessarily protected by any level of government. In the GAI there are 19 IBAs, six of which include areas designated as provincial Ecological Reserves (Table 4-11; Figure 4-18).

The warm waters between Flemish Cap and the mid-Atlantic Ridge are an important staging area for migrating seabirds (Egevang et al. 2010; Boertmann 2011; Sittler et al. 2011; Frederiksen et al. 2012; Bennison and Jessopp 2015; van Bemmelen et al. 2017). In the mid-Atlantic the Evlanov Seamount, and Basin Important Bird Area (IBA), was designated because 72,000 to 168,750 individuals of the IUCN Near Threatened Sooty Shearwater are present during April and May (BirdLife International 2020a). Part of this IBA is protected within the Charlie-Gibbs South High Seas MPA (http://www.charlie-gibbs.org/charlie/). To the east of that IBA are two IBAs: Atlantic, Northeast 2 – Marine and Atlantic, Northeast 3 – Marine (BirdLife International 2020b,c). These two IBAs were designated because of the presence of the IUCN Endangered Zino's Petrel (*Pterodroma* madeira) during its incubation period (May to August). In the vicinity of the western cluster of Azores Islands are three additional IBAs. The Corvo e Flores IBA was designated because the coastal waters are used for foraging and resting by a breeding population of 30,000 Cory's Shearwaters (*Calonectris diomedea*), as well as concentrations of breeding Roseate Tern (*Sterna dougallii*) and Common Tern (*S. hirundo*) (BirdLife International 2020d). The Norte do Corvo – Oceânica IBA lies 135 km north of Corvo Island and was designated because of concentrations of Cory's Shearwaters for feeding and resting during incubation (June) and chick-rearing (August) (BirdLife International 2020e). The Norte do Corvo e Faial – Oceânica IBA lies 250 km northeast of Corvo Island and was designated because of the presence of a long term feeding and resting concentration of Cory's Shearwaters that nest on Corvo Island and Praia Island (BirdLife International 2020f). There are additional IBAs in the rest of the Azores archipelago a few hundred kilometres to the southeast.



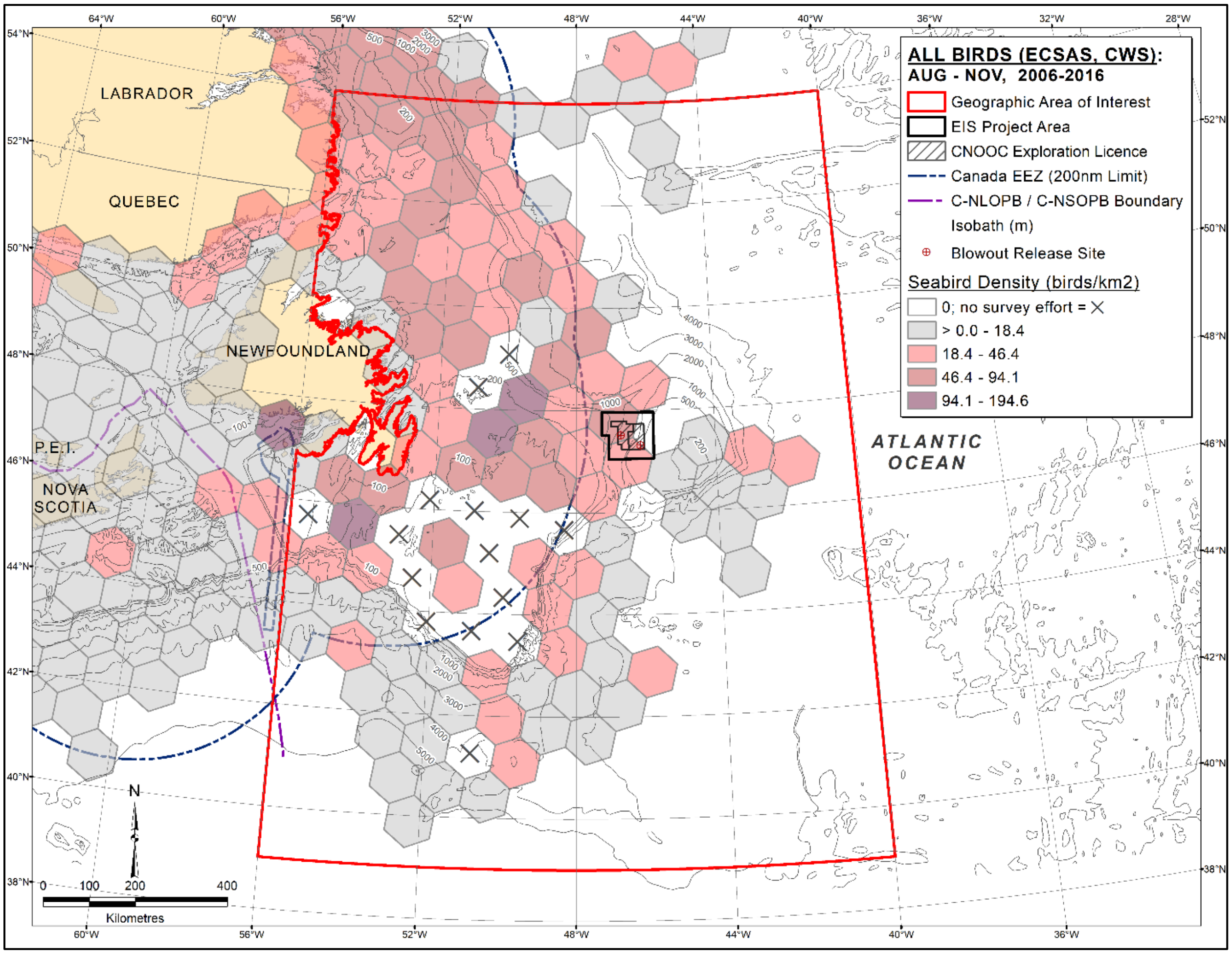
Source: Bolduc et al. (2018).

Figure 4-15. Seabird distribution and densities within the GAI during December–March 2006–2016.



Source: Bolduc et al. (2018).

Figure 4-16. Seabird distribution and densities within the GAI during April–July 2006–2016.

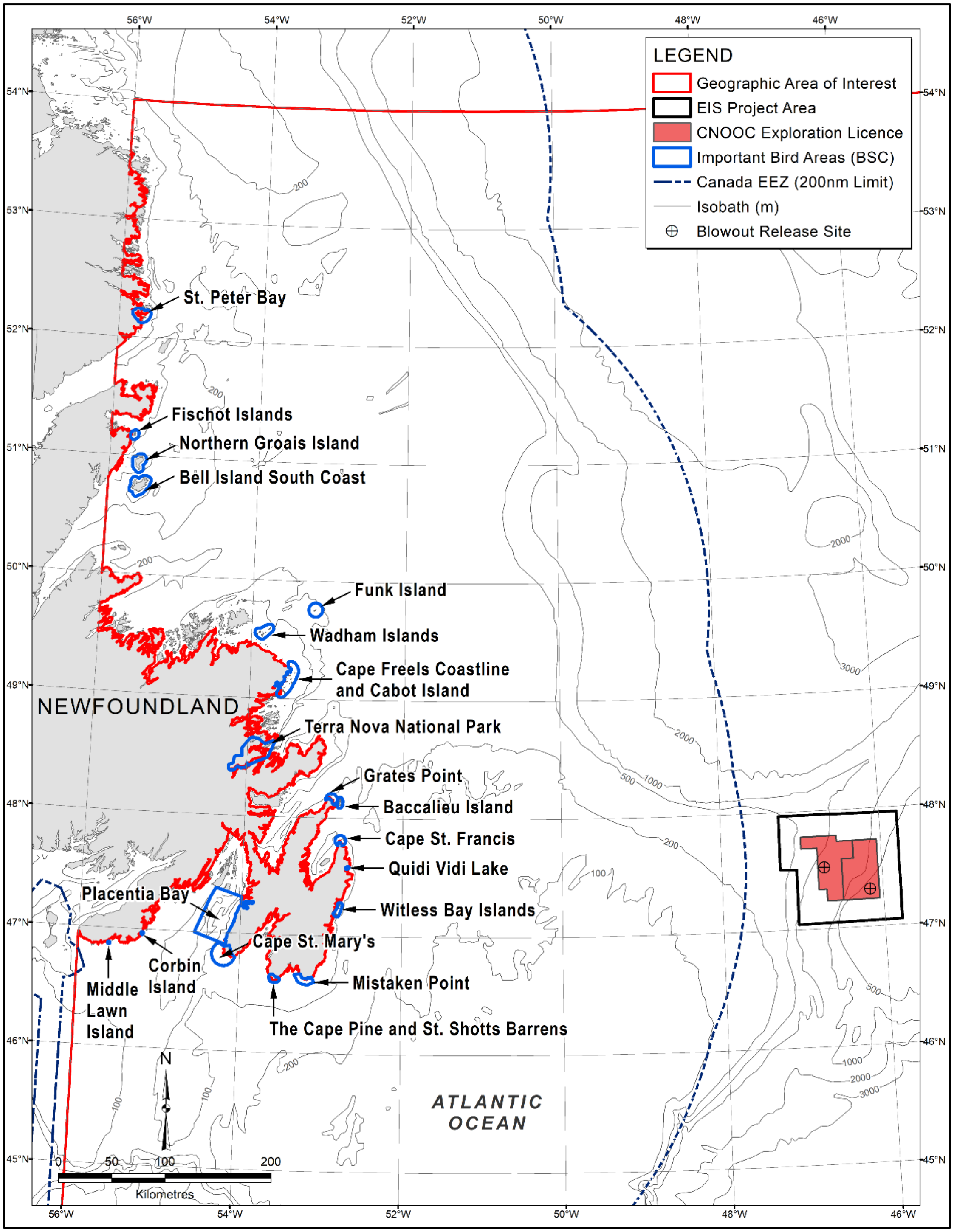


Source: Bolduc et al. (2018).

Figure 4-17. Seabird distribution and densities within the GAI during August–November 2006–2016.

Table 4-11. Important Bird Areas Occurring within the SIMA GAI.

Important Bird Area	Reason for Designation	Key Species
St. Peter Bay	Continentally significant concentrations of congregatory species	Common Eider (moulting) Harlequin Duck (moulting)
Fischot Islands	Globally significant concentrations of congregatory species	Common Eider (wintering)
Northern Groais Island	Continentally significant concentrations of congregatory species	Black-legged Kittiwake Herring Gull Harlequin Duck (moulting)
Bell Island South Coast	Continentally significant concentrations of congregatory species	Great Black-backed Gull Herring Gull Common Eider Harlequin Duck (moulting)
Funk Island *	Globally significant colonial waterbird/seabird concentrations	Common Murre Northern Gannet
Wadham Islands and adjacent marine area	Globally significant colonial waterbird/seabird concentrations	Atlantic Puffin Common Eider (wintering) Leach's Storm-Petrel
Cape Freels Coastline and Cabot Island	Globally significant colonial waterbird/seabird concentrations	Common Eider (wintering) Common Murre
Terra Nova National Park	Nationally significant colonial waterbird concentrations	Common Tern Arctic Tern
Grates Point	Nationally significant concentrations of congregatory species	Common Eider (wintering)
Baccalieu Island *	Globally significant colonial seabird concentrations	Leach's Storm-Petrel Atlantic Puffin Black-legged Kittiwake Northern Gannet
Cape St. Francis	Continentally significant concentrations of congregatory species	Dovekie
Quidi Vidi Lake	Globally significant concentrations of congregatory species. Large aggregations of transitory gulls when lake is ice-covered.	Herring Gull Great Black-backed Gull Glaucous Gull Iceland Gull
Witless Bay Islands *	Globally significant colonial seabird concentrations	Atlantic Puffin Common Murre Razorbill Black-legged Kittiwake Herring Gull Leach's Storm-Petrel
Mistaken Point *	Globally significant concentrations of congregatory species	Common Eider (wintering) Purple Sandpiper Manx Shearwater
Cape Pine and St. Shott's Barrens	Globally significant concentrations of congregatory species	American Golden-Plovers Whimbrel
Cape St. Mary's *	Globally significant colonial seabird concentrations	Northern Gannet Black-legged Kittiwake Harlequin Duck (wintering)
Placentia Bay	Globally significant concentrations of congregatory species	Shearwaters
Corbin Island	Globally significant colonial seabird concentrations	Leach's Storm-Petrel Herring Gull
Middle Lawn Island *	Globally significant colonial seabird concentrations	Manx Shearwater Leach's Storm-Petrel
* Overlapping boundary with Provincially-designated Ecological Reserve		



Source: IBA Canada (2019).

Figure 4-18. Important Bird Areas along shoreline occurring in the GAI.

4.3.4 Migratory Bird Species at Risk

Five extant species designated as SARA Schedule 1 species at risk occur in the GAI: Barrow's Goldeneye, Harlequin Duck, Ivory Gull, Piping Plover, and Red Knot (SARA 2002, 2019). A summary of waterbird species at risk designations for SARA, COSEWIC, the Newfoundland and Labrador *Endangered Species Act* (ESA), and the International Union for the Conservation of Nature (IUCN) is presented in Table 4-12.

Table 4-12. SARA-, COSEWIC-, ESA-, and IUCN- listed marine-associated bird species/populations that may occur in the GAI.

Species	NL ESA Status	Federal Status		IUCN Red List
		***SARA* Listing**	**COSEWIC Assessment**	
Common Eider	None	None	None	Near threatened
Harlequin Duck (eastern pop.)	Vulnerable	Special Concern (Schedule 1)	Special Concern	None
Black Scoter	None	None	None	Near threatened
Long-tailed Duck	None	None	None	Vulnerable
Barrow's Goldeneye (eastern pop.)	Vulnerable	Special Concern (Schedule 1)	Special Concern	None
Piping Plover (*melodus* ssp.)	Endangered	Endangered (Schedule 1)	Endangered	Near threatened
Red Knot (*rufa* ssp.)	Endangered	Endangered (Schedule 1)	Endangered	Near threatened
Buff-breasted Sandpiper	None	Special Concern (Schedule 1)	Special Concern	Near threatened
Red-necked Phalarope	None	Special Concern (Schedule 1)	Special Concern	None
Black-legged Kittiwake	None	None	None	Vulnerable
Ivory Gull	Endangered	Endangered (Schedule 1)	Endangered	Near threatened
Ross's Gull	None	Threatened (Schedule 1)	Threatened	None
Peregrine Falcon (*anatum/tundrius)*	Vulnerable	Special Concern (Schedule 1)	Special Concern	None
Leach's Storm-petrel	None	None	None	Vulnerable
Bermuda Petrel	None	None	None	Endangered
Desertas Petrel	None	None	None	Vulnerable
Zino's Petrel	None	None	None	Endangered
Sooty Shearwater	None	None	None	Near threatened
Razorbill	None	None	None	Near threatened
Atlantic Puffin	None	None	None	Vulnerable

Source: NL Fisheries and Land Resources (2019); BirdLife International (2020); COSEWIC (2020); Government of Canada (2020).

The eastern population of Barrow's Goldeneye is considered *Special Concern* by both *SARA* and COSEWIC. One of the main wintering areas of this population is found along the eastern coast of Newfoundland (Robert et al. 2000). The eastern population of Harlequin Duck is also considered *Special Concern*. Within the GAI, Harlequin Duck winters along the southern coast of the Newfoundland and known moulting sites include Cape St. Mary's, Grey Islands (collective name that includes Northern Groais Island and Bell Island South Coast IBAs), and St. Peter Bay (Soulliere and Thomas 2009; Thomas 2008; COSEWIC 2013).

Ivory Gulls, considered *Endangered* by *SARA*, breed in the High Arctic and winter in the pack ice or along the ice edge (SARA 2019; COSEWIC 2006). A large portion of the Ivory Gull population winters in the Labrador Sea and some individuals occur farther south, extending into the GAI (C-NLOPB 2008, 2014).

Piping Plovers are considered *Endangered* but are generally not found within the GAI. However, in 2013 one pair was found nesting at Deadman's Point Provincial Park on the Bonavista Peninsula (C-NLOPB 2014). The *rufa* subspecies of Red Knot is considered *Endangered* by COSEWIC. It passes through the GAI during migration and may occur in coastal areas (ECCC 2016; C-NLOPB 2014).

Red-necked Phalaropes are considered a species of *Special Concern* by COSEWIC. The species is not listed either federally (*SARA*) or provincially (*ESA*). They breed in the Arctic and low subarctic but during migration and winter they are primarily pelagic (Rubega et al. 2000). They are recorded in the GAI in small numbers during migration, from April–October (Bolduc et al. 2018).

4.4 Marine Mammals

Marine mammals that occur within the GAI are listed in Table 4-13. The months of likely peak occurrence within the GAI and the status of species at risk are also listed. Polar bears are listed as Vulnerable under the provincial ESA (GNL 2019).

The St. Lawrence Estuary and lower reaches of the Saguenay River have been identified as critical habitat for beluga whales (DFO 2012). The identification of blue whale critical habitat is currently being conducted (DFO 2016b). In 2010, three adjacent canyons, the Gully, Shortland Canyon, and Haldimand Canyon, were identified as critical habitat for northern bottlenose whales on the Eastern Scotian Shelf (DFO 2016c). The Grand Manan and Roseway Basins have been identified as critical habitat for north Atlantic right whales (SARA 2019). None of these critical habitats occur within the GAI. No other critical habitat has been identified for marine mammals that occur within the GAI. Detailed overviews of the marine mammals that can occur in the GAI are provided in Sections 6.3.5 of the EIS (Nexen 2018) and 4.2.3 of the Eastern Newfoundland SEA (C-NLOPB 2014). Figure 4-2 in Section 4.1.4 shows offshore sensitive areas for fish and fish habitat which are relevant to marine mammals in many instances.

Table 4-13. Marine mammals occurring within the GAI.

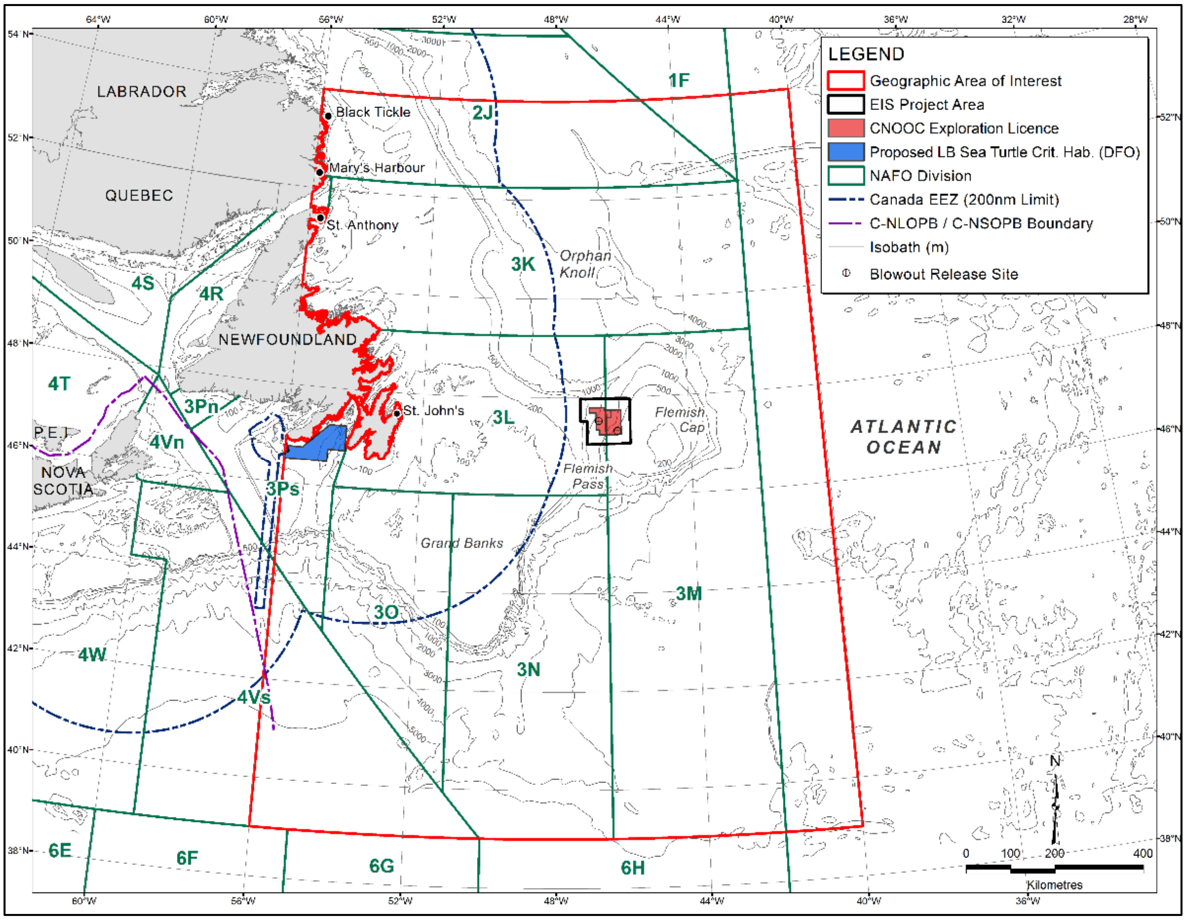
Species	Peak Occurrence	Species at Risk Status									
		SARA			COSEWIC			IUCN			
		E	T	SC	E	T	SC	E	V	LC	DD
Mysticetes (baleen whales)											
North Atlantic right whale *(Eubalaena glacialis)*	Summer	S1			X			X			
Common minke whale (North Atlantic subspecies) *(Balaenoptera acutorostrata acutorostrata)*	Year-round									X	
Sei whale (*Balaenoptera borealis*)	Summer							X			
Blue whale (*Balaenoptera musculus*) Atlantic population	Year-round	S1			X			X			
Fin whale (*Balaenoptera physalus*) Atlantic population	Summer			S1			X		X		
Humpback whale (*Megaptera novaeangliae*) Western North Atlantic population	Summer									X	
Odontocetes (toothed whales)											
Short-beaked common dolphin (*Delphinus delphis*)	Year-round									X	
Long-finned pilot whale (*Globicephala melas*)	Year-round									X	
Risso's dolphin (*Grampus griseus*)	Summer									X	
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)	Year-round									X	
White-beaked dolphin (*Lagenorhynchus albirostris*)	Year-round									X	
Killer whale (*Orcinus orca*) Northwest Atlantic/Eastern Arctic population	Year-round						X				X
Striped dolphin (*Stenella coeruleoalba*)	Year-round									X	
Common bottlenose dolphin (*Tursiops truncatus*)	Summer									X	
Harbour porpoise (*Phocoena phocoena*) Northwest Atlantic population	Year-round						X			X	
Beluga whale (*Delphinapterus leucas*) St. Lawrence Estuary population	Winter	S1			X					X	
Cuvier's beaked whale (*Ziphius cavirostris*)	Year-round									X	
Sowerby's beaked whale (*Mesoplodon bidens*)	Year-round			S1			X				X
True's beaked whale (*Mesoplodon mirus*)	Year-round										X

Species	Peak Occurrence	Species at Risk Status									
		SARA			COSEWIC			IUCN			
		E	T	SC	E	T	SC	E	V	LC	DD
Northern bottlenose whale (*Hyperoodon ampullatus*) Scotian Shelf population	Year-round	S1			X						X
Davis Strait-Baffin Bay-Labrador Sea population	Year-round						X				X
Sperm whale (*Physeter macrocephalus*)	Year-round								X		
Pygmy sperm whale (*Kogia breviceps*)	Year-round										X
Pinnipeds (seals)											
Harp seal (*Pagophilus groenlandicus*)	Winter									X	
Harbour seal (Atlantic and Eastern Arctic subspecies) (*Phoca vitulina concolor*)	Year-round									X	
Hooded seal (*Cystophora cristata*)	Winter								X		
Grey seal (*Halichoerus grypus*)	Year-round									X	
Ringed seal (*Phoca hispida*)	Year-round									X	

Source: Amec (2014) and OBIS (2017) *in* Nexen (2018); Nexen (2018); COSEWIC (2019); IUCN (2019); SARA (2019)
Note: IUCN = International Union for Conservation of Nature; E = Endangered; T = Threatened; SC = Special Concern; V = Vulnerable; LC = Least Concern; DD = Data Deficient; S = Schedule.

4.5 Sea Turtles

Leatherback and loggerhead sea turtles *(Caretta caretta)* occur within the GAI. These turtles are usually absent during the winter months, but they may be present during April–December (C-NOLPB 2014; Nexen 2018). Both species are listed as *Endangered* on Schedule 1 of *SARA* and COSEWIC (SARA 2019; COSEWIC 2019). The proposed Recovery Strategy for the Atlantic population of leatherbacks identified potential critical habitat in Placentia Bay, and in areas south and east of the Burin Peninsula (as well as two locations offshore Nova Scotia; DFO 2016c; Figure 4-19). While loggerheads are less common than leatherbacks, they are most abundant on the Grand Banks during their spring migration and summer foraging (C-NLOPB 2014; Nexen 2018). Sea turtles occurring in the GAI are described in Sections 6.3.5 of the EIS (Nexen 2018) and 4.2.3.4 of the Eastern Newfoundland SEA (C-NLOPB 2014).



Source: DFO (2016c).

Figure 4-19. Proposed leatherback sea turtle critical habitat in the GAI.

5.0 Oil Spill Modelling

5.1 Background and Approach

Oil spill trajectory modelling relevant to the CNOOC Flemish Pass Exploration Drilling Project was performed as part of the EIS to evaluate the effects of potential spill scenarios. Trajectory modelling for hydrocarbon releases in EL 1144 and EL 1150 was conducted twice, in 2018 (RPS 2018) and 2019 (RPS 2019). RPS (2019) was included as an appendix in CNOOC (2019). The durations of blowout and model simulation for the trajectory modelling conducted in 2018 was intended to represent circumstances associated with the capping of the well, while the durations used in the 2019 modelling was intended to represent the time required to drill a relief well. In addition to the trajectory modelling, oil fate and behaviour were also modelled (SL Ross 2017).

The scope of the modelling for an unmitigated subsea blowout scenario included several of the following factors.

- prediction of the movement and weathering of the oil originating from two different release sites using spatial wind data, current data, and specific hydrocarbon properties;
- seasonal variation in the modelled impacts during summer and winter conditions;
- modelling to predict the probability and areal extent of oiling above threshold levels at the sea surface, on shorelines, and in the water column for each scenario;
- modelling to show the single spill trajectory with the highest amount of oil reaching the shore; and
- calculation of the maximum amount of shoreline oiling.

The OILMAPDeep blowout model and the SIMAP oil trajectory and fate model were used to simulate the hypothetical release scenarios. OILMAPDeep was used to define the near-field dynamics of the subsurface blowout plume, which in turn was used to initialize the far-field modelling conducted in SIMAP. As noted earlier, two approaches were used during the spill modelling: (1) stochastic; and (2) deterministic. More detailed information related to the spill modelling approach is contained in Sections 2.2 of RPS (2018, 2019).

5.1.1 Stochastic Approach

The stochastic approach uses numerous trajectories of the same release scenario to determine the particular areas that are at increased risk of exposure to oil based on the potential variability of meteorological and oceanographic conditions during and after a release (171 runs for both EL 1144 and EL 1150; 81 winter and 90 summer). Stochastic modelling associated with EL 1144 and EL 1150, individual trajectory start dates were selected randomly every 14 days throughout the window of environmental data coverage to ensure that these data were adequately sampled. Results provide the probable behaviour of potential releases, including the areas associated with probability of oil exposure at some time during or after a release, and the shortest time required for oil to reach any point within the areas predicted to be exposed above a specified threshold.

5.1.2 Deterministic Approach

Six individual trajectories of interest were identified and selected from the stochastic ensemble of results for the deterministic analysis. The 95th percentile 'worst case' results for surface oil exposure, water column dissolved hydrocarbon concentrations, and shoreline length exposure were identified from the stochastic model scenarios at each blowout release location. These representative deterministic simulations maximize the predicted effects from the suite of stochastic simulations. Note that the 95th percentile results for surface oil exposure came from the winter modelling, while the 95th percentile results for water column dissolved hydrocarbon concentrations and shoreline length exposure came from the summer modelling.

The deterministic trajectory and fate simulations provide an estimate of the oil's fate and transport through the environment as well as its physical and chemical behaviour for a specific set of environmental conditions. While the stochastic analysis provides insight into the probable behaviour of oil spills given historic wind and current data for the geographic area of interest, the deterministic analysis provides individual trajectory oil weathering information, expected concentrations and thicknesses of oil contamination, mass balance, and other information related to a single release at a given location and time. Results of the deterministic simulations provide a history of the fate and weathering of oil over the duration of the release (i.e., mass balance) expressed as the percentage of released oil on the water surface, on the shoreline, evaporated, entrained in the water column, and degraded. In addition, cumulative footprints of the individual trajectories over the course of the entire modeling duration will depict the cumulative path of floating surface oil, mass of shoreline oil, and the maximum concentration of dissolved hydrocarbons in the water column at any point in time.

5.1.3 Thresholds

The thresholds used to define areas, lengths, and volumes exposed above certain levels of concern are discussed in more detail in Table 16.5 of the EIS (Neven 2018) and Table 2-2 in the RPS Trajectory Modelling report (RPS 2019) in terms of selection rationale, visual appearance, and relevant citations. Table 5-1 provides the various ecological and socioeconomic thresholds for oil on surface, oil in the water column, and oil on shoreline. These thresholds were taken into account when determining the rationale for the selection of PRIs and NRIs associated with the natural attenuation of spilled crude oil seen in Section 6.3.1.1.

Table 5-1. Thresholds used to define areas, lengths and volumes exposed above certain levels of concern (ecological and socio-economic).

Threshold Type	Threshold	
	Ecological	Socio-economic
Oil on surface	10 g/m^2 (10 µm thickness)	0.04 g/m^2 (0.04 µm thickness)
Oil in the water column	100 µg/L THC (1 µg/L PAHs)[1]	100 µg/L THC (1 µg/L PAHs)[1]
Oil on shoreline	100 g/m^2	1.0 g/m^2

[1] µg/L equivalent of parts per billion (ppb); polycyclic aromatic hydrocarbons (PAHs) constitute ~ 1% of whole oil (THC).

5.1.4 Spill Scenarios

For the stochastic modelling, 'Summer' and 'Winter' seasons represent mean weather conditions for two periods of time: (1) May–October for 'Summer'; and (2) November–April for 'Winter'. Stochastic modelling for the EL 1144 and EL 1150 release locations included 81 winter and 90 summer individual simulations within each stochastic scenario. Deterministic modelling was derived from stochastic simulations that produced the worst environmental impacts from an emergency response point of view and analyzed in the EIS as an unmitigated spill result. For the CNOOC Flemish Pass SIMA, the unmitigated deterministic simulations represent a natural attenuation unmitigated spill scenario for both summer and winter at two well locations. Thus, the four spill scenarios considered are as follow:

- EL 1144 - Summer
- EL 1144 - Winter
- EL 1150 - Summer
- EL 1150 - Winter

Based on the modelling conducted by RPS (2019) representative of a timeline associated with drilling a relief well, all four scenarios are characterized by a 120-day release duration over a modelling simulation period of 160 days. No modelling that included the use of dispersants was conducted for any scenario.

5.2 Oil Spill Modelling Results

As mentioned above, two locations, one within each of EL 1144 and EL 1150, were selected for modelling to evaluate a WCCD scenario.

5.2.1 Rationale for Selection of EL 1144-Summer as Focal Scenario for SIMA Assessment

Table 5-2 provides a comparison of the two hypothetical release locations in terms of release rate, total release volume, stochastic analysis results, and deterministic analysis results.

Table 5-2. Comparison of oil spill modelling results between EL 1144 and EL 1150.

Parameter	Modelling Release Location	
	EL 1144	**EL 1150**
Water depth	1,137 m	378 m
Release rate	184,000 bpd	44,291 bpd
Release volume	22,080,000 bbl	5,314,920 bbl
Stochastic Analysis Results		
Range of areas of average surface oil thickness >0.04 µm [1% bin]	8,211,000–8,371,000 km^2	8,152,000–8,304,000 km^2
Range of areas of average surface oil thickness >0.04 µm [10% bin]	6,657,000–7,208,000 km^2	6,483,000–6,877,000 km^2
Range of areas of average surface oil thickness >0.04 µm [90% bin]	2,205,000–2,532,000 km^2	2,053,000–2,328,000 km^2
Range of areas of water column dissolved hydrocarbons >1 µg/L at some depth in water column [1% bin]	709,200–763,600 km^2	120,200–315,800 km^2
Range of areas of water column dissolved hydrocarbons >1 µg/L at some depth in water column [10% bin]	463,888–468,800 km^2	87,810–139,200 km^2
Range of areas of water column dissolved hydrocarbons >1 µg/L at some depth in water column [90% bin]	130,900–149,700 km^2	23,960–25,530 km^2
Range of lengths of shoreline with average amount of oil >1 g/m^2 [1–5% bin]	629–1,668 km	450–1,603 km
Range of lengths of shoreline with average amount of oil >1 g/m^2 [5–15% bin]	317–1,048 km	46–1,144 km
Range of lengths of shoreline with average amount of oil >1 g/m^2 [15–25% bin]	60–345 km	161–308 km
Range of lengths of shoreline with average amount of oil >1 g/m^2 [25–50% bin]	331–473 km	133–340 km
Range of lengths of shoreline with average amount of oil >1 g/m^2 [50–75% bin]	60–188 km	18–69 km
Range of lengths of shoreline with average amount of oil >1 g/m^2 [75–100% bin]	0–14 km	0 km
Range of average probabilities of shoreline oil contamination	1%	9–19%
Range of maximum probabilities of shoreline oil contamination	48-77%	41–70%
Range of minimum times to shore	15–34 days	15–51 days
Range of maximum times to shore	146–160 days	141–160 days
Deterministic Analysis Results		
95^{th} percentile surface oil exposure – on surface	12.2%	10.8%
95^{th} percentile surface oil exposure – evaporated	43.3%	47.4%
95^{th} percentile surface oil exposure – in water column	4.2%	3.5%
95^{th} percentile surface oil exposure – on seabed sediment	<0.1%	<0.1%
95^{th} percentile surface oil exposure – on shoreline	<0.1%	<0.1%
95^{th} percentile surface oil exposure – degraded	40.2%	36.5%
95^{th} percentile surface oil exposure – outside grid	<0.1%	1.8%
95^{th} percentile water column – on surface	9.8%	8.0%
95^{th} percentile water column – evaporated	48.1%	50.6%
95^{th} percentile water column – in water column	5.3%	6.5%
95^{th} percentile water column – on seabed sediment	<0.1%	<0.1%
95^{th} percentile water column – on shoreline	<0.1%	<0.1%
95^{th} percentile water column– degraded	36.7%	34.2%

Parameter	Modelling Release Location	
	EL 1144	EL 1150
95th percentile water column – outside grid	0.1%	0.8%
95th percentile shoreline contact – on surface	12.1%	7.2%
95th percentile shoreline contact – evaporated	47.1%	50.2%
95th percentile shoreline contact – in water column	3.1%	6.6%
95th percentile shoreline contact – on seabed sediment	<0.1%	<0.1%
95th percentile shoreline contact – on shoreline	<0.1%	<0.1%
95th percentile shoreline contact – degraded	37.4%	34.4%
95th percentile shoreline contact – outside grid	0.2%	1.6%
95th percentile surface oil exposure-approximate surface area exceeding ecological thickness threshold	872,300 km^2	20,120 km^2
95th percentile surface oil exposure-approximate shoreline length exceeding ecological mass/unit area threshold	441 km	51 km
95th percentile surface oil exposure-approximate subsurface volume exceeding ecological THC threshold	214,850 km^3	57,300 km^3
95th percentile surface oil exposure-approximate surface area exceeding socioeconomic thickness threshold	5,844,000 km^2	2,153,000 km^2
95th percentile surface oil exposure-approximate shoreline length exceeding socioeconomic mass/unit area threshold	455 km	55 km
95th percentile surface oil exposure-approximate subsurface volume exceeding socioeconomic THC threshold	214,850 km^3	57,300 km^3
95th percentile water column-approximate surface area exceeding ecological thickness threshold	1,046,000 km^2	225,700 km^2
95th percentile water column -approximate shoreline length exceeding ecological mass/unit area threshold	432 km	106 km
95th percentile water column -approximate subsurface volume exceeding ecological THC threshold	220,850 km^3	196,700 km^3
95th percentile water column -approximate surface area exceeding socioeconomic thickness threshold	4,093,000 km^2	4,142,000 km^2
95th percentile water column -approximate shoreline length exceeding socioeconomic mass/unit area threshold	437 km	124 km
95th percentile water column -approximate subsurface volume exceeding socioeconomic THC threshold	220,850 km^3	196,700 km^3
95th percentile shoreline contact-approximate surface area exceeding ecological thickness threshold	1,086,000 km^2	169,800 km^2
95th percentile shoreline contact -approximate shoreline length exceeding ecological mass/unit area threshold	758 km	625 km
95th percentile shoreline contact -approximate subsurface volume exceeding ecological THC threshold	158,650 km^3	203,700 km^3
95th percentile shoreline contact -approximate surface area exceeding socioeconomic thickness threshold	4,974,000 km^2	4,442,000 km^2
95th percentile shoreline contact -approximate shoreline length exceeding socioeconomic mass/unit area threshold	767 km	634 km
95th percentile shoreline contact -approximate subsurface volume exceeding socioeconomic THC threshold	158,650 km^3	203,700 km^3

Note:
Bins are based on stochastic probabilities; for example, a 90% bin for range of areas of average surface oil thickness >0.04 µm indicates that 90% of the 171 modelled simulations predicted this range.
Each range consists of predicted areas/lengths for annual, winter and summer simulations.
Statistics related to shoreline oil contamination refer to all shorelines (Canadian and Portuguese).

Based on the information provided in Table 5-2, modelling using the EL 1144 release location represents a worst-case scenario compared to the modelling using the EL 1150 release location. Table 5-3 provides a comparison of stochastic analysis results between the EL 1144-Summer scenario and the EL 1144-Winter scenario.

Table 5-3. Comparison between EL 1144-Summer and EL 1144-Winter modelling scenarios.

Parameter	Season	
	Summer	Winter
Stochastic Analysis Results		
Area of average surface oil thickness >0.04 µm [1% bin]	8,339,000 km^2	8,371,000 km^2
Area of average surface oil thickness >0.04 µm [10% bin]	6,657,000 km^2	7,208,000 km^2
Area of average surface oil thickness >0.04 µm [90% bin]	2,532,000 km^2	2,205,000 km^2
Area of water column dissolved hydrocarbons >1 µg/L at some depth in water column [1% bin]	709,200 km^2	763,600 km^2
Area of water column dissolved hydrocarbons >1 µg/L at some depth in water column [10% bin]	463,800 km^2	468,800 km^2
Area of water column dissolved hydrocarbons >1 µg/L at some depth in water column [90% bin]	149,700 km^2	130,900 km^2
Length of shoreline with average amount of oil >1 g/m^2 [1–5% bin]	629 km	1,245 km
Length of shoreline with average amount of oil >1 g/m^2 [5–15% bin]	317 km	1,048 km
Length of shoreline with average amount of oil >1 g/m^2 [15–25% bin]	60 km	345 km
Length of shoreline with average amount of oil >1 g/m^2 [25–50% bin]	335 km	331 km
Length of shoreline with average amount of oil >1 g/m^2 [50–75% bin]	188 km	0 km
Length of shoreline with average amount of oil >1 g/m^2 [75–100% bin]	14 km	0 km
Average probability of shoreline oil contamination	1%	1%
Maximum probability of shoreline oil contamination	77%	48%
Minimum time to shore	34 days	15 days
Maximum time to shore	160 days	160 days

Note:
Bins are based on stochastic probabilities; for example, a 90% bin for range of areas of average surface oil thickness >0.04 µm indicates that 90% of the 171 modelled simulations predicted this range.
Statistics related to shoreline oil contamination refer to all shorelines (Canadian and Portuguese).

Although the stochastic analysis results in Table 5-3 indicate that the EL 1144-Winter scenario is characterized as having larger areas of threshold exceedances in the 1% and 10% bins, the EL 1144-Summer scenario has larger areas of threshold exceedances in the 90% bins. With respect to shoreline length with threshold exceedance, while the EL 1144-Winter scenario has greater lengths associated with the 1–25% probability range, the EL 1144-Summer scenario has greater lengths associated with the higher probability ranges (25–100%). The EL 1144-Winter scenario has a lower minimum time of oil reaching shore, but this statistic is dominated by shoreline of the Azores, not the Newfoundland and Labrador shoreline. Therefore, based on the information presented in Tables 5-2 and 5-3, and the fact that there are more susceptible biological resources and critical life stages in the waters during the summer months, the EL 1144-Summer scenario is selected as the focal scenario for analysis in this SIMA. Discussion with CNOOC (D. Sullivan, CW-Health, Safety and Environment Lead-Deepwater, CNOOC International, pers. comm., March 2019) confirmed this choice of focal scenario. The other three spill scenarios (i.e., EL 1144-Winter, EL 1150-Summer, and EL 1150-Winter) are briefly compared to EL 1144-Summer in terms of alternate scenario risk ratings in Section 6.4.7.

5.2.2 EL 1144 – Summer Scenario

The focal modelling scenario is characterized by a 120-day release duration and a modeling simulation period of 160-days. All details associated with the spill modelling for the release location within EL 1144 are available in RPS (2019), including 'winter' and 'annual' results. The modelling results are discussed in the context of three potential results of the hypothetical blowout in EL 1144: (1) thickness of crude oil on the sea surface; (2) dissolved hydrocarbons in the water column; and (3) amount of crude oil on shoreline and sea bottom.

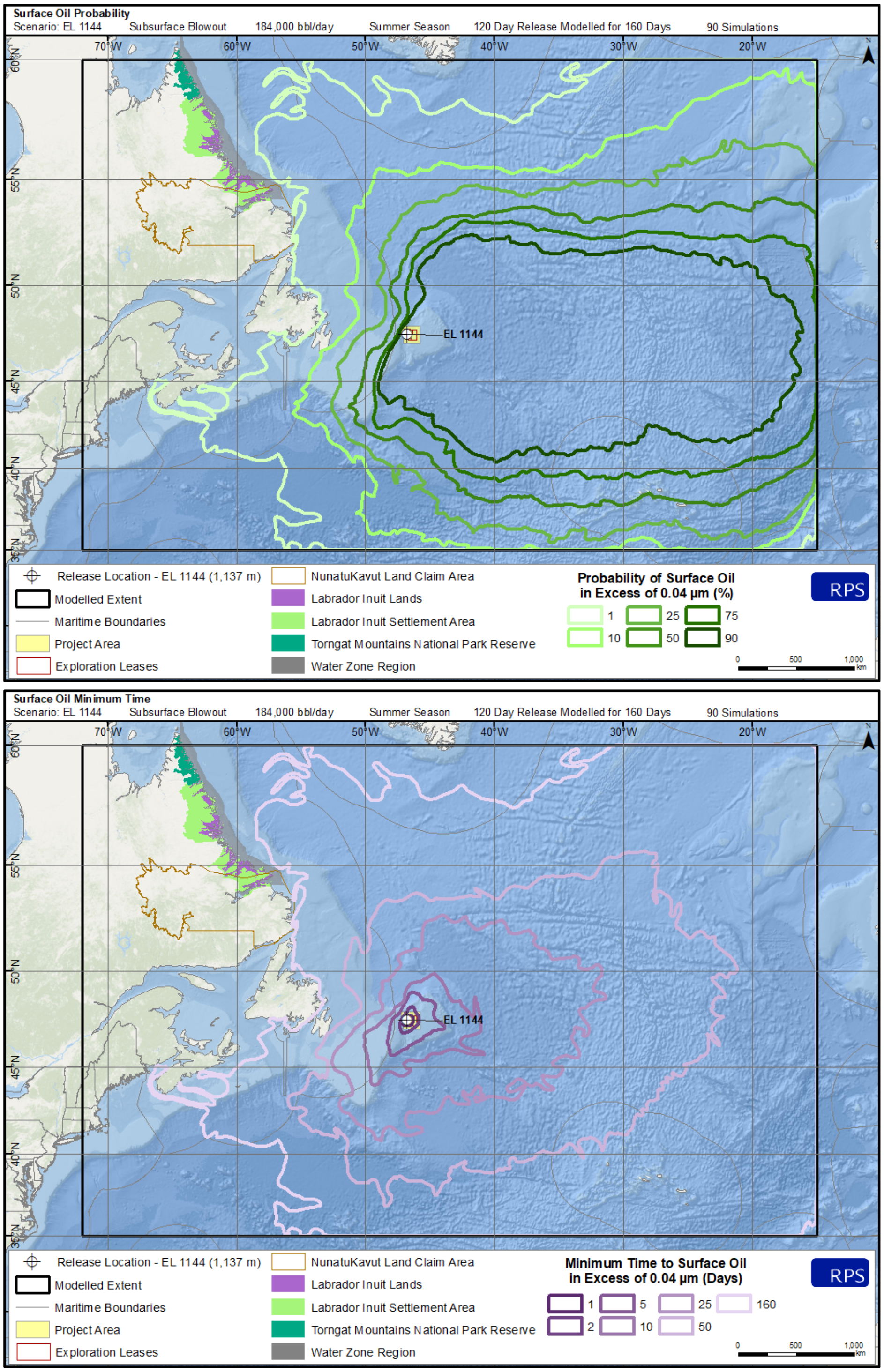
5.2.2.1 Thickness of Crude Oil on Sea Surface

Note that the ecological and socio-economic thresholds for the thickness of crude at the ocean's surface are 0.01 mm and 0.00004 mm, respectively (see Table 2-2 in RPS 2019).

Stochastic Modelling Analysis

The stochastically-derived areas associated with the probability of surface oil thickness exceeding 0.04 µm during a summer subsea blowout within EL 1144 are indicated in Table 4-1 of RPS (2019) and shown in Figure 5-1. Figure 5-1 shows the probability contours for surface oil thickness >0.04 µm and minimum time to threshold exceedance. The predicted areas of the ocean surface with oil thickness exceeding threshold for 1%, 10%, and 90% probability contours are 8,339,000 km^2, 6,657,000 km^2, and 2,532,000 km^2, respectively (see Table 4-1 in RPS 2019).

As indicated in Figure 5-1, the predicted area of 25–90% probability of threshold exceedance lies primarily to the east of the EL 1144 blowout location. It includes the Flemish Cap, the Flemish Pass, the Orphan Knoll and the eastern and southern portions of the Grand Banks. In terms of the predicted minimum time to threshold exceedance, the area representing 1–10 days is similar to that already described for the predicted area of 25–90% probability of threshold exceedance.

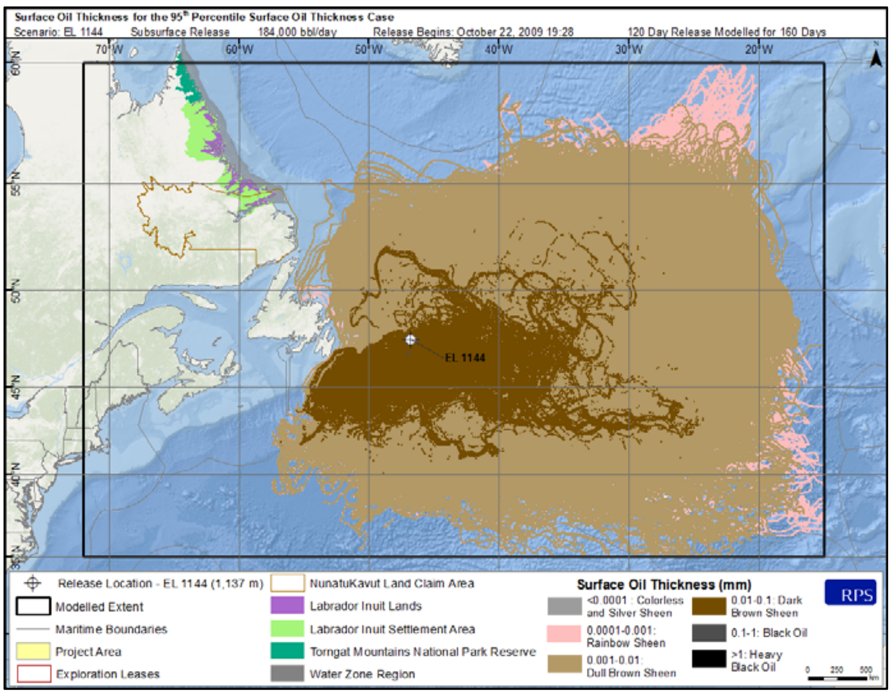


Source: RPS (2019).

Figure 5-1. Probability of surface oil thickness >0.04 µm (top) and minimum time to threshold exceedance (bottom) resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

Deterministic Modelling Analysis

Figure 5-2 indicates the surface oil thickness deterministic modelling results for the 95th percentile average surface oil thickness resulting from a 120-day subsurface blowout in EL 1144. The plot is dominated by three ranges of surface oil thickness: (1) 0.001–0.01 mm - dull brown sheen; (2) 0.01–0.1 mm – brown sheen; and (3) 0.0001–0.001 mm – rainbow sheen. Examples of the appearance of oil on the water surface are provided in Figure A-1 in the Appendix. These are presented in descending order of areal coverage. All three 'thickness' areas extend beyond the boundaries of the GAI. The predicted area representing the thickest layer of oil (i.e., 0.01–0.1 mm) includes much of the Grand Banks, the Flemish Cap, and the Flemish Pass, and extends ~1,000 km to the west of the EL 1144 release location.

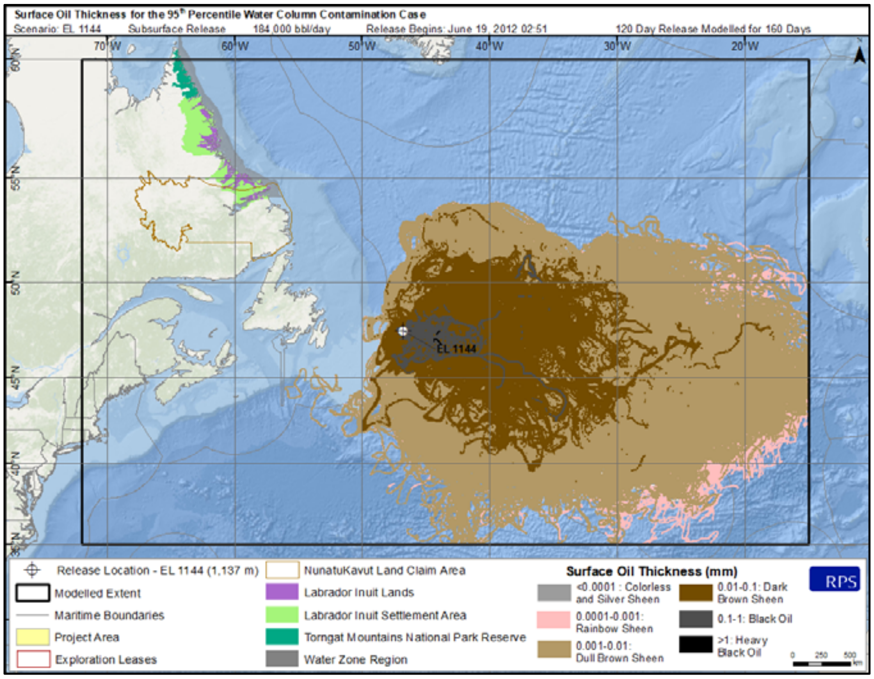


Source: RPS (2019).

Figure 5-2. Representative scenario for 95th percentile average oil thickness resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

Figure 5-3 indicates the surface oil thickness deterministic modelling results for the 95th percentile water column contamination case resulting from a 120-day subsurface blowout in EL 1144. This plot is dominated by four ranges of surface oil thickness: (1) 0.001–0.01 mm – dull brown sheen; (2) 0.01–0.1 mm – brown sheen; (3) 0.1–1.0 mm – black oil; and (4) 0.0001–0.001 mm – rainbow sheen. These are presented in descending order of areal coverage.

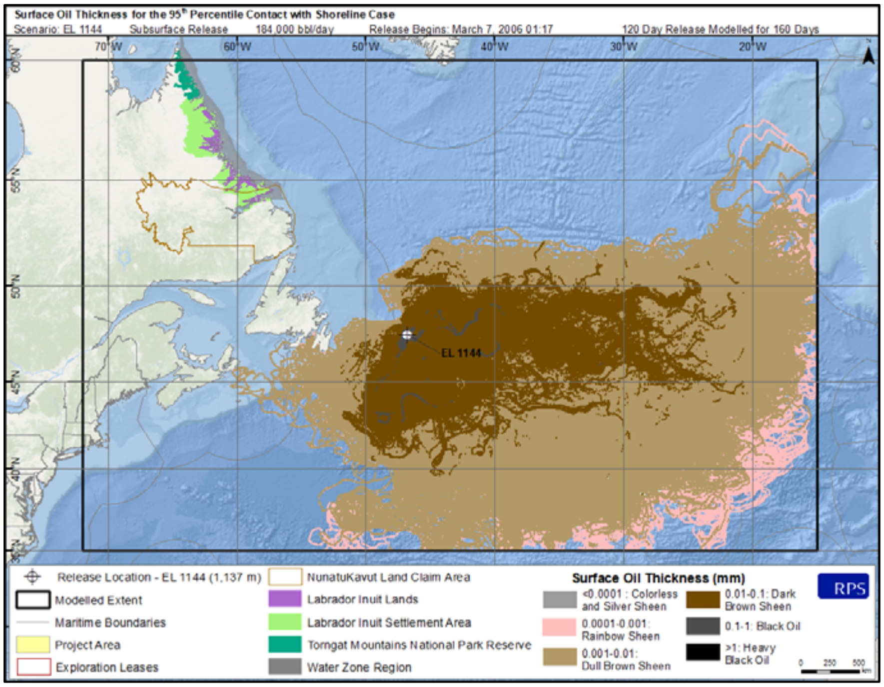
All four areas extend beyond the boundaries of the GAI, although the area of thickest oil occurs mostly within the GAI. The predicted area representing the thickest layer of oil (i.e., 0.1–1.0 mm) includes the Flemish Cap and the Flemish Pass.



Source: RPS (2019).

Figure 5-3. Representative scenario for 95th percentile water column contamination case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

Figure 5-4 indicates the surface oil thickness deterministic modelling results for the 95th percentile contact with shoreline case resulting from a 120-day subsurface blowout in EL 1144. This plot is also dominated by four ranges of surface oil thickness: (1) 0.001–0.01 mm – dull brown sheen; (2) 0.01–0.1 mm – brown sheen; (3) 0.0001–0.001 mm – rainbow sheen; and (4) 0.1–1.0 mm – black oil. These are presented in descending order of areal coverage. Three of the 'thickness' areas, excluding that for 'black oil', extend beyond the boundaries of the GAI. The predicted area representing the thickest layer of oil (i.e., 0.01–0.1 mm) is somewhat localized to the release location in EL 1144. While Figure 5-4 also indicates shoreline contact on the southern Avalon Peninsula, Placentia Bay, and the Burin Peninsula, the probability of this is very low (i.e., 1–10% range).



Source: RPS (2019).

Figure 5-4. Representative scenario for 95th percentile contact with shoreline case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

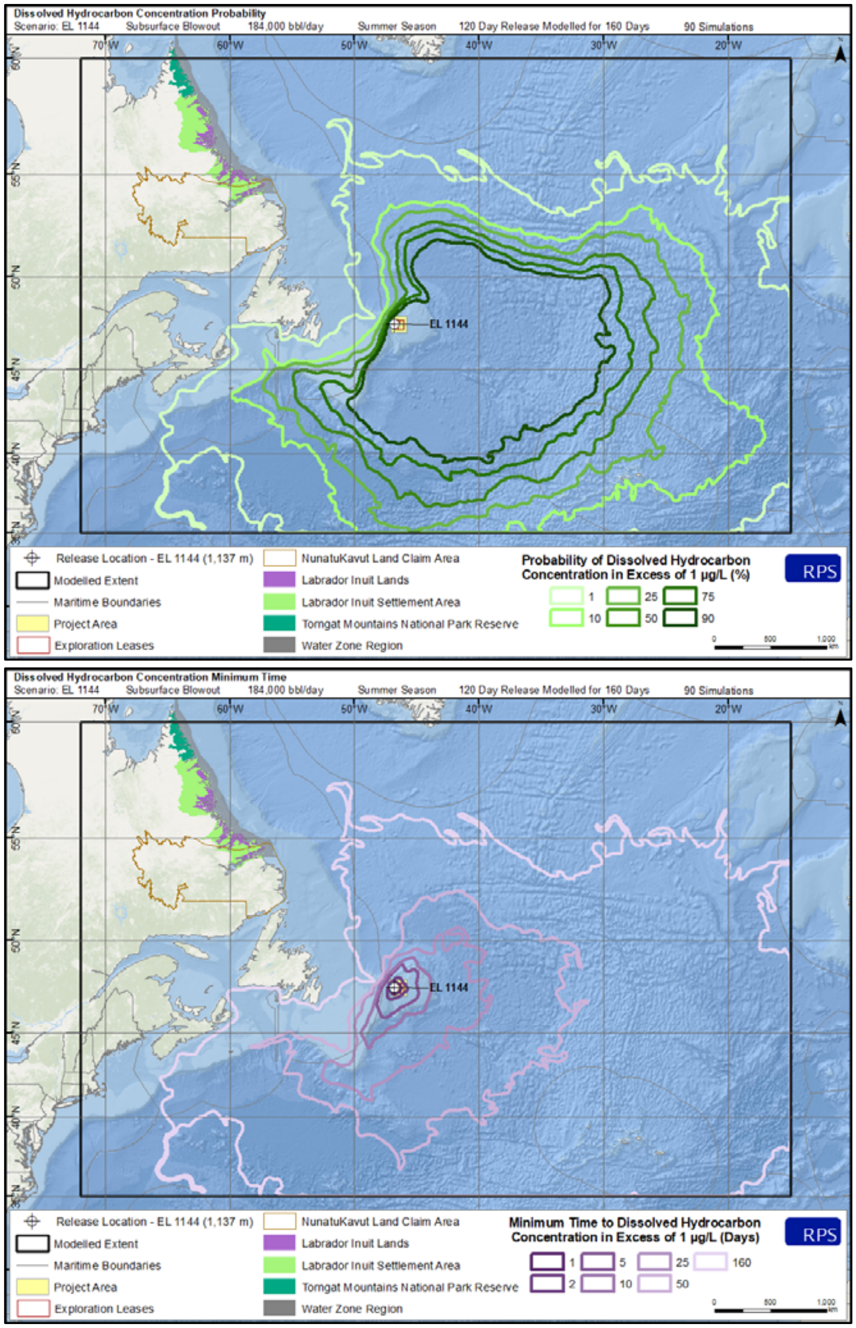
5.2.2.2 Dissolved Hydrocarbons in Water Column

Note that the ecological and socio-economic threshold for maximum dissolved hydrocarbon concentration at any depth in the water column is 1.0 µg/L (i.e., 1.0 ppb) (see Table 2-2 in RPS 2019).

Stochastic Modelling Analysis

The stochastically-derived areas associated with the probability of dissolved hydrocarbons in the water column exceeding 1 µg/L (i.e., 1 ppb) during a summer subsea blowout within EL 1144 are indicated in Table 4-1 of RPS (2019) and represented by Figure 5-5 of this SIMA document. Figure 5-5 shows the probability contours for dissolved hydrocarbons concentrations >1µg/L and minimum time to threshold exceedance. The predicted areas of the ocean with dissolved hydrocarbons in the water column exceeding threshold for 1%, 10%, and 90% probability contours are 709,200 km^2, 463,800 km^2, and 149,700 km^2, respectively (see Table 4-1 in RPS 2019).

As indicated in Figure 5-5, the predicted area of 10–90% probability of threshold exceedance lies primarily to the east of the EL 1144 blowout location. It includes the Flemish Cap, the Flemish Pass, the Orphan Knoll, and the eastern and southern portions of the Grand Banks. In terms of the predicted minimum time to threshold exceedance, the area representing 1–10 days is similar to that already described for the predicted area of 10–90% probability of threshold exceedance.

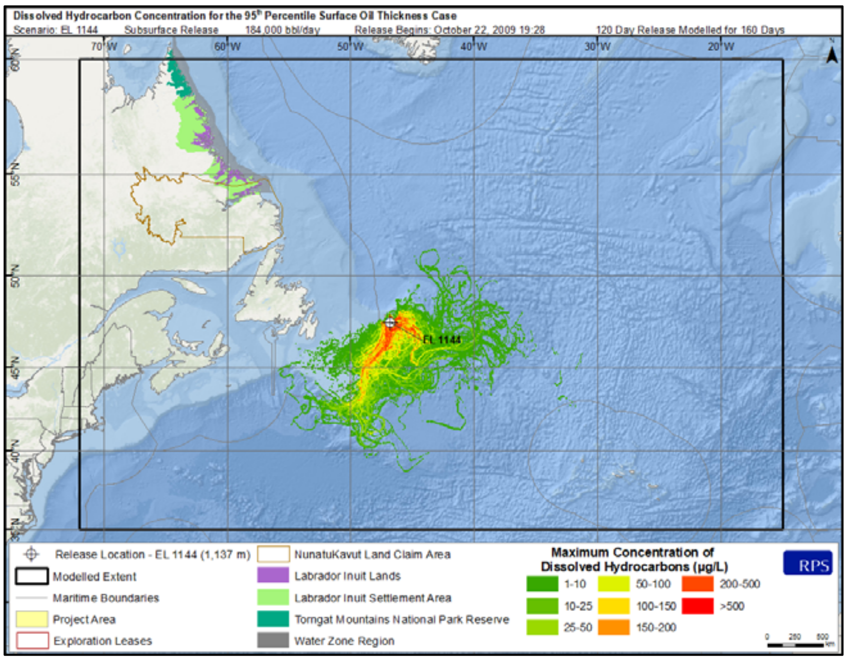


Source: RPS (2019).

Figure 5-5. Summer probability of dissolved hydrocarbon concentrations >1 µg/L at some depth in the water column (top) and minimum time to threshold exceedance (bottom) resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

Deterministic Modelling Analysis

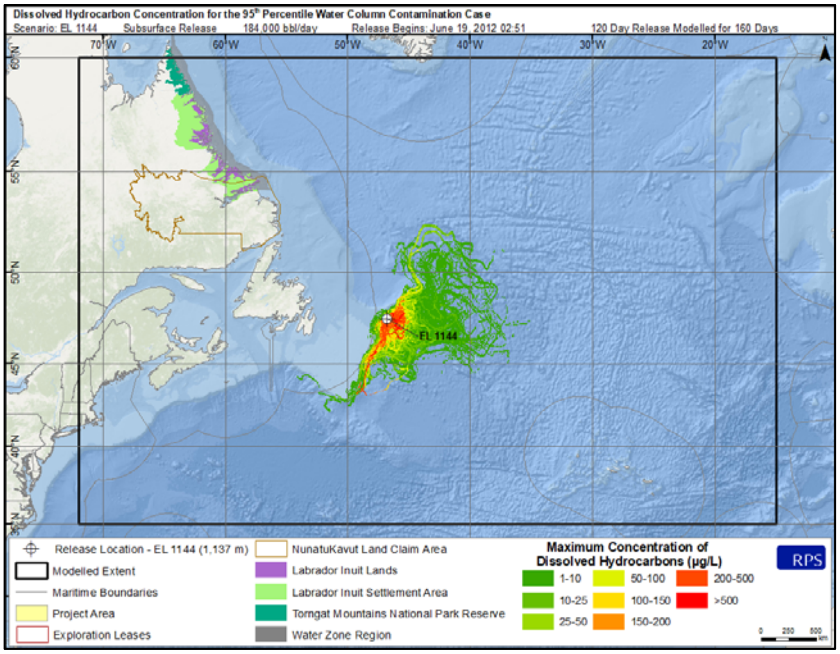
Figure 5-6 indicates the deterministic modelling results for maximum dissolved hydrocarbon concentration at any depth in the water column for the 95th percentile surface oil thickness resulting from a 120-day subsurface blowout in EL 1144. The plot is dominated by the 1–150 µg/L range. Maximum dissolved hydrocarbon concentrations >150 µg/L are indicated in the vicinity of the blowout location, ~300 km to the east of the blowout location around the Flemish Cap and ~500 km southwest of the release location along the slope of the Grand Banks.



Source: RPS (2019).

Figure 5-6. Maximum dissolved hydrocarbon concentration at any depth in the water column for the 95th percentile surface oil thickness case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

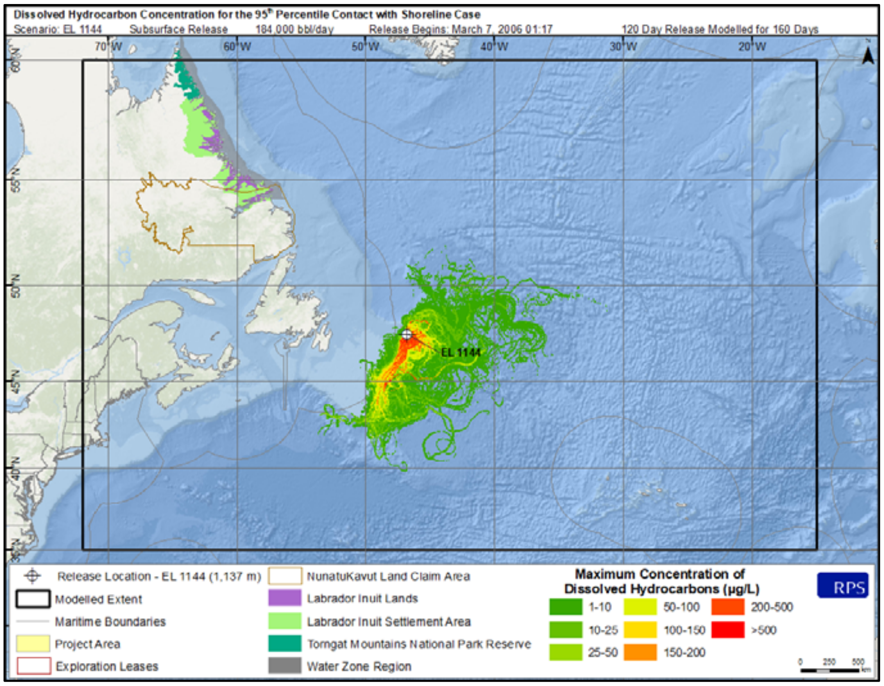
Figure 5-7 indicates the deterministic modelling results for maximum dissolved hydrocarbon concentration at any depth in the water column for the 95th percentile water column contamination case resulting from a 120-day subsurface blowout in EL 1144. The plot is dominated by the 1–150 µg/L range. Maximum dissolved hydrocarbon concentrations >150 µg/L are indicated in the vicinity of the blowout location, ~300 km to the east of the blowout location around the Flemish Cap and ~500 km southwest of the release location along the slope of the Grand Banks.



Source: RPS (2019).

Figure 5-7. Maximum dissolved hydrocarbons at any depth in the water column for the 95th percentile water column contamination case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

Figure 5-8 indicates the deterministic modelling results for maximum dissolved hydrocarbon concentration at any depth in the water column for the 95th percentile contact with shoreline case resulting from a 120-day subsurface blowout in EL 1144. The plot is dominated by the 1–150 µg/L range. Maximum dissolved hydrocarbon concentrations >150 µg/L are indicated in the vicinity of the blowout location, ~300 km to the east of the blowout location around the Flemish Cap and ~500 km southwest of the release location along the slope of the Grand Banks.



Source: RPS (2019).

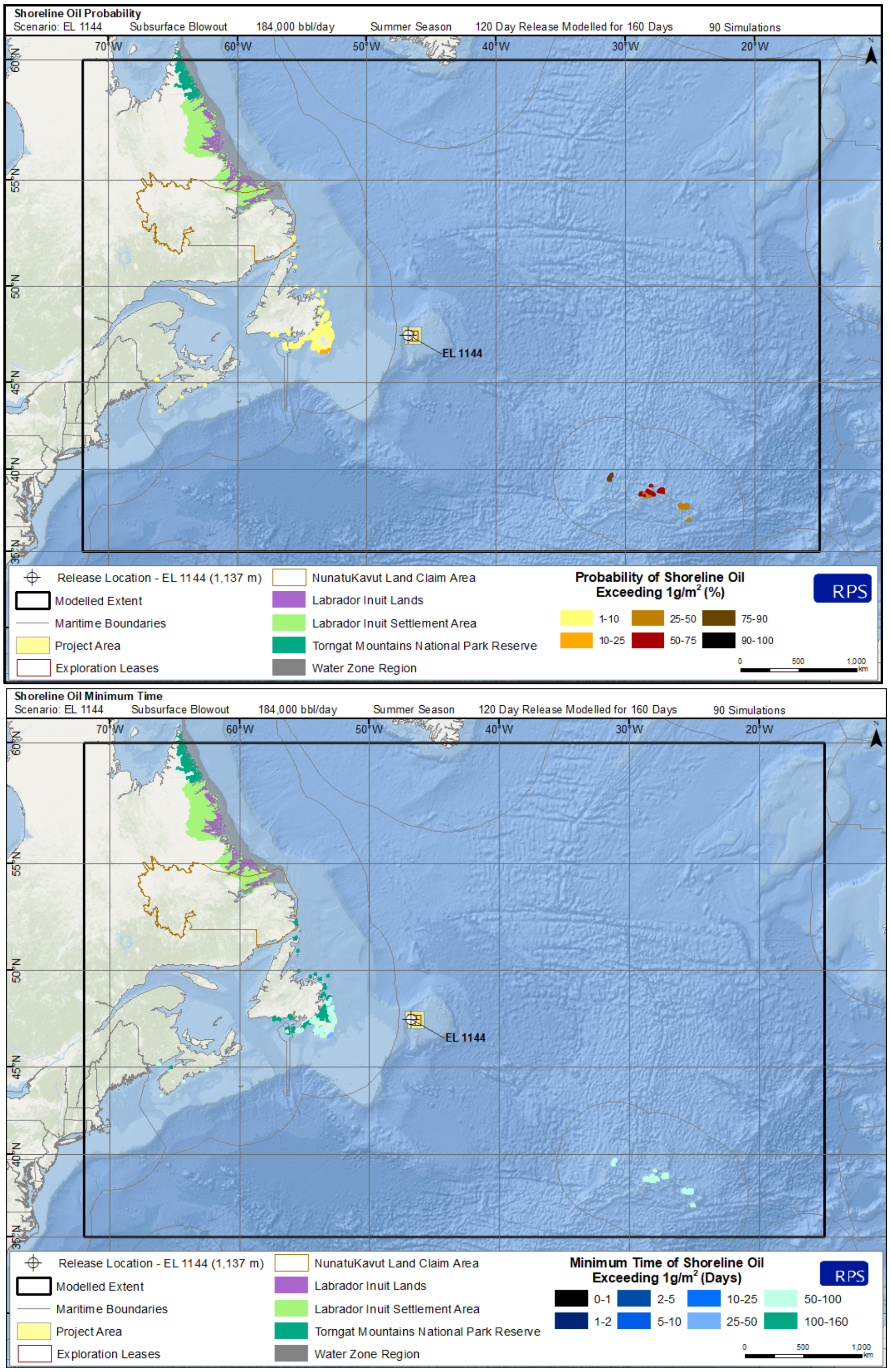
Figure 5-8. Maximum dissolved hydrocarbons at any depth in the water column for the 95th percentile contact with shoreline case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

5.2.2.3 Amount of Crude Oil on Shoreline and Sediment

Note that the ecological and socio-economic threshold for the amount of crude oil on a shoreline is 100 g/m^2 and 1.0 g/m^2, respectively (see Table 2-2 in RPS 2019).

Stochastic Modelling Analysis

The stochastically-derived lengths of shoreline associated with the probability of the amount of crude oil on the shoreline exceeding 1 g/m^2 during a summer subsea blowout in EL 1144 are indicated in Table 4-1 of RPS (2019) and shown in Figure 5-9. Figure 5-9 shows the probabilities for shoreline oil to exceed the threshold of 1 g/m^2, and minimum time to this threshold exceedance. The stochastic modelling analysis focused on the probability and minimum time for surface, shoreline, and water column threshold exceedances and did not investigate sediment oiling.



Source: RPS (2019).

Figure 5-9. Probability of shoreline contact >1 g/m² (top) and minimum time to threshold exceedance (bottom) resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

The probabilities of threshold exceedance on portions of Newfoundland and Labrador shoreline are primarily 1–10% with a small area on the southern Avalon Peninsula showing a 10–25% probability. The predicted lengths of shoreline with the amount of crude oil exceeding threshold within 1–5%, 5–15%, 15–25%, 25–50%, 50–75%, and 75–100% probability ranges are 629 km, 317 km, 60 km, 335 km, 188 km and 14 km, respectively (see Table 4-1 in RPS 2019). The average and maximum probabilities of shoreline oil contamination for 'all shorelines' predicted by stochastic modelling for a summer blowout in EL 1144 are 1% and 77%, respectively (Table 4-2 in RPS 2019).

The predicted minimum and maximum times for oil to reach shoreline are 34 days and 160 days, respectively (Table 4-2 in RPS 2019). The 25–90% probability of shoreline oil exceeding threshold indicated >2,000 km southeast of the release location pertains to the Azores, outside of the GAI.

While RPS (2019) did not provide predicted probabilities of shoreline oil contamination and times for oil to reach Newfoundland shorelines specifically, they were provided for Labrador shorelines. The average and maximum probabilities of shoreline oil contamination for Labrador shorelines predicted by stochastic modelling for a summer blowout in EL 1144 are both (Table 4-2 in RPS 2019). The predicted minimum and maximum times for oil to reach Labrador shoreline are both 159 days (Table 4-2 in RPS 2019).

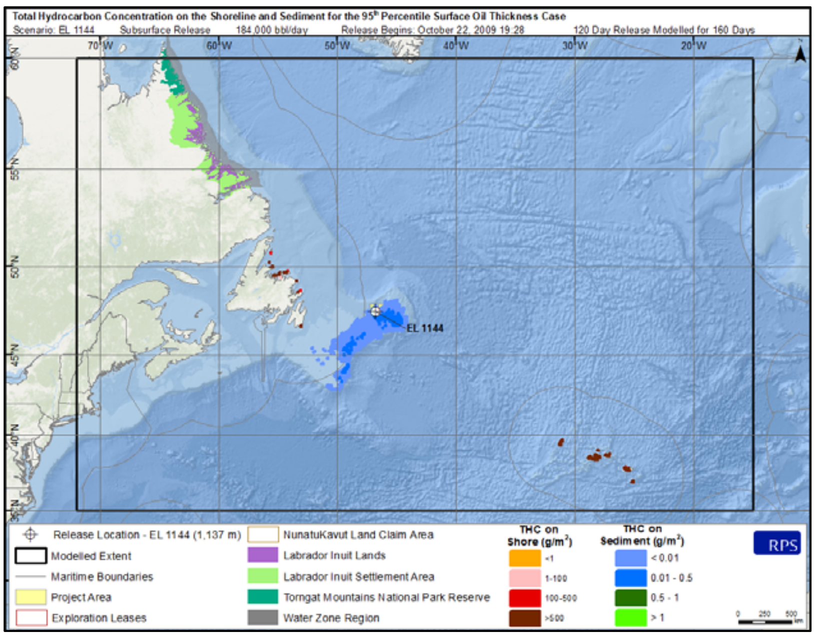
Deterministic Modelling Analysis

The deterministic modelling analysis included sediment oiling for each release, with typical values <0.01 g/m^2 and all results <0.5 g/m^2. In all cases, sediment oil made up <0.01% of the total release. An analysis of sediment thresholds has been conducted (French McCay 2016). In the DWH NRDA, the DWH Trustees (2016), based on sediment bioassay studies, identified 1 mg total PAHs per kg dry sediment as a threshold for toxicity (lethal or sublethal) to invertebrates living in sediments. Using a typical density of sediment of 2.6 g/cm^3 and a sediment porosity of 22.6% water (CERC 1984), the concentration of mineral matter in sediments is 2.0 g/cm or 2,000 kg/m. Assuming oil penetrates to a typical depth of bioturbation in well-worked sediments of 10 cm (French et al. 1996) and oil is 1% PAH, the loading rate that would yield 1mg PAH/kg dry sediment is 2,000 g/m. However, when oil first settles, it is not evenly distributed deeply into the sediments. (Stout et al. 2015) found that oil settled onto deep water sediments after the DWH oil spill was primarily in the upper 1 cm months to a year after the release was stopped. If oil penetration is initially only 1 cm into the sediment, the threshold loading would be 200 g/m, similar to the derived intertidal loading threshold. This more conservative threshold of 200 g/m^2 is an appropriate threshold for ecological risk assessments.

Figure 5-10 indicates the deterministic modelling results for total hydrocarbon concentration (THC) on shoreline and bottom sediment for the 95th percentile surface oil thickness resulting from a 120-day subsurface blowout in EL 1144. In terms of shoreline contact, various locations on the east and northeast shores of Newfoundland are indicated, with THC ranging from 100–>500 g/m^2.

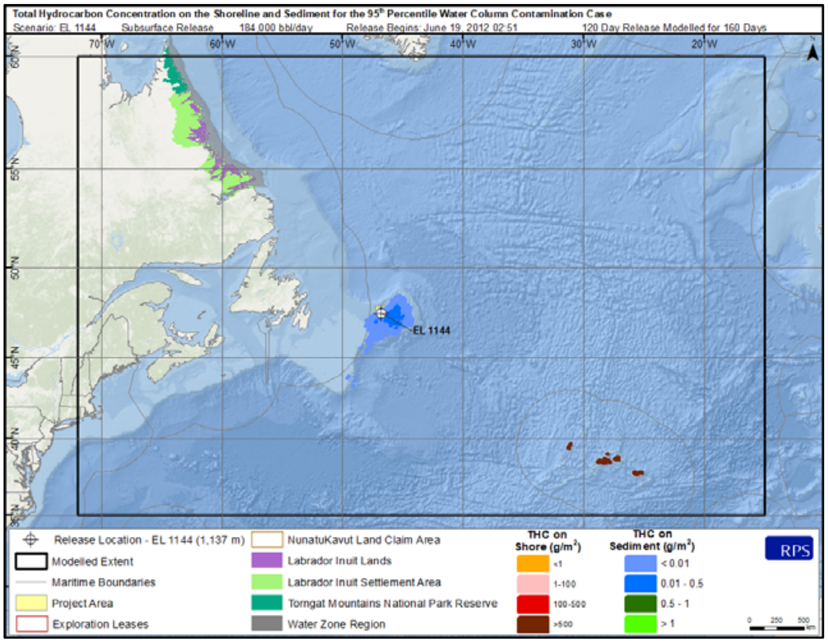
The predicted locations of oil contact with the offshore bottom sediment occur on the Flemish Cap, the Flemish Pass, and the eastern Grand Banks. Predicted bottom sediment THC concentrations range from <0.01–0.5 g/m^2. Shoreline contact >2,000 km to the southeast of the EL 1144 blowout location pertains to the Azores, outside of the GAI.

Figure 5-11 shows the deterministic modelling results for the THC on the shore and sediment for 95th percentile water column contamination case resulting from a 120-day subsurface blowout in EL 1144. No shoreline contact is predicted for Newfoundland and Labrador. The predicted locations of oil contact with the offshore bottom sediment occur on the Flemish Cap and the Flemish Pass. Predicted bottom sediment THC concentrations range from <0.01–0.5 g/m^2. Shoreline contact >2,000 km to the southeast of the EL 1144 blowout location pertains to the Azores, outside of the GAI.



Source: RPS (2019).

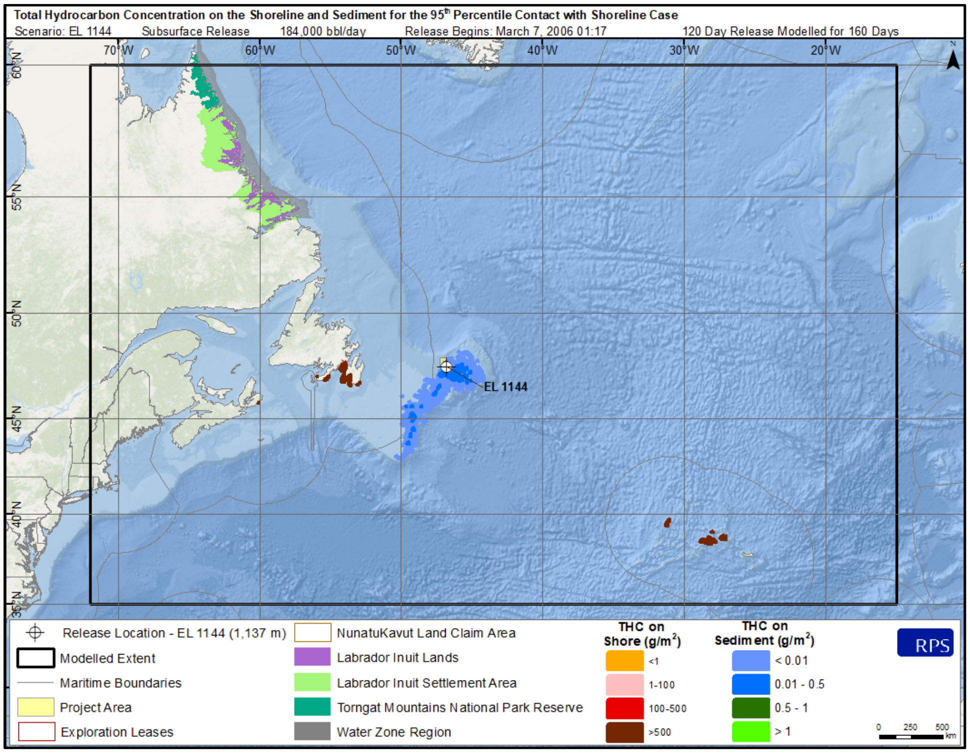
Figure 5-10. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile surface oil thickness case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.



Source: RPS (2019).

Figure 5-11. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile water column contamination case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

Figure 5-12 shows the deterministic modelling results for the THC on the shore and sediment for 95th percentile contact with shoreline case resulting from a 120-day subsurface blowout in EL 1144. In terms of shoreline contact, various locations on the southern shores of the Avalon and Burin peninsulas as well as Placentia Bay, Newfoundland are indicated, with THC exceeding 500 g/m^2. The predicted locations of oil contact with the offshore bottom sediment occur on the Flemish Cap, the Flemish Pass, and the eastern Grand Banks. Predicted bottom sediment THC concentrations range from <0.01–0.5 g/m^2. Shoreline contact >2,000 km to the southeast of the EL 1144 blowout location pertains to the Azores, outside of the GAI.

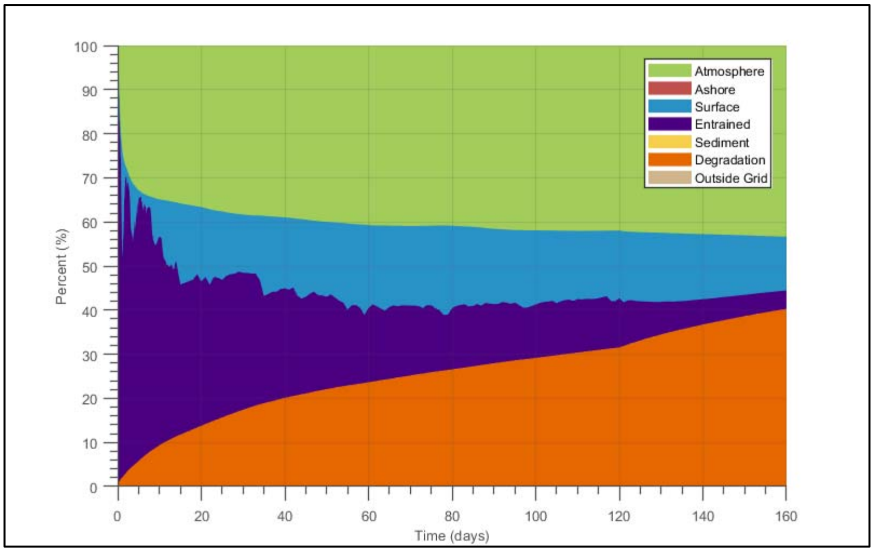


Source: RPS (2019).

Figure 5-12. Total hydrocarbon concentration (THC) on the shore and sediment for the 95th percentile contact with shoreline case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

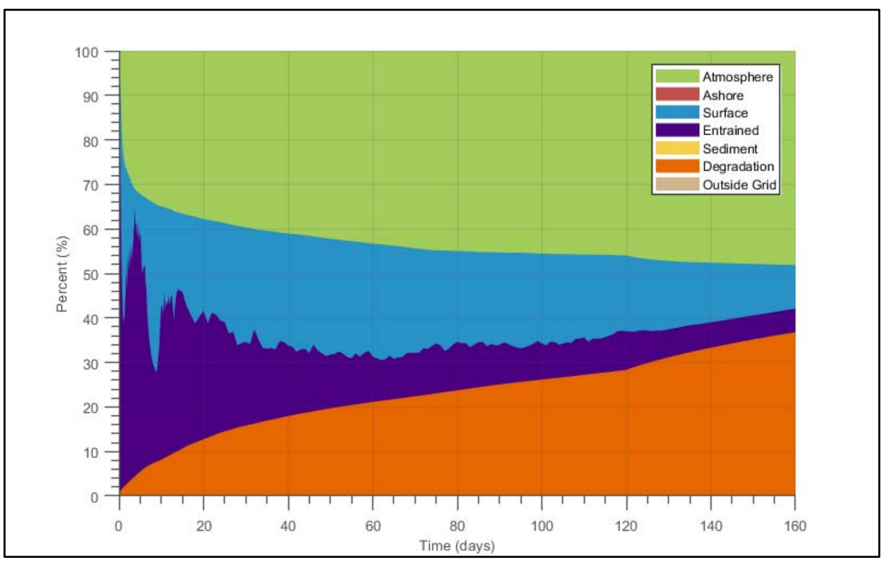
5.2.2.4 Mass Balance Plots

Deterministic analysis mass balance plots were also provided in RPS (2019) to illustrate the predicted weathering and fate of oil for a specific run over the entire model duration as a fraction of the oil released up to that point. Figures 5-13–5-15 are mass balance plots of the 95th percentile surface oil thickness case, 95th percentile water column contamination case, and 95th percentile shoreline contact case, respectively. Considering all three 95th percentile cases, predictions on the fate of the released crude at the end of the modelling simulations include 43–48% of crude will be evaporated into the atmosphere, 10–14% of the crude will still be on the ocean's surface, 2–4% of the crude will be entrained in the water column, and 37–38% of the crude will be degraded. Predicted percentages of total crude released that will be on shoreline, on the bottom sediment or outside of the modelling domain are negligible.



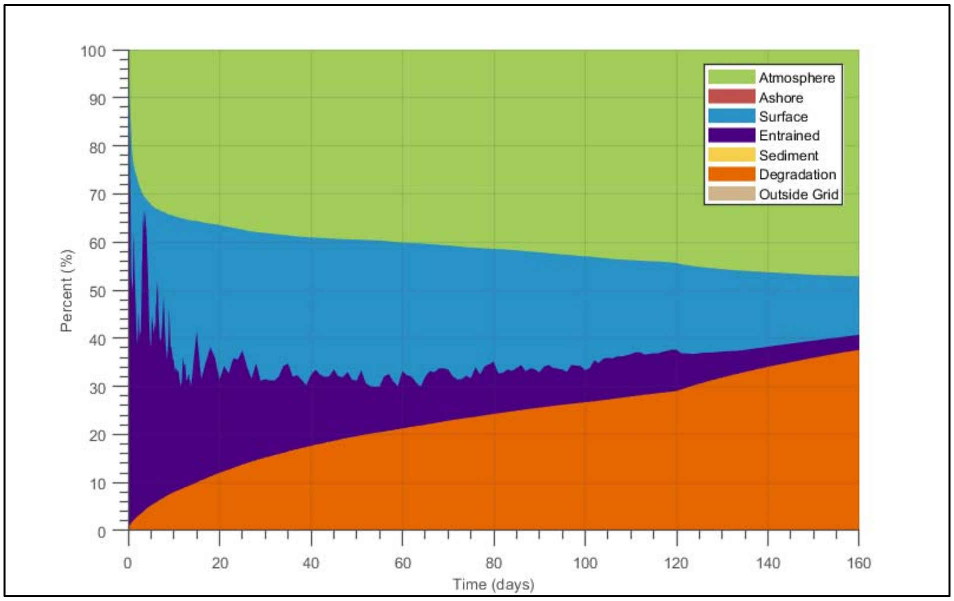
Source: RPS (2019).

Figure 5-13. Mass balance plots of the 95th percentile surface oil thickness cases resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.



Source: RPS (2019).

Figure 5-14. Mass balance plots of the 95th percentile water column contamination cases resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.



Source: RPS (2019).

Figure 5-15. Mass balance plots of the 95th percentile shoreline contact case resulting from a 120-day subsurface blowout at the EL 1144 hypothetical well site during summer.

6.0 Risk Assessment of Response Options

This section provides discussion and ultimately the Comparative Risk Matrix in relation to assessment of the response options.

6.1 Potential Risks for Natural Attenuation

The CNOOC EIS (Nexen 2018) describes the risks of mortality, injury or habitat quality for resources due to an unmitigated offshore subsea blowout oil spill. The potential exposure pathways, toxicity and effects of an unmitigated spill associated with various resources are briefly summarized below. More detailed information is provided in Section 16.6 of the EIS (Nexen 2018).

6.1.1 Fish and Fish Habitat

Section 16.6.2 in Appendix C of the EIS Addendum (CNOOC 2019) provides more detail regarding the potential issues and interactions associated with exposure of marine fish and fish habitat, including the relevant species at risk, to hydrocarbons and dispersants. In addition, Table 16-20 of the EIS Addendum provides a summary of residual accidental event-related environmental effects on marine fish and fish habitat for the various spill scenarios. The key points are summarized below.

Risks for fish and fish habitats exposed to an oil spill could include the following:

- reduction of water and/or sediment quality;
- reduction of primary productivity (phytoplankton and zooplankton) due to lower air-water gas exchanges and light penetration;
- disruption in food web dynamics; and
- lethal and sub-lethal effects from acute or chronic exposure to water-soluble fractions of hydrocarbons.

The principal potential results of the hypothetical blowout modelling that directly apply to the Fish and Fish Habitat ROC are ‘dissolved hydrocarbons in the water column’ and ‘crude oil on shorelines and sea bottom’.

Figure 5-5 in Section 5.2.2.2 shows the predicted summer probability of dissolved hydrocarbon concentrations exceeding 1 µg/L at some depth in the water column (most likely in upper 10 m), and the predicted minimum time to threshold exceedance resulting from a 120-day subsurface blowout at a hypothetical location in EL 1144. Based on these predictions, components of the Fish and Fish Habitat ROC would be most susceptible to effects in the vicinity of the eastern Northern Grand Bank, the Flemish Pass, and the Flemish Cap.

Figure 5-9 in Section 5.2.2.3 shows the predicted summer probability of shoreline contact and amount of crude on shoreline exceeding 1 g/m^2, and the predicted minimum time to threshold exceedance resulting from a 120-day subsurface blowout at a hypothetical location in EL 1144. The probability of the amount of oil exceeding 1 g/m^2 on the Newfoundland and Labrador shoreline is quite low (1–10%), with a slightly higher predicted probability for the southern Avalon Peninsula shoreline (10–25%). No accumulation of crude on the sea bottom is indicated in Figure 5-9. The predicted minimum time to threshold exceedance is 100–160 days, during which time the oil would degrade substantially.

Greater concentrations of total hydrocarbons in the surface mixed layer following a subsea blowout could result in higher mortalities and sub-lethal effects on fish and invertebrate eggs and larvae, and juvenile fishes. If dissolved hydrocarbons are transported towards inshore waters, residual effects of exposure to them on various stages of fish and invertebrate species could potentially remain sub-lethal and/or lethal.

In the event of a blowout scenario, there would likely be a temporary decline in the abundance of phytoplankton in the immediate area of the spill. While some zooplankton (i.e., those with higher motility) might be able to avoid exposure to the dissolved hydrocarbons (e.g., Araújo et al. 2014; Seuront 2010 *in* Appendix C of CNOOC 2019), others would not (e.g., Peiffer and Cohen 2015). Exposure of hydrocarbons on the phytoplankton community may result in altered productivity and growth that may also affect the population and community structure (Buskey et al. 2016 *in* Appendix C of CNOOC 2019). Laboratory studies on Arctic diatom species showed that growth was inhibited at crude oil concentrations of over 50 mg/L (Van Baalen and O'Donnel 1984 *in* Appendix C of CNOOC 2019). Crude oil concentrations of up to 1 mg/L may show stimulant effects on the growth rates of phytoplankton, whereas concentrations exceeding 1 mg/L may inhibit growth. Exposure of phytoplankton to crude oil in concentrations of over 100 mg/L would result in severe or complete growth inhibition (Rablais 2014 *in* Appendix C of CNOOC 2019). Depending on species presence and tolerance to crude oil exposure, community composition may shift as seen during the DWH spill (Ozhan et al. 2014 *in* Appendix C of CNOOC 2019).

Additionally, zooplankton communities may be at higher risk than phytoplankton since they can take up oil components both passively (i.e., through ingestion of contaminated phytoplankton), and actively via direct ingestion where lethal concentrations dispersed from the DWH spill where estimated to be 27 ppm (Almeda et al. 2014, 2016 *in* Appendix C of CNOOC 2019). Lab studies have concluded that reproduction was less successful in copepods that were exposed to a range of hydrocarbon concentrations due to reduced egg production and delayed hatching, and that weathered oil was generally less toxic compared to fresh oil (Almeda et al. 2013 *in* Appendix C of CNOOC 2019). Weathered oil was also seen to have no effect on survival and development of larval echinoderm and bivalve species; however, fresh oil did result in adverse effects (Stefansson et al. 2016 *in* Appendix C of CNOOC 2019).

Oil exposure can have sublethal and lethal effects on early life stages of ichthyoplankton (Lee et al. 2015, Sørensen et al. 2015, O'Shaughnessy et al. 2018 *in* Appendix C of CNOOC 2019). Herring larvae exposed to a total PAH concentration range of 0.129–6.019 µg/L for 12 days exhibited high rates of mortality compared to a control group (Ingvarsdóttir et al. 2012 *in* Appendix C of CNOOC 2019). Atlantic cod and haddock *(Melanogrammus aeglefinus)* exposed to a crude oil concentration range of 10–600 µg/L exhibited heart and craniofacial deformities (Sørensen et al. 2017 *in* Appendix C of CNOOC 2019). Although Hernandez et al. (2016) found that red snapper larvae collected after the DWH spill had poorer body condition (reduced body weight) compared to larvae collected before the spill, other factors, such as dispersants and freshwater input, could also have caused this effect. A study in which Pacific herring were exposed to crude oil found that oil alone was acutely toxic to eggs and larvae and caused yolk sac edema (Barron et al. 2003).

Algae, also considered a component of fish habitat, would be most susceptible to exposure to hydrocarbons should oil reach the shoreline (i.e., intertidal and shallow subtidal zones) due to its immobility.

In bivalves, PAHs generally accumulate in the gonads, resulting in significant reproductive delays (Frouin et al. 2007 *in* Appendix C of CNOOC 2019). The DWH spill caused significant species richness and diversity declines in decapods. Exposure to the hydrocarbons may have caused localized mortalities and reduced female fecundity and recruitment (Felder et al. 2014 *in* Appendix C of CNOOC 2019).

Effects of exposure of corals and sponges to hydrocarbons, typically quantified *in situ* by visual observation, include polyp retraction or partial loss, and covering in brown flocculent material (Busky et al. 2016, Prouty et al. 2016, Ragnarsson et al. 2017 *in* Appendix C of CNOOC 2019). The bioaccumulation of PAHs in sponges is highly variable due to species-specific filtering capacities. Behavioural changes in sponges may also occur after exposure to hydrocarbons (Kutti et al. 2016 *in* Appendix C of CNOOC 2019).

Lethal and sublethal exposure values for fish have been found within the range of 0.3-60 µg/L TPH dissolved PAHs when using dissolved fraction oil and for cold water fish species, those values range between 0.03-11 mg/L TPH. In comparison, the ecological threshold of hydrocarbon exposure effects on marine species is approximately 1.0 µg/L dissolved PAHs (Lee et al. 2015 *in* Appendix C of CNOOC 2019).

Other studies have shown that components of dissolved oil can travel across respiratory membranes in gills (Lee et al. 2015 *in* Appendix C of CNOOC 2019) and that PAHs may disrupt fish cardiac function (Brette et al. 2017 *in* Appendix C of CNOOC 2019). Deep-sea fish species may be more susceptible to hydrocarbon release as they are slower growing, have lower metabolisms, and live longer compared to pelagic species (Cordes et al. 2016 *in* Appendix C of CNOOC 2019).

Coastal and offshore sensitive fish habitat areas occurring within the GAI are shown in Figures 4-1 and 4-2, respectively, in Section 4.0 of this SIMA. Proposed critical habitat areas for northern and spotted wolffishes, both being species at risk, are shown in Figure 4-3 in Section 4.0. More discussion related to sensitive areas is provided in Section 6.1.6.

6.1.2 Marine and Migratory Birds

Section 16.6.3 in Appendix C of the EIS Addendum (CNOOC 2019) provides more detail regarding the potential issues and interactions associated with exposure of marine and migratory birds, including the relevant species at risk, to hydrocarbons and dispersants. In addition, Table 16-21 of the EIS Addendum provides a summary of residual accidental event-related environmental effects on marine and migratory birds for the various spill scenarios. Key points are summarized below.

The principal potential results of the hypothetical blowout modelling that directly apply to the Marine and Migratory Bird ROC are 'crude oil on the sea surface' and 'crude oil on shorelines and sea bottom'.

Figure 5-1 in Section 5.2.2.2 shows the predicted summer probability of surface oil thickness exceeding 0.04 µm and the predicted minimum time to threshold exceedance resulting from a 120-day subsurface blowout at a hypothetical location in EL 1144. Based on these predictions, the Marine and Migratory ROC would be most susceptible to effects in the vicinity of the eastern Northern Grand Bank, the Flemish Pass, and the Flemish Cap. However, given the sensitivity of birds to oiling, the vulnerability of these birds extends beyond the area described above.

Figure 5-9 in Section 5.2.2.3 shows the predicted summer probability of shoreline contact and amount of crude on shoreline exceeding 1 g/m^2, and the predicted minimum time to threshold exceedance resulting from a 120-day subsurface blowout at a hypothetical location in EL 1144. The probability of the amount of oil exceeding 1 g/m^2 on the Newfoundland and Labrador shoreline is quite low (1–10%), with a slightly higher predicted probability for the southern Avalon Peninsula shoreline (10–25%). The predicted minimum time to threshold exceedance is 100–160 days, during which time the oil would degrade substantially.

Aquatic migratory birds are among the most vulnerable and visible species to be affected by oil spills. Risk of adverse effects to birds exposed to oil can occur through three main pathways: (1) external exposure to oil (resulting in coating of oil on feathers); (2) inhalation of particulate oil and volatile hydrocarbons; and (3) ingestion of oil through preening or oiled prey.

The oiling of the plumage which can reduce the insulating properties of feathers and cause hypothermia in cold-water regions is the greatest risk facing marine and migratory birds that are exposed to oil (Fraser and Racine 2016). Although some may survive these immediate effects, long-term physiological changes may eventually result in lower reproductive rates or premature death. While oil is degraded by natural weathering processes (Payne et al. 1991), it is not clear how its degradation affects toxicity to seabirds (Leighton et al. 1985; Leighton 1993; Stubblefield et al. 1995a,b).

The toxicity of ingested hydrocarbons to birds is unclear given that some studies have shown little to no effects of ingestion (Ainley et al. 1981, Stubblefield et al. 1995, Alonso-Alvarez et al. 2007 *in* Appendix C of CNOOC 2019) while others have shown sublethal and lethal effects, including brain damage, liver damage, pneumonia, and immunotoxic effects (Hartung and Hunt 1966, Lawler et al. 1978, Miller et al. 1980, McEwan and Whitehead 1980, Trivelpiece et al. 1984, Butler et al. 1986, 1988, Khan and Ryan 1991, Barron 2012 *in* Appendix C of CNOOC 2019). When ingested or inhaled, toxic compounds found in oil can have debilitating or fatal results due to their negative impact on internal organs (Fry and Lowenstine 1985, Leighton 1993, Briggs et al. 1997 *in* Wiese and Ryan 2003). A study conducted in Newfoundland 1984–1999 on beached sea bird carcasses found through autopsy that many birds were internally contaminated by oil which was likely the cause of mortality (Weise and Ryan 2003).

In 1995, the effect of naturally weathered Exxon Valdez crude oil on the Mallard Duck (*Anas platyrhynchos*) was assessed, noting the occurrence of deleterious effects only at the highest concentrations. This suggested that weathered oil was substantially less toxic to Mallard Ducks and their developing embryos than fresh oil (Stubblefield et al. 1995a,b). Sub-lethal effects of hydrocarbons ingested by marine birds may affect their reproductive rates or survival rates (Fingas 2015). Sub-lethal effects could persist for years, depending on generation times of affected species and the persistence of spilled hydrocarbons.

Adult marine birds foraging offshore to provide for their young could become oiled while at sea and subsequently transfer hydrocarbons back to shore. This could contaminate their eggs or nestlings, and cause embryo or nestling mortality. While the survival rate for oiled birds typically depends on the extent of oiling, the survival rate for heavily oiled birds is low (French-McCay 2009).

The chance of lethal effects of exposure to oil on birds is primarily dependent on the probability of exposure, which is influenced by bird behaviours such as time spent in contact with the water in the open ocean and along the shoreline, and avoidance behaviour (French-McCay 2009).

Figures 4-15–4-18 in Section 4.0 show the seabird distributions and densities within the GAI during 2006–2016. Regardless of the time of year, seabird concentrations are relatively high in the vicinity of the hypothetical blowout location in EL 1144. Based on the seabird densities shown in Figures 4-15–4-18, a blowout at any time of year would impact seabirds. The locations of major seabird colonies and IBAs that occur within the GAI are shown in Figures 4-14 and 4-18, respectively. While the seabird colonies and IBAs are potentially vulnerable to effects from an offshore blowout, the probability of crude reaching the shoreline of Newfoundland is very low.

However, the foraging ranges of seabirds, notably alcids and Leach's Storm-Petrel, nesting in colonies within these IBAs overlap with oil trajectory models and, therefore, these populations are likely to be impacted by a blowout.

More discussion related to sensitive areas is provided in Section 6.1.6.

6.1.3 Marine Mammals and Sea Turtles

Section 16.6.4 in Appendix C of the EIS Addendum (CNOOC 2019) provides more detail regarding the potential issues and interactions associated with exposure of marine mammals and sea turtles, including the relevant species at risk, to hydrocarbons and dispersants. In addition, Table 16-22 of the EIS Addendum provides a summary of residual accidental event-related environmental effects on marine mammals and sea turtles for the various spill scenarios. More discussion related to sensitive areas is provided in Section 6.1.6. Key points are summarized below.

The principal potential results of the hypothetical blowout modelling that directly apply to the Marine Mammal and Sea Turtle ROCs are 'crude oil on the sea surface' and 'crude oil on shorelines and sea bottom'.

Figure 5-1 in Section 5.2.2.2 shows the predicted summer probability of surface oil thickness exceeding 0.04 µm and the predicted minimum time to threshold exceedance resulting from a 120-day subsurface blowout at a hypothetical location in EL 1144. Based on these predictions, the Marine Mammal and Sea Turtle ROCs would be most susceptible to effects in the vicinity of the eastern Northern Grand Bank, the Flemish Pass and the Flemish Cap.

Figure 5-9 in Section 5.2.2.3 shows the predicted summer probability of shoreline contact and amount of crude on shoreline exceeding 1 g/m^2, and the predicted minimum time to threshold exceedance resulting from a 120-day subsurface blowout at a hypothetical location in EL 1144. The probability of the amount of oil exceeding 1 g/m^2 on the Newfoundland and Labrador shoreline is quite low (1–10%), with a slightly higher predicted probability for the southern Avalon Peninsula shoreline (10–25%). The predicted minimum time to threshold exceedance is 100–160 days, during which time the oil would degrade substantially.

6.1.3.1 Marine Mammals

Although some studies suggest that cetaceans can detect oil spills, they do not appear to consistently avoid contact with most types of oil (Geraci et al. 1983; St. Aubin et al. 1985; Harvey and Dahlheim 1994; Matkin et al. 1994; Smultea and Würsig 1995). There is some evidence that dolphins decrease their respiration rate and increase their dive duration in the presence of surface oil, which should minimize exposure to surface oil (Smultea and Würsig 1995). Oil has little effect on thermoregulation since cetaceans and pinnipeds rely on a subcutaneous layer of blubber for insulation (Geraci 1990). The exception is seal pups that have not yet developed insulating blubber and polar bears (Kooyman et al. 1976 *in* Helm et al. 2015). It is assumed that exposure of the eye to oil may result in temporary or permanent damage (St. Aubin 1990). Oil can coat the baleen of mysticetes and reduce filtration, thereby reducing feeding efficiency (Geraci 1990). This effect is considered reversible once adherent oil is removed (Geraci 1990). Inhalation of volatiles and aspiration of aerosolized oil compounds from an oil spill or blowout can result in inflammation of the mucous membranes and absorption of hydrocarbons into the bloodstream (Geraci 1990). Whales may ingest oil with water or by consuming contaminated prey. Species such as harbour porpoise and harbour seals that feed in more restricted areas (e.g., bays) are likely at greater risk of ingesting oil (Würsig 1990) should spilled substances extend to the shorelines. Ingested oil that is not excreted in vomit or feces can be absorbed into the tissues and have toxic effects (Geraci 1990), although it has been reported that ingested oil may be removed from an animals' system after returning to uncontaminated waters (Engelhardt 1978, 1982, 1983). Bence and Burns (1995) reported that only small traces of oil were found in the blubber of a grey whale and the liver of a killer whale exposed to oil from the *Exxon Valdez* spill.

Following the DWH spill in the Gulf of Mexico in 2010, there has been increased study of the effects of oil spills on marine mammals. Although initial avoidance of slicks by cetaceans had been observed (except in the case of sheens) (Sidorovskaia et al. 2016), several species have been seen swimming through, and feeding in, large slicks (see Helm et al. 2015; Wilkin et al. 2017). As noted earlier, although oil could coat the baleen of mysticete whales and reduce filtration efficiency, this effect is considered reversible (Geraci 1990). Oil from the DWH spill has been observed adhering to the skin of 11 species of cetaceans (Aichinger Dias 2017), persisting for at least two years after blowout for some species. As discussed above, oil from such spills can have negative effects on cetacean health. Atlantic bottlenose dolphins (*Tursiops truncatus*) oiled during the DWH spill revealed respiratory abnormalities, impaired stress response (hormonal), and elevated adrenal hormone levels (Schwacke et al. 2014; Balmer et al. 2015; Lane et al. 2015; Venn-Watson et al. 2015; Smith et al. 2017). These effects persisted for at least four years after the blowout (Smith et al. 2017). In addition, immune function in these individuals was consistent with bacterial infection (De Guise et al. 2017). Annual survival in these populations was significantly lower than that in an unoiled area (McDonald et al. 2017; Mullin et al 2017), and dead-stranding rates were up to four times greater in the areas with heaviest oiling (Kellar et al. 2017). The reproductive success rates in dolphins in oiled areas were reduced by more than two-thirds (Kellar et al. 2017), while the percentage of pregnant females giving birth to viable calves was reduced by 75% (Lane et al. 2015). Most of the pregnant females that failed to give birth to viable calves had previously been diagnosed with lung disease coinciding with the blowout.

Oil spills can also have negative effects on cetaceans at the population level. Bottlenose dolphin populations impacted by the DWH blowout were significantly reduced in size (McDonald et al. 2017). These populations were very susceptible to the effects of this particular spill event because the small size of pod home ranges resulted in continuous exposure to the oil (Wells et al. 2017b). Killer whale pods in Prince William Sound that were photo-identified before the *Exxon Valdez* oil spill, lost 33% to 41% of their members in the first year (Matkin et al. 2008). The loss of adult females suppressed reproduction so that pod size failed to recover to pre-spill levels or declined during 16 years of follow-up monitoring (Loughlin 1994; Peterson et al. 2003; Matkin et al. 2008). Mortality has been reported in seals fouled with oil, particularly in seal pups in colder waters who have yet to develop adequate blubber (St. Aubin 1990). Exposure of seals to oil can result in conjunctivitis (Spraker et al. 1994), corneal abrasion and swollen nictitating membranes, or permanent eye damage (St. Aubin 1990) and therefore reduced foraging ability (Levenson and Schusterman 1997). Heavily fouled seals can experience reduced locomotion and even drowning (Davis and Anderson 1976; Sergeant 1991). Harbour seals observed immediately after oiling appeared lethargic and disoriented, a response that may be attributed to lesions observed in the thalamus of the brain (Spraker et al. 1994). Seals may ingest oil by consuming contaminated prey or by nursing contaminated milk. Once ingested, oil absorbed into the tissues can result in minor kidney, liver, or brain lesions (Geraci and Smith 1976; Spraker et al. 1994). However, Spraker et al. (1994) found lesions characteristic of hydrocarbon toxicity in the brains of oiled seals collected several months after the *Exxon Valdez* spill.

The extent of the potential effects depends on how the spill and marine mammal distributions overlap spatially and temporally. For this SIMA, a 10 μm thick layer of oil on water is used as the threshold concentration for potential lethal effects on marine mammals (French et al. 1996; French-McCay and Rowe 2004; French-McCay 2009). When marine mammals congregate in high numbers, there is potential for higher impact.

There is limited information about how low concentrations of dispersed oil in the water column may affect marine mammals. However, it is generally accepted that dispersed oil will pose less of a threat due to the reduced probability of physical oiling of marine mammals at the surface.

6.1.3.2 Sea Turtles

Sea turtles may be more susceptible to the effects of exposure to hydrocarbons than marine mammals because they do not respond with avoidance behaviour, exhibit indiscriminate feeding, and take large pre dive inhalations (see Milton et al. 2010; Vander Zanden et al. 2016). Effects of exposure to oil in sea turtles include reduced lung capacity, decreased oxygen uptake, reduced digestion efficiency, and damaged eyelid and nasal tissues (Lutz and Lutcavage 1989). Ingestion of oil is particularly deleterious to sea turtle health (Camacho et al. 2013). Loggerhead sea turtles have presented with skin lesions after exposure to oil, although effects were reversed ten days post-exposure (Bossart et al. 1995). Sea turtles are often found heavily oiled after a spill and approximately 1% of sea turtle strandings in the US are associated with oil (Lutcavage et al. 1997 *in* Milton et al. 2003). Many of the surface-pelagic juvenile sea turtles oiled during the DWH blowout in 2010 showed physiological derangements (Stacy et al. 2017), and visibly oiled sea turtles found dead or dying had elevated levels of PAHs (Ylitalo et al. 2017). The US National Marine Fisheries Service (NMFS 2014) documented over 600 dead sea turtles after the DWH spill, 75% of which were Kemp’s Ridley sea turtles and at least 18 individuals of which were visibly oiled. An additional 450 oiled sea turtles were rescued, rehabilitated, and released; 95% of these were loggerhead sea turtles.

A 10 μm thick layer of oil on water is used as the threshold concentration for potentially lethal effects on sea turtles (French et al. 1996; French-McCay and Rowe 2004; French-McCay 2009), and the potential effects of a blowout depends on whether the distribution of the spill and sea turtles overlap spatially and temporally.

While the proposed leatherback sea turtle critical habitat in the area of the mouth of Placentia Bay (see Figure 4-19) is potentially vulnerable to effects from an offshore blowout, the probability of crude reaching that area is very low.

6.1.4 Fisheries

Section 16.6.7 in Appendix C of the EIS Addendum (CNOOC 2019) provides more detail regarding the potential issues and interactions associated with exposure of fisheries (commercial, recreational, Indigenous) and other ocean uses to hydrocarbons and dispersants. In addition, Table 16-31 of the EIS Addendum provides a summary of residual accidental event-related environmental effects on fisheries and other ocean uses for the various spill scenarios. Key points are summarized below.

The principal potential results of the hypothetical blowout modelling that directly apply to the Fisheries ROC are 'crude oil on the sea surface', dissolved hydrocarbons in the water column', and 'crude oil on shorelines and sea bottom'. Much of the effect of an oil spill on the fisheries is the perception of taint by those who use the product. Therefore, defining an area in which the effect is greatest, based on perception, is difficult.

The subsea oil spill scenarios considered in this assessment could result in effects on the availability of fisheries resources, access to fisheries resources, fouling of fishing or cultivation gear, and market perception. Hydrocarbons could reach active fishing areas within the CNOOC SIMA GAI where harvesting is more concentrated. Under some circumstances, oil could reach coastal locations, potentially interacting with nearshore fisheries and aquaculture operations. As indicated in the EIS (Nexen 2018), active, free-swimming adult fishes are less likely to suffer long-term damage from oil spills than younger or less motile life stages or species, primarily due to the ability to actively avoid an area contaminated by oil (e.g., Bøhle 1986; Martin 2017). Simulated oil spills of 1500 and 4500 m^3/day for up to 90 days on Atlantic cod spawning grounds predicted a decrease in adult cod biomass of up to 12%, but there were no predicted effects on adult reproductive potential, and juvenile survival was considered sufficient to replenish the population (Carroll et al. 2018). The diverse age distribution of various free-swimming fish species, like Atlantic cod, helps protect adult populations from single-year recruitment losses after a major oil spill (Carroll et al. 2018). There have been conflicting results between recent ecological modeling and monitoring data for fish population responses to the large-scale DWH spill event, whereby the modeling predicts relatively high impacts on fish and shellfish but monitoring data have mainly detected minor, inconsistent population level effects (Ward et al. 2018). Contrary to free-swimming fishes, sedentary species, such as edible seaweeds and shellfish, have been found to be more sensitive to oiling due to their inability to move away from a contaminated area (ITOPF 2011). Overall, more studies are needed to investigate fish and shellfish population level effects to long-term and/or large-scale oil exposures (Pasparakis et al. 2019).

The effects on fisheries resources vary depending on the spatial and temporal distribution of the spill. Any changes in harvesting could be influenced by other factors such as natural fluctuations in target species populations, variation in fishing effort, climatic effects, and/or contamination from other sources which can make it difficult to assess the direct implications of an oil spill on fisheries resources (ITOPF 2011). However, further assessment/analysis can be conducted during a spill incident or event if it becomes necessary to do so in order to minimize potential effects on active commercial and/or Indigenous fishing activities within defined spatial fisheries management areas in the NL Region.

The distributions of inshore and offshore domestic pelagic and demersal commercial fishery harvesting locations during 2016 and 2017 within the GAI are shown in Figures 4-5–4-12. Figures 4-5, 4-6, 4-9, and 4-10 indicate that harvest locations associated with the inshore pelagic and demersal fisheries in 2016 and 2017 are >300 km from the hypothetical blowout location in EL 1144. However, the harvest locations associated with the offshore pelagic and demersal fisheries in 2016 and 2017 (Figures 4-7, 4-8, 4-11, and 4-12) occur as close as <50 km from the hypothetical blowout location in EL 1144, predominantly to the northwest, west and southwest of the blowout location. Locations of nearshore licensed aquaculture sites currently listed within the GAI are shown in Figure 4-13 in Section 4.0. While vulnerable to effects from an offshore blowout, the probability of crude reaching the shoreline of Newfoundland is very low.

6.1.5 Sensitive Areas

Section 16.6.5 in Appendix C of the EIS Addendum (CNOOC 2019) provides more detail regarding the potential issues and interactions associated with exposure of sensitive areas to hydrocarbons and dispersants. Table 16-29 of the EIS Addendum provides a summary of residual accidental event-related environmental effects on sensitive areas for the various spill scenarios. Figures 4-1–4-3 in Section 4.0 indicate the locations in the GAI of sensitive coastal habitat, sensitive offshore habitat and proposed critical habitat for northern and spotted wolffishes, respectively.

The principal potential results of the hypothetical blowout modelling that directly apply to the sensitive areas are ‘crude oil on the sea surface’, dissolved hydrocarbons in the water column’, and ‘crude oil on shorelines and sea bottom’.

Sensitive areas could be compromised as a result of a subsea blowout for the same reasons provided for fish and fish habitat, marine and migratory birds, marine mammals and sea turtles. Which aspects of a Tier 3 spill potentially causing the most effects on a sensitive area depends on its attributes. For example, if an area is deemed to be a sensitive area because of high concentrations of ichthyoplankton, then dissolved hydrocarbons in the water column would be most relevant to that area. For areas deemed to be sensitive areas because of high concentrations of migratory seabirds in one area and inshore critical nursey habitat within another area, the aspects of a spill most relevant to these areas would likely be thickness of surface oil and oil contact with shore, respectively.

The release location for the 'EL 1144-Summer' spill scenario is located within the Convention of Biological Diversity's Northwest Atlantic EBSA, and within 100 km of two NAFO coral/sponge closure areas and a NAFO 3M seasonal shrimp closure area (see Figure 4-2). Other sensitive areas that are located between 100 km and 200 km from the hypothetical blowout location in EL 1144 include more NAFO coral/sponge closure areas, the DFO Placentia Bay-Grand Banks EBSA, a NAFO 3M seasonal shrimp closure area in the vicinity of the Flemish Cap, and the DFO Northeast NL Slope Marine Refuge (see Figure 4-2). The hypothetical blowout site in EL 1144 is also within 100 km of the proposed northern and spotted wolfish critical habitat (see Figure 4-3).

6.2 Risks Associated with Dispersants and Dispersed Oil Exposure

The toxicity- and biodegradation-associated risks related to exposure to dispersants and dispersed oil are discussed in this section.

6.2.1 Toxicity

The toxicity of the crude oil is considerably higher than that of dispersants maintained within the Global Dispersant Stockpile (GDS). The GDS currently stocks three dispersants – Dasic Slickgone NS, Finasol OSR 52, and Corexit 9500A (OSRL 2017). In Canada, only Corexit 9500A and Corexit 9580A are listed in the *Regulations Establishing a List of Spill-treating Agents* (*Canada Oil and Gas Operations Act*). For Corexit 9500A, there is an extensive dataset on the toxicity of this commercial product to a variety of aquatic species (see revised EIS Section 16.0 in Appendix C of the EIS Addendum of CNOOC 2019).

Through determining the risks associated with dispersants, laboratory studies are frequently used to test dispersants against each other. These studies come with some major caveats as they are not tested in real-world spill conditions, however results have consistently shown that 500A is considerably less toxic than oil (Fingas et al. 1995; Environmental Protection Area [EPA] Office of Research and Development 2010). Due to the low application rates needed to disperse oil, exposure concentrations are low which results in low toxicity risk from dispersants. Regardless of the low risk of toxicity from dispersant use, information obtained through scientific study of the effects of exposure on various aquatic biota is presented in this section.

For the purposes of this SIMA, it is assumed that all dispersant operations use visual monitoring (e.g., ROVs or spotter aircraft) to ensure that dispersants are properly applied to areas of concentrated oil, resulting in a chemically dispersed plume of oil. Therefore, the discussion of toxicity is limited to describing the effect of dispersed oil as a dispersant-only condition is unlikely to occur during an actual response. Dispersed oil exposures in the water are the predominant exposure pathways for environmental considerations. Controlled studies in wave basins (e.g., test facility used by DFO) as well as post-spill monitoring have shown that sediments rarely have accumulations of dispersed oil at levels that pose environmental concerns. Dispersed oil does not adhere to sediments as readily as untreated crude oil (Yergeau et al. 2014 *in* Slaughter et al. 2017).

The toxicity of dispersed oil in the water column is related to three factors:

- Exposure concentrations that develop after the oil is spilled and treated;
- Duration of exposure; and
- Toxicological sensitivity of the exposed species.

Oil toxicity is determined by its chemical makeup, of which certain compounds such as benzene, toluene, ethylbenzene and xylenes (known as BTEX) can be acutely toxic and volatile. These compounds however tend to evaporate rapidly, and together with other partially soluble compounds in oil that release slowly into the water column, they are known as the "water accommodated fraction," or WAF. The use of dispersants in the water column can increase BTEX dissolution and prevent the evaporation of VOCs that pose a risk to response workers. When fresh oil is treated with dispersants at the seafloor close to the blowout source (SSDIs), the soluble compounds in the oil will dissolve into the lower water column. Coelho et al. (2011) compiled a review of hydrocarbon measurements taken in the vicinity of DWH Source Control during SSDI operations and indicated that BTEX concentrations up to 200 ppb were recorded in deep sea dispersed oil plumes at depths of 1,200 m and located 1 km from the blowout location. The BTEX concentrations were rapidly diluted to non-detectable levels at distances greater than 10 km from Source Control. Fate and transport models predict that oil concentrations rapidly dilute within a few kilometers of the blowout location with the use of SSDI (Gros et al. 2017; French-McCay et al. 2017). The toxicity of dispersed oil is dependant on the toxicity of the oil rather than the dispersant. The use of dispersants make oil more bioavailable to organisms in the water column (i.e., bacteria) due to the increased dissolution of the soluble components, and the formation of small stable oil droplets that will include PAHs and alkylated homologues (Slaughter et al. 2017).

Due to the interspecific and ontogenetic variation in an organism's response to dispersant exposure, it is important to identify the species and life stages living in the area to be treated with dispersants to ensure decisions are based on local environmental conditions.

In a study conducted by Clarke et al. (2001), three types of crude oil (Kuwait, weathered Kuwait, and Forties) along with two dispersants (Corexit 9500 and 9527) were tested during continuous (96 hr) and short-term (48 hr) exposures to early life stages of mysids (*Holmesimysis costrata* and

Mysidopsis bahia), silversides (*Menidia beryllina)*, and turbot (*Scophthalmus maximus*). They found that physically dispersed oil appeared to be less toxic than chemically dispersed oil when LC_{50} is expressed in terms of nominal "oil-added" values. However, when the effects were expressed in terms TPH, dose-response relationships for each species were similar between physically and chemically dispersed oil (Clarke et al. 2001; NRC 2005).

Following the use of SDA under typical environmental conditions, the concentration of dispersed oil in the upper 10 m of the water column may be as high as 30–50 ppm TPH. However, those concentrations rapidly dilute to <10 ppm within the first hour and to <1 ppm within a few hours. The durations of exposures of organisms to dissolved TPH following SDA are relatively short and typically occur in the upper few meters of the water column (Slaughter et al. 2017). During the DWH oil spill, dispersed oil concentrations within the subsea sea plume were typically very low, at approximately 100 ppb to several ppm (NOAA 2012; IPIECA and IOGP 2015b) and was bounded by depths of about 1,100–1,300 m (Slaughter et al. 2017).

A more robust discussion about the role of dispersants, the principles of chemical dispersion, and the factors that affect dispersant effectiveness is provided in Appendix B. The following sections provide scientific information on the potential toxicity of dispersants to the various marine faunal groups.

6.2.1.1 Toxic Effects on Marine Invertebrates

The potential effects of exposure to dispersants on marine biota have been studied intensively since the DWH spill. During the remediation effort for DWH, the oil dispersant Corexit 9500A was used extensively, resulting in a variety of effects to marine biota. While the manufacturer states that Corexit is non-toxic and biodegradable when considered on its own, marine organisms are most likely to encounter dispersants and oil combined. This combination may alter the toxicity of the dispersant. Studies have noted adverse effects of the use of DWH dispersants on phytoplankton communities (Bretherton et al. 2019) and deep-sea bacteria (Bælum et al. 2012).

Bretherton et al. (2019) examined the impact of oil and dispersants on phytoplankton community composition and physiology over a period of 72 hrs. The plankton community was exposed to WAF, a 1:20 CEWAF (mixture of dispersant to oil), a 10-fold dilution of the CEWAF mixture (DCEWAF), and a control. The short-term changes in photosynthetic rate were then monitored. The CEWAF and DCEWAF treatments appeared to have detrimental effects on the photosynthetic responses, suggesting that photosynthesis was inefficient or slowed. The CEWAF and DCEWAF treatments also altered the phytoplankton community composition with diatoms accounting for only 16% and 7%, respectively, of the community, compared to >50% in the control and WAF treatments. In addition, diatoms exposed to WAF, CEWAF, and DCEWAF treatments produced more TEP (transparent exopolymer particles) than those exposed to the control only.

TEPs, which can be broadly categorized as extracellular polymeric substances (EPS) are thought to play a central role in the coagulation process of marine snow as aggregates (Bretherton et al. 2019). Dispersed oil has been shown to be 2–3 times more toxic to copepods (zooplankton) than crude oil, with the toxicity of the dispersed oil increasing with sunlight exposure (Almeda et al. 2013 *in* Appendix C, CNOOC 2019). Additionally, marine snow exposed to dispersed oil will form aggregates, sinking to the seabed and eventually becoming incorporated into the sediment. While the sedimentation of oil-laden marine snow is helpful in the removal of oil from surface waters, this process can change the benthic community structure and potentially cause long-lasting detrimental effects to benthic organisms. Further, the effect of oil and dispersed oil on the health of phytoplankton potentially affects the fate of oil, as the physiological state of phytoplankton changes their EPS and TEP production (Breatherton et al. 2019).

Another DWH-associated study found that coral larvae exposed to the WAF, CEWAF, and Corexit 9500A exhibited significantly reduced settlement and survival rates with increasing concentrations of the substances (Goodbody-Gringley et al. 2013). Larvae exposed to WAF for 48 hrs exhibited a 47% survival rate, whereas those exposed to CEWAF for the same duration did not show any effect on survival rate. However, when exposed to CEWAF concentrations of 4.28 ppm and 30.99 ppm for 72 hrs, the larvae exhibited survival rates of 27% and 7%, respectively. The survival rate of larvae exposed to only Corexit 9500A for 72 hrs decreased as the dispersant concentration increased (13% at 50 ppm, and 0% at 100 ppm) (Goodbody-Gringley et al. 2013). Studies on deep-sea coral have also shown that dispersant-oil solutions can have dramatic effects on larval settling abilities and post-settlement survival (DeLeo et al. 2016 *in* Appendix C of CNOOC 2019).

The Eastern oyster *(Crossostrea virginica)*, a commercially-important shellfish in the Gulf of Mexico, has a spawning season that coincided with the timing of the DWH spill (Vignier et al. 2015). Oyster gametes exposed to CEWAF for 30 minutes exhibited a significantly reduced rate of fertilization compared to gametes exposed to high energy water accommodated fraction (HEWAF; oil mixed with seawater). Continuous exposure (24 hr) of the gametes to a combination of CEWAF and dispersant adversely affected embryo and early larval development in the oyster (Vignier et al. 2015). In a study of survival of pink shrimp larvae *(Farfantepenaeus duorarum)* exposed to WAF, CEWAF, and Corexit, it was noted that the Corexit alone had the greatest impact on survival while WAF had the least (Laramore et al. 2016). The LC_{50} associated with 24 hrs of exposure of the shrimp zoea to Corexit was 3.1 ppm, while the LC_{50} associated with 24 hrs of exposure to CEWAF and WAF were 15.4 ppm and 67.4 ppm, respectively. After 72 hrs of exposure to these concentrations, zoea mortality was 100% (Laramore et al. 2016).

6.2.1.2 Toxic Effects on Finfishes

Laboratory studies have shown an increased rate of deformities and mortality on herring eggs exposed to dispersants (Greer et al. 2012 *in* Appendix C of CNOOC 2019). Linden (1976) and Wilson (1976) also noted adverse effects of exposure to dispersants on early stages of herring.

Linden (1976) observed a significant inhibition of larval development while Wilson (1976) observed abnormalities and deformations in embryos of herring, plaice, and sole.

Recent studies of the effects of Corexit 9500A on capelin *(Mallotus villosus)* sperm behaviour and embryo development have been conducted in Newfoundland (Beirao et al. 2018, 2019). They noted that surfactants present in the dispersant can affect sperm membrane functionality and decrease embryo survival. Sperm were exposed to different concentrations of WAF and CEWAF solutions, to the dispersant only, and to a negative control (15 ppt water). Sperm behaviour was not affected under any scenario, even at the highest concentration of CEWAF (10 % at 1:20). However, the ability of sperm to fertilize was significantly affected by exposure to the dispersant. Fertilization rates were 34% at the highest concentration of CEWAF, 19% when exposed to the dispersant alone, and 74% under the negative control scenario (Beirao et al. 2018). Capelin embryos exposed to CEWAF (10% at 1:10) for 10 hrs exhibited a survival rate of ~69% but no hatching was observed. At diluted concentrations of CEWAF (1% at 1:10 and 1% at 1:50), some hatching was observed (Beirao et al. 2019).

In 2014, research examining the toxic effects of dispersed oil on deep sea organisms was initiated under an API Joint Industry Task Force. While results are still preliminary, a recent presentation by Naile (2016) suggests that the sablefish, a deep-water species, may have exposure thresholds similar to more commonly tested shallow water species. These new findings provide some insight into how the scientific community can apply existing data on shallow water species to deep water environments.

In addition, a recent publication summarizes information related to the sensitivities of Arctic species to both physically and chemically dispersed oil (Bejarano et al. 2017). Many of Arctic species considered also occur in the Newfoundland and Labrador offshore.

It has been noted that challenges arise when dissociating the impact of the dispersant from the impact of PAHs. In addition, most studies have been conducted under laboratory conditions, perhaps resulting in effects that differ from those in the natural environment. Overall, the effect of a dispersant on certain marine biota appears to be adverse when the organisms are exposed to the dispersant for relatively long periods of time (>24 hrs). This exposure time may not reflect the level of exposure encountered during an oil spill response under natural conditions. While some microbial communities may benefit from the added sources of carbon that oil spills and mitigation efforts provide, the long-term effects of these processes are yet to be studied. In Newfoundland, the current distances between offshore drilling activities and the NL coastal areas (i.e., at least 315 km) would likely decrease the probability that dispersants used during an accidental release at the well site would impact coastal marine fish species.

6.2.1.3 Toxic Effects and Feather Weatherproofing on Marine Birds

Generally, the use of dispersants is considered beneficial for marine birds by reducing the potential for exposure to surface oil. In addition, it has been suggested that the toxicity of dispersants to marine birds is minimal (Prince 2015 *in* Appendix C of CNOOC 2019). However, Fiorello et al. (2016) found that Common Murre, a species that forages underwater, develops conjunctivitis and is at higher risk of corneal ulcers when exposed to Corexit 9500A. Preliminary studies of dispersant use during the DWH blowout show that dispersants enhance oil's toxicity to early life stages of coastal waterbirds (Beyer et al. 2016).

The effect of dispersants on the structural integrity of feathers, which determines feathers' ability to repel water, has received little study. Mallard ducks coming into dispersants on the water's surface display a reduction in their buoyancy and their ability to remove water from their plumage (Lambert et al. 1982). Mallards and Common Eiders exposed to oil/dispersant mixture show enhanced plumage contamination (Jenssen and Ekker 1991). This may arise from the surfactant component of dispersants. Recently, Whitmer et al. (2018) found that the effects of a mixture of dispersant and oil on feather structure, waterproofing, and buoyancy of Common Murres did not differ from the effects of oil alone. The effect was dose-dependent and resolved over two days. In contrast, a high concentration of dispersant alone caused an immediate, life-threatening loss of waterproofing and buoyancy. However, these effects resolved within two days.

6.2.1.4 Toxic Effects on Marine Mammals and Sea Turtles

Although the effects of dispersants on marine mammals and sea turtles are not well known (Frasier et al. 2020), they can be toxic or change the characteristics of an oil spill, thereby exposing certain biota to oil longer and/or increasing long-term oil toxicity in the water column (Dupuis and Ucan-Marin 2015; Beyer et al. 2016; Frasier 2020). However, according to Prince (2015), the positive effects of its use on a spill likely outweigh the environmental consequences. In short, the use of dispersants is considered controversial (Beyer et al. 2016) and there is no clear consensus whether dispersants, chemically dispersed oil, or non-dispersed oil are relatively more or less toxic to marine mammals and sea turtles (Frasier 2020). Marine mammals and sea turtles are susceptible to floating oil due to the fact they need to surface at regular intervals to breathe. The use of dispersants may be beneficial for marine mammals and sea turtles within a spill area by reducing the exposure to floating oil on the sea surface. The use of dispersant after the DWH spill was largely responsible for the formation of a deep oil plume (~1,100-m depth) and at depth dispersant release may be a new pathway for potential hydrocarbon exposure to deep-diving marine mammals such as sperm and beaked whales (Frasier et al. 2020). The dispersion of oil may expose swimming or feeding marine mammals to the consumption of contaminated plankton, skin/fur contamination, and potentially the clogging of baleen (Lee et al. 2015). Laboratory tests using biopsied skin tissues from live, free ranging sperm whales demonstrated that contamination by chemically dispersed crude oil was more toxic to the health and genetic material of skin cells than non-chemically dispersed oil (Wise et al. 2014, 2018b). Hydrocarbons consumed by marine mammals through contaminated prey can be metabolized and excreted. Some hydrocarbons, however, may be stored in blubber and other fat deposits which may be released into circulation during periods of physiological stress (low prey availability, migration, lactation), and may be bioavailable and toxic to a fetus or newborns (Lee et al. 2015). Hydrocarbons and chemical dispersants may also cause immunological changes in marine mammals. Leukocytes from peripheral bottlenose dolphin blood demonstrated an immune response following in vitro contact with Louisiana sweet crude oil and Corexit chemical dispersant, including the immunosuppression of lymphocyte proliferation and enhancement of natural killer cell activity, simultaneously decreasing disease resistance and increasing tumor or virus detection capabilities (White et al. 2017). Effects on sea turtles from exposure to chemical dispersants or chemically dispersed oil are unknown but may include digestion and lung or salt gland disfunction (Shigenaka 2003 *in* Frasier et al. 2020) and represent a toxicity concern (Mitchelmore et al. 2017), particularly at established foraging sites. During 2011 and 2012, satellite-tracked loggerhead sea turtles in the Gulf of Mexico exhibited long-term site fidelity and did not significantly change their foraging patterns despite exposure to oil and chemical dispersants following the DWH spill (Vander Zanden et al. 2016). Kemp's ridley's sea turtles were similarly found to continue to forage in oiled areas in the northern Gulf of Mexico (Frasier et al. 2020). Altered blood chemistry, electrolyte imbalances, and improper hydration were evident during a loggerhead hatchling exposure study to crude oil, dispersant, and a combination of oil and dispersant, and hatchlings exposed to dispersant and the oil/dispersant combination also failed to gain weight (Harms et al. 2014 *in* Frasier et al. 2020). Conversely, Bailey (2019) did not find significant effects on hatchling loggerhead blood chemistry from laboratory exposure to crude oil and Corexit dispersant, although Corexit exposure resulted in decreased concentrations of lactate, taurine, and cholines in heart tissue samples and altered metabolism in the liver.

6.2.2 Biodegradation

Since one of the key justifications for dispersant use is to promote biodegradation of oil in the open ocean before floating oil reaches sensitive shoreline habitats, it is important that decision makers in oil spill response understand biodegradation.

Crude oil is a natural, heterogenous mixture of hydrocarbons, which may be comprised of up to 20,000 chemicals, mainly consisting of alkanes of differing chain lengths and branch points, cycloalkanes, and mono-aromatic and polycyclic aromatic hydrocarbons (PAHs) (McGenity et al. 2012). Some of these compounds contain nitrogen, sulfur, and oxygen, in addition to trace amounts of heavy metals such as nickel, vanadium, and phosphorus. The bioavailability and toxicity of crude oil differs due to the variation in composition and physio-chemical properties such as viscosity, solubility, and the capacity to absorb (McGenity et al. 2012). Crude oil, which may exist naturally from the geosphere in the form of seeps, or artificially through an oil spill, is broken down in the marine environment through a process called biodegradation.

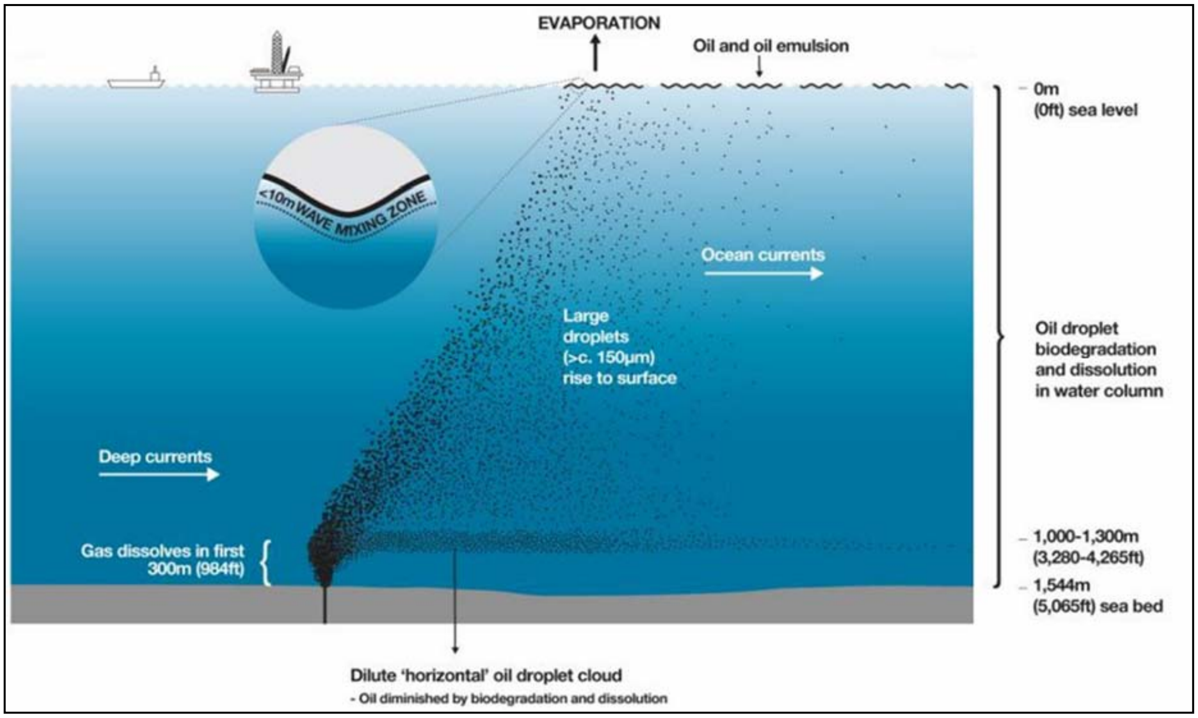
Biodegradation is the process wherein living microorganisms (e.g., bacteria, yeasts, molds, and filamentous fungi) alter and/or metabolize complex hydrocarbon compounds into simpler products in order to obtain energy and nutrients. Biodegradation occurs naturally where organic matter such as oil is removed from the environment. It is the ultimate fate for oil released from natural oil seeps and for non-recovered oil following unintentional releases (Slaughter et al. 2017). Biotic (e.g., microbial growth and enzymatic activity) and abiotic factors (e.g., water temperature, water salinity, wind and wave energy, oxygen, and nutrient levels) are required for oil to biodegrade. The quantity and quality of the hydrocarbon mixture and the properties of the affected ecosystem also affect oil biodegradation. The ranking of easily biodegraded hydrocarbons (i.e., linear alkanes) to more slowly processed hydrocarbon classes (i.e., cyclic alkanes) is as follows:

linear alkanes > branched alkanes > small aromatics > cyclic alkanes

Oil-degrading microorganisms take up oxygen and metabolize hydrocarbons for energy via aerobic respiration, the end-products of which are carbon dioxide and water. Some microbes, however, can degrade oil under anaerobic conditions (absence of oxygen) but the process occurs at a much slower rate. Microbes involved in biodegradation also require nutrients such as nitrogen and phosphorus to complete the process.

The rate of biodegradation is dependent upon the composition and the quantity of oil available to the microbes during a spill or occurring naturally in the marine environment. Molecular weight and the structure of the oil plays a role in the rate at which biodegradation can occur, with lower molecular weight fractions being utilized first by microbes. Light crude oils (i.e., oils with a low density, viscosity, and specific gravity, and high API gravity) are readily biodegraded, and heavy crude (oils with a high density, viscosity, and specific gravity, and a low API gravity) biodegrade more slowly as the higher proportion of high molecular weight hydrocarbons takes longer to process. Similarly, refined oil products show a range in biodegradation rates, with lighter fuels such as diesel, biodegrading at faster rates than lubricating oils that contain large, long-chained paraffinic molecules (Slaughter et al. 2017). Biodegradation begins on the oil components left in the environment after evaporative losses, and during a subsea oil blowout, the process will begin immediately as rising and entrained oil droplets in the intrusion zone (typically at 1,000–1,300 m) are colonized by deep water microbial communities (Figure 6-1).

After an oil spill, the population of oil-degrading microorganisms will increase after a few days as the presence of readily-degradable hydrocarbons will support the high metabolic demands of the community. This is a natural process by which hydrocarbons are transformed into less harmful compounds through the metabolic or enzymatic activity of microorganisms that gain energy as well as carbon from this process. Petroleum hydrocarbons may be degraded to carbon dioxide, water, and cellular biomass, or degraded to smaller products that can undergo successive degradations until the compound is fully mineralized (Kissin 1987; Mango 1997).



Source: IPIECA and IOGP (2015a).

Figure 6-1. Schematic of oil transport in deep water seafloor blowout.

There is limited information on the effects of SSDI on the biodegradation process which will be discussed in the next section, however studies during the DWH oil spill do provide some insight. Bælum et al. (2012) investigated the success rate of oil and Corexit degradation by indigenous microbial communities using bacteria from deep, uncontaminated waters from the Gulf of Mexico. The results indicated that CO_2 evolution significantly increased in microbial communities exposed to oil and/or Corexit compared to a control community. Microbial communities exposed to oil alone degraded 25% of the dissolved oil after five days, compared to the degradation of 40% of an oil and Corexit mixture. The presence of CO_2 shows that the microbial community was enriched by the presence of oil and the dispersant which served as carbon sources for growth, resulting in a microbial bloom that persisted for 20 days (Bælum et al. 2012). These results suggest the potential for the use of microbial communities in oil degradation (i.e., spill mitigation).

It is usually not possible to determine the microbial community pre-spill due to a lack of routine water sampling. Although different genera of oil degrading bacteria likely occur at different depths and temperatures in the water column, all of them have the capability to degrade at least some constituents of crude oil rapidly when the oil is dispersed as small droplets (Røy 2012). Hazen et al. (2010) and Valentine et al. (2011) documented the dynamic changes in the microbial communities in the water column following the DWH spill and found that the characteristics of the microbes changed as oil residues peaked. They also discovered that once the well was capped, the microbial population trends moved back to the expected pre-spill quantities and composition.

6.2.2.1 Effect of Dispersants on Biodegradation

Dispersants that are effectively applied during a spill can potentially increase the rate and extent of biodegradation by dispersing a relatively thick and extensive oil slick into the water column as micro-sized (<300 µm) oil droplets. The resulting dispersed oil will create greater surface area for microbial communities to colonize and will prevent oil from forming tar balls or mousse. This process will also retain the oil droplets within the water column, preventing potential oil slicks to strand on shorelines or become entrained in the sediment where degradation rates are commonly much slower (Slaughter et al. 2017).

A Norwegian laboratory flume study assessed degradation rates of physically and chemically dispersed Macondo oil (Brakstad et al. 2014) and found that the use of Corexit 9500A resulted in smaller median droplet sizes compared to untreated oil. Within the first hour, accelerated n-alkane degradation was apparent in the lighter alkanes (below approximately nC-24) of chemically dispersed oil and smaller droplets were more susceptible to biodegradation. Within one day, the degradation of the n-alkanes (up to and beyond nC-30) was nearly complete in chemically dispersed oil (Brakstad et al. 2014).

McFarlin et al. (2014) found that biodegradation was stimulated by dispersants, especially during the first few weeks in a study focused specifically on crude oil, with and without dispersant application, at environmentally relevant concentrations in Arctic waters. Another study on the effects of temperature and Corexit 9500A on biodegradation rates concluded that the presence of the dispersant resulted in slight increases in biodegradation rates at temperatures of 5ºC and 25ºC. While some changes were observed in microbial community structures at 25ºC, none were noted at 5ºC (Techtmann et al. 2017).

A Canadian wave tank study, funded by British Petroleum, found that a naturally-occurring bacterial community from Halifax harbor (NS) exhibited a large increase in oil degrading phyla within 24 hours of dispersant treatment while little change was observed for untreated oil. It was also concluded that the use of dispersants improved the availability of oil to the microbial community (Yergeau et al. 2014 *in* Slaughter et al. 2017). Tremblay et al. (2017) concluded that the addition of dispersants to crude oil enhanced oil degradation rates in open ocean surface waters. Additionally, modelling work conducted by French-McCay et al. (2017) predicted that SSDI substantially increased dissolution and degradation rates of soluble hydrocarbons (e.g., BTEX), thereby reducing VOC emissions at the waters' surface, the amount of oil and emulsified oil on surface, and the overall footprint of floating oil.

6.2.2.2 Global Implications

Oil degrading bacteria occur in virtually all of the world's oceans (Hazen et al. 2016); evidence of microbial degradation of hydrocarbons are not limited to the relatively warm, nutrient rich waters of the Gulf of Mexico. A study conducted in the Mediterranean deep sea found rapid changes in naturally-occurring bacterial communities when exposed to simulated oil spills, and both the community structures and the biodegradation rates observed were similar to those observed during the DWH incident (Liu et al. 2017). Additionally, Campeão et al. (2017) found that the deep-water microbial communities occurring in the Amazonian margin deep sea water are capable of degrading oil within 48 hrs.

The findings of research conducted on the impacts of dispersed crude oil on populations and community structures of oil degrading microbes during the DWH spill have therefore been validated by several peer-reviewed studies. They have confirmed that some constituents of crude oil can be degraded rapidly, regardless of depth and temperature. The presence of dispersants may affect the community structure of oil degrading microbes at some depths and temperatures, but degradation remains rapid for at least some crude oil components.

6.3 Risk Analysis Process

IPIECA et al. (2017) developed a new methodology for assessing the risks associated with oil spill response options. This new methodology helps address the challenges experienced in scoring and acquiring stakeholder concurrence in past risk assessments; a single comparative matrix is used instead of the more typical square risk reporting matrix. The single comparative risk matrix incorporates four elements:

(1) Potential Relative Impact Assessment;
(2) Impact Modification Factor;
(3) Relative Impact Mitigation Score; and
(4) Total Impact Mitigation Score.

These elements provide a method to score the response options for each ROC or ROC constituent. The overall score is a qualitative prediction of how each response option might mitigate the overall impacts to the resources of concern when compared to "natural attenuation" (i.e., no intervention). For this CNOOC SIMA, the ROCs/ROC constituents described in Section 4.0 are consolidated into various environmental compartments, which also includes Species at Risk. This consolidation allows for a more manageable risk assessment as the inclusion of broad ROCs/ROC Constituents prevents complex scenarios that would need further breakdowns. This is particularly important if the final Comparative Risk Matrix needs to be quickly revised for a future spill exercise or actual incident (IPIECA et al. 2017).

The environmental compartments and their associated ROCs/ROC constituents for the risk assessment in this SIMA include the following.

- Shoreline (intertidal and shallow subtidal <20 m depth) – algae, marine and migratory birds, invertebrates, fishes, and marine mammals;
- Ocean Surface – marine and migratory birds, marine mammals, and sea turtles;

- Upper Water Column (≤20 m depth) – phytoplankton and zooplankton, ichthyoplankton and invertebrate eggs/larvae, invertebrates, fishes, diving marine and migratory birds, marine mammal, and sea turtles;
- Lower Water Column (>20 m depth) – phytoplankton and zooplankton, ichthyoplankton and invertebrate eggs/larvae, invertebrates, fishes, diving marine and migratory birds, marine mammal, and sea turtles;
- Seabed – corals and sponges, other invertebrates, fish and invertebrate eggs/larvae, and fishes; and
- Fisheries (encompassing commercial fisheries, indigenous fisheries, recreational fisheries, and aquaculture)

The above ROCs/ROC constituents include Species at Risk (SAR) and Sensitive Areas. During a spill, actual slick surveillance would identify which SAR and Sensitive Areas might be affected, and those local resource experts would be consulted. At the same time, the risk matrix would be adapted to real time conditions (e.g., on that day, in that location). Justifications for the scoring, in consultation with appropriate stakeholders, would explain which areas might serve as "drivers" in the decision-making process, based on the specific resources threatened by advancing oil or dispersed oil. Furthermore, the SIMA process may need to be revised multiple times during a spill, as different seasonal resources, such as marine and migratory birds, enter the response area.

The Sensitive Areas should be used to prioritize the application of response tactics during an ongoing spill response. Decisions, such as when and where to apply dispersants, for example, would be made by stakeholder and designated agencies and would be outside of the scope of this SIMA. As already stated earlier in this document, this SIMA focuses on a holistic approach to the protection of the environment and not on the protection of specific species or individual organisms.

The following sections represent the steps for the single comparative matrix process which analyzes the impacts of oil spill response options described in Section 3.0 against the SIMA GAI ROCs/ROC constituents. More detailed information on the SIMA guidelines is provided in IPIECA et al. (2017).

6.3.1 Step 1: Potential Relative Impact Assessment

Each ROC/ROC constituent is given a potential relative impact rating that corresponds to a numerical weight (e.g., none = 1; low = 2; medium = 3; and high = 4). The weight attributed to each ROC/ROC constituent is unique and tailored to the specific SIMA. The basic principle of assigning a potential relative impact or weight requires the estimation of the proportion of the resource affected and time to recovery. It also considers the spatial scale for each individual ROC/ROC constituent being considered. For purposes of this SIMA and by following the IPIECA et al. (2017) guidelines, a "Local" impact was assumed to be one that was limited to the spill area, while a "Regional" impact could extend beyond the boundaries of the spill area. The Local (L) spatial scale is generally applied to algae, fish, invertebrate eggs and larvae, corals and sponges, and other invertebrates, while the remaining ROCs/ROC constituents (i.e., phytoplankton and zooplankton, fishes, marine and migratory birds, marine mammals, sea turtles, and fisheries) are assessed on a Regional (R) level. The exception to this relates to the Seabed (benthic) environmental compartment in which all ROCs/ROC constituents associated with this compartment are assessed at a Local (L) scale. To do this, key factors related to the Project Area and GAI, such as sensitive ecosystems, critical habitats, and protected species as they relate to potential impacts from an oil spill, are taken into consideration. This assessment is based on potential impacts to the resource if there is no intervention after the oil spill. Table 6-1 shows the potential relative impact assessment developed for the CNOOC SIMA and the rationale for selection of PRIs and NRIs is provided in Section 6.3.1.1.

Table 6-1. Potential relative impact assessment.

Environmental Compartment	ROC/ROC Constituent	Spatial Scale	Natural Attenuation	
			Potential Relative Impact	Numerical Relative Impact (A)
Shoreline (Newfoundland)	Algae	L	Low	2
	Invertebrates	L	Low	2
	Fishes	R	Low	2
	Marine and Migratory Birds	R	Medium	3
	Marine Mammals	R	Low	2
	Shoreline Compartment Average			
Ocean Surface	Marine and Migratory Birds	R	High	4
	Marine Mammals	R	Medium	3
	Sea Turtles	R	Medium	3
	Ocean Surface Compartment Average			
Upper Water Column (≤20 m depth)	Phytoplankton and Zooplankton	R	Medium	3
	Ichthyoplankton and Invertebrate Eggs/Larvae	R	Medium	3
	Invertebrates	R	Low	2
	Fishes	R	Low	2
	Diving Marine and Migratory Birds	R	Medium	3
	Marine Mammals	R	Low	2
	Sea Turtles	R	Low	2
	Upper Water Column Compartment Average			
Lower Water Column (>20 m depth)	Zooplankton	R	Medium	3
	Ichthyoplankton and Invertebrate Eggs/Larvae	R	Medium	3
	Invertebrates	R	Low	2
	Fishes	R	Low	2
	Marine Mammals	R	Low	2
	Sea Turtles	R	Low	2
	Lower Water Column Compartment Average			

Environmental Compartment	ROC/ROC Constituent	Spatial Scale	Natural Attenuation	
			Potential Relative Impact	Numerical Relative Impact (A)
Seabed (benthic)	Corals and Sponges	L	Low	2
	Other Invertebrates	L	Low	2
	Fish and Invertebrate Eggs/Larvae	L	Low	2
	Fishes	L	Low	2
	Seabed (benthic) Compartment Average			
Socio-economic	Fisheries	R	High	4

Note: L denotes Local; R denotes Regional.

6.3.1.1 Rationale for Selection of PRIs and NRIs Associated with Natural Attenuation of Spilled Crude Oil

Shoreline

There is a relatively low probability of crude oil reaching the Newfoundland shore. The ecological cut-off threshold to oil exposure on the shoreline has been set at 100 g/m^2, above which oiling would have sublethal effects on intertidal invertebrates and lethal effects on birds (Nexen 2018; RPS 2019). Therefore, all ROC/ROC constituents, except for migratory birds, were assigned a Low-2 PRI/NRI rating instead of a None-1 PRI/NRI rating. Considering how susceptible marine and migratory birds are to oiling, this ROC was assigned a Medium-3 PRI/NRI rating.

Ocean Surface

The ecological cutoff threshold to oil floating on the water surface has been set at 10 g/m^2, the point at which sublethal effects on marine mammals and sea turtles are assumed to occur (Nexen 2018; RPS 2019). Thus, the marine mammal and sea turtle ROCs were assigned a Medium-3 PRI/NRI rating given the transient nature of these animals and the potential to interact with crude oil at surface. Marine and migratory birds were assigned a High-4 PRI/NRI rating due to bird mortality observed at levels at and above the reported ecological threshold (Nexen 2018; RPS 2019).

Upper Water Column

The ecological cutoff threshold for the in-water concentration of dissolved PAHs is 1.0 ppb (µg/L). This corresponds to approximately 100 ppb (100 µg/L) of whole oil (THC) in the water column, where soluble PAHs are 1% of the total mass of fresh oil. This value is typically used as a screening threshold for the potential effects oil in the water column may have on sensitive organisms (Nexen 2018; RPS 2019). From a biological perspective, the ROC/ROC constituents that typically spend most of their time in the upper 20 m of the water column during the summer months were assigned higher PRIs/NRIs. The upper water column is where elements of the crude oil at surface mostly dissolve (water soluble elements) or disperse (oil droplets) into the sea water. Plankton, including phytoplankton, zooplankton, ichthyoplankton and invertebrate eggs and larvae, and diving seabirds were considered to be the most at risk in this part of the water column and were therefore assigned a PRI/NRI of Medium-3. Other biological ROCs/ROC constituents (invertebrates, fishes, marine mammals, and sea turtles) have been assigned the PRI/NRI rating Low-2 given their potential ability to avoid the upper water column by directed movement.

Lower Water Column

Given the uncertainty associated with the extent of crude oil occurrence in the portion of the water column below 20 m (levels of dissolution and dispersion) due to variability in oceanographic conditions such as sea state, all biological ROCs/ROC constituents (zooplankton, ichthyoplankton, invertebrate eggs and larvae, invertebrates, fishes, marine mammals, and sea turtles) were assigned the PRI/NRI Low-2. The same ecological cutoff threshold observed for the Upper Water Column is also used here. Untreated sinking oil is mainly a function of suspended organic particulate matter (i.e., marine snow) within the water whose levels in the offshore are likely low compared to the inshore. Much of the suspended particulate matter in the ocean enters from river discharge and other ecological processes along the shoreline.

Seabed

The transport of crude oil from a naturally attenuating spill to the seabed is predicted to be minimal (i.e., <0.02% of released crude). As with the lower water column discussed above, untreated sinking oil is mainly a function of the marine snow levels within the water column. Given the low amounts of crude oil predicted to reach the seabed, the ROCs/ROC constituents associated with this environmental compartment (i.e., corals and sponges, other invertebrates, fish and invertebrate eggs and larvae, and fishes) uncertainty associated with the extent of crude oil occurrence in the portion of the water column were assigned the PRI/NRI Low-2.

Socio-economic

Fisheries (including commercial and Indigenous fisheries) was assigned a High-4 PRI/NRI rating given the perception of tainting by the public and how that could affect commercial and ceremonial value, the possibility of gear fouling, and actual tainting of fishery resource. This activity is considered to be Regional in spatial scope as fisheries operate on a wide spatial scale. The socio-economic thresholds for surface oil, shoreline oil, and water column oil are set at 0.04 g/m^2, 1 g/m^2, and 100 µg/L respectively as seen in Table 5-1 (Nexen 2018; RPS 2019).

6.3.2 Step 2: Impact Modification Factor

As each feasible response option is evaluated, it is assigned an impact modification factor (Table 6-2) to indicate the level of impact a given response could affect a ROC/ROC constituent, when compared to the natural attenuation option. For the purposes of this SIMA, all options are assumed to be feasible, although that may not be the case at the actual time of a response.

Table 6-2. Impact modification factor.

Impact Modification Factor	Description
+4	Major mitigation of impact
+3	Moderate mitigation of impact
+2	Minor mitigation of impact
+1	Negligible mitigation of impact
0	No alteration of impact
-1	Negligible additional impact
-2	Minor additional impact
-3	Moderate additional impact
-4	Major additional impact

For this SIMA, the impact modification factors are assigned for each response option (i.e., shoreline protection and recovery, on-water mechanical recovery, *in situ* burning (ISB), surface dispersant application (SDA), and a combination of surface dispersant application and subsea dispersant application ([SDA/SSDI]) based on a qualitative review of published information and professional judgement for each of the ecological and socio-economic resources when compared to the natural attenuation option. The basic principle of assigning an impact modification factor requires estimating the proportion of the resource affected and how long it would take for that resource to recover. The IPIECA Guidelines (IPIECA et al. 2017) provides guidelines for assigning impact modification factors and the rationale for the selection of each IMF is provided in Section 6.3.2.1.

6.3.2.1 Rationale for Selection of IMFs Associated with the Various Response Options/ROCs and ROC Constituents

Shoreline Protection and Recovery

Only the ROCs/ROC constituents associated with the shoreline environmental compartment are applied here. Spill modelling predicted a low probability of crude oil reaching the Newfoundland shoreline, and the oil that reach the shoreline would be in a heavily weathered state, especially if other response options were applied. The shoreline protection and recovery option IMF assigned to all of the shoreline ROCs/ROC constituents is +1 (negligible mitigation of impact) an all other IMFs assigned for this response option are 0 (no alteration of impact) given the lack of association between this response option and the other four environmental compartments.

On-water Mechanical Recovery

For on-water mechanical recovery, wind, wave height, and the number of daylight hours are limiting factors. For this response option the rate of encountered oil is typically low (estimated on-water mechanical recovery during DWH spill was 5% of released oil), however, from a public perception perspective, acceptance of this response option is relatively high.

Mechanical recovery physically removes crude oil from the environment, which is regarded as positive for the potentially affected ROCs/ROC constituents in the various environmental compartments. Given the removal of some of the surface oil and the low probability of spilled crude oil reaching the Newfoundland shoreline, an IMF of +1 was assigned to all of the ROCs/ROC constituents in the Shoreline environmental compartment, with the exception of Marine and Migratory Birds that were assigned +2 IMF due to the vulnerability to oiling.

Given the likely low success rate of mechanical removal of crude oil from the ocean's surface, the Marine and Migratory Bird ROC was assigned a +2 IMF (minor mitigation of impact) in the Upper Water Column as slightly less crude oil on surface should also translate to slightly less dissolution and dispersion.

Regarding the Lower Water Column and Seabed environmental compartments, minimal crude oil is predicted to sink to these areas under the natural attenuation scenario. All biological ROCs/ROC constituents, except for Phytoplankton and Zooplankton, Ichthyoplankton and Invertebrate Eggs/Larvae associated with the Lower Water Column environmental compartment, were assigned a +1 IMF, the lowest rating for mitigation of impact. The Seabed ROC/ROC constituent exceptions were assigned a +1 IMF rating because the abundance of these plankton in the Lower Water Column is likely less than the abundance in the Upper Water Column where the plankton were assigned a +1 IMF.

Due to positive public perceptions, Fisheries has been assigned a +2 IMF.

In-Situ Burning (ISB)

ISB significantly reduces the amount of crude oil on the surface compared to on-water mechanical removal, however, a surface oil thickness of at least 2-5 mm must be present. ISB has the same limitations as mechanical recovery (e.g., wind, waves, available daylight hours) and the practical recovery rate success is similar. The IMF ratings assigned to the various ROCs/ROC constituents in the five environmental compartments are the same as those indicated for mechanical recovery. Fisheries has been assigned a slightly less positive assignment of same +1 IMF due to public perception of the use of burning as a response option.

Surface Dispersant Application (SDA)

Dispersants function as surfactants, where crude oil is broken down into droplets that disperse primarily into the upper water column. The dispersal of oil results in a greater surface area: volume ratio, thereby increasing the rate of biodegradation. The surface oil encounter rate for SDA is higher than those for on-water mechanical recovery and in-situ burning response options as surface dispersants can be applied from either aircrafts or relatively fast vessels. Aircraft response requires daylight and good visibility to target oil, to ensure that marine mammals are not in the application area, and to ensure that the dispersant is effective (i.e., surface colour change), and vessel SDA requires a suitable sea state. If wave heights exceed 4 m, breaking waves entrain oil in the water column and prevent appropriate interaction between the oil and the dispersant.

Dispersants would not likely be applied to inshore surface oil, so the IMFs assigned to the ROCs/ROC constituents in the Shoreline environmental compartment are the same as for on-water mechanical recovery and ISB. Algae, Invertebrates, Fishes, and Marine Mammals have been assigned +1 IMFs, and the Marine and Migratory Birds ROC has been assigned a +2 IMF. Any response option that removes oil from surface and promotes dissolution is positive for biota occurring on the shoreline.

For the Ocean Surface environmental compartment, the IMFs for the biological ROCs/ROC constituents all indicate some mitigation of impact. While removal of surface oil is typically good for seabirds, there is relatively little known about the effects of exposure of birds to dispersants and dispersants + oil. Therefore, a minor mitigation of impact IMF of +2 has been assigned to the Marine and Migratory Birds ROC. The other two ROCs associated with this environmental compartment, i.e., Marine Mammals and Sea Turtles, have been assigned the negligible mitigation of impact IMF of +1 since there is less risk of surface oiling.

All ROCs/ROC constituents on the Upper Water Column environmental compartment have been assigned negative IMFs, an indication of potential additional impact. Plankton and Zooplankton, Ichthyoplankton and Invertebrate Eggs/Larvae, and Marine and Migratory Birds have been assigned IMFs of -2 since they directly interact with the upper water column where oil will be dispersed. Invertebrates, Fishes, Marine Mammals, and Sea Turtles have been assigned -1 IMFs since these animals have the potential to avoid the upper water column. It is noted however that sea turtles will likely be rare in the immediate area of the spill.

The Lower Water Column would not likely be affected by SDA to the same degree as the Upper Water Column. Marine snow contaminated by oil will likely sink slowly through the lower water column and organic particulates in the water column should be less abundant than in waters closer to shore. Phytoplankton and Zooplankton, Ichthyoplankton and Invertebrate Eggs/Larvae have been assigned IMFs of 0 as most will be in the upper water column. All other ROCs/ROC constituents associated with the lower water column environmental compartment have been assigned IMFs of -1 since these animals have greater potential to encounter oil in the lower water column compared to the plankton.

As with the Lower Water Column, the Seabed would not likely be affected by surface dispersant application to the same degree as the Upper Water Column. While the amount of oil reaching the seabed should be minimal due to SDA, it has potential to exceed impact on the seabed under the natural attenuation scenario. The remaining biological ROCs/ROC constituents associated with this environmental compartment has been assigned an IMF of -1.

Due to the perception of tainted animals targeted in the Fisheries ROC, there is a possibility that the public will see the surface application of dispersants as the addition of toxic substances to the marine environment. As commercial fisheries are rated as Regional in scale it has been assigned -2 IMF.

SDA and Subsea Dispersant Injection (SDA+SSDI)

The SSDI component of this response option would take longer to mobilize than the SDA component, taking approximately 10 days and 2 days, respectively. SDA+SSDI have been grouped together for this response option as it is likely that by the time the SSDI response has been mobilized, the released subsea oil will have the potential to reach the surface, thus, the necessary use of SDA. Once operational, SSDI has fewer environmental limitations than the response options discussed previously, and the combined means of dispersant application also results in the highest spilled oil encounter rate of all response options.

Dispersants applied at both surface and at the blowout will result in considerably less crude oil reaching surface which may decrease the probability of shoreline oiling. Thus, all ROCs/ROC constituents in the shoreline environmental compartment, except for Marine and Migratory Birds, have been assigned the IMF of +2 (minor mitigation of impact). Marine and Migratory Birds, which are quite sensitive to oiling effects, has been assigned the IMF of +3.

In the Ocean Surface environmental compartment, the reduced amount of surface oil lowers the risk to biota that interact with the ocean surface. All biological ROCs/ROC constituents have been assigned positive IMFs (mitigation of impact), +3 for Marine and Migratory Birds, and +1 for Marine Mammals and Sea Turtles.

The SDA component will promote the dissolution and dispersion of oil into the water column and the SSDI component will substantially lower the amount of crude oil reaching the ocean surface. Subsequently, less oil will be dissolved and dispersed in the Upper Water Column which results in all biological ROCs/ROC constituents being assigned positive IMFs. Phytoplankton and Zooplankton, Ichthyoplankton and Invertebrate Eggs/Larvae, and Marine and Migratory Birds have been assigned the +2 IMF while Invertebrates, Fishes, Marine Mammals, and Sea Turtles have been assigned the +1 IMF.

During DWH large plumes of dispersed oil were observed at substantial depths (i.e., 1,000 m+) due to the high encounter rate with oil, resulting in substantial amounts of spilled crude becoming neutrally buoyant and remaining in the water column. While Phytoplankton and Zooplankton and Ichthyoplankton and Invertebrate Eggs/Larvae will likely not be impacted in the shallower region of the Lower Water Column (IMF=0), all other ROCs/ROC constituents could be impacted more than under the natural attenuation scenario. Invertebrates and Fishes have been assigned -2 IMFs and Marine Mammals and Sea Turtles have been assigned -1 IMFs. Studies associated with the DWH blowout event indicated more impact of the oil spill on the Seabed (benthic) habitat than anticipated, which were attributed to the large deep-water plumes of dispersed oil that formed after SSDI. Therefore, sensitive sessile Corals and Sponges have been assigned a -3 IMF, Other Invertebrates and Fish and Invertebrate Eggs and Larvae have been assigned a -2 IMF. Fishes, which are mobile, have been assigned a -1 IMF. Marine Mammals are unlikely to encounter dispersants in the benthic habitat but will benefit from the dilution of oil, so a +1 IMF score has been assigned.

From a socio-economic perspective, the application of dispersants at surface and at the blowout itself could intensify negative public perception regarding animals harvested in fisheries and aquaculture. For this reason, Fisheries have been assigned a -3 IMF.

6.3.3 Step 3: Relative Impact Mitigation Scores

For each ROC/ROC constituent, the Numerical Relative Impact value (Table 6-3) is multiplied by the associated Impact Modification Factor (IMF) (see Table 6-2) to create a Relative Impact Mitigation Score (RIMS) for a response option, as shown generically in Table 6-3 for the Shoreline environmental compartment. The score for each ROC/ROC constituent-response option combination represents the relative change that the response option would have on the impact. By using a qualitative ranking of impacts, a numerical value can be generated. The relative impact mitigation score is generated by assessing response options and ROC/ROC constituent using four possible numerical impact values (1, 2, 3 and 4) and nine impact modification factors (+4 to -4), resulting in 36 possible scoring possibilities per resource.

Table 6-3. Relative impact mitigation scores.

Environmental Compartment	ROC/ROC Constituent	Spatial Scale	Natural Attenuation		Response Option	
			Potential Relative Impact	Numerical Relative Impact (A)	Impact Modification Factors (B_1)	Relative Impact Mitigation Score (AxB_1)
Shoreline (Newfoundland)	Algae	L	Low	2	+2	+4
	Invertebrates	L	Low	2	+2	+4
	Fishes	R	Low	2	+1	+2
	Marine and Migratory Birds	R	Medium	3	+3	+9
	Marine Mammals	R	Low	2	+2	+4
	Shoreline Compartment Average					5

Note: L denotes Local; R denotes Regional.

Within each environmental compartment, a mean relative impact mitigation score (rounded off to nearest whole number) is then calculated across ROCs/ROC constituents (see Table 6-3). This step allows environmental compartments such as "Shoreline" (contains three ROCs/ROC constituents; Algae, Invertebrates, Fishes, Marine and Migratory Birds, and Marine Mammals) to be compared without bias to other environmental compartments, regardless of the number of ROCs/ROC constituents within that compartment. For the CNOOC SIMA, Table 6-4 displays the colour code as a scale from red to dark green indicating major increase in impact to major impact mitigation, respectively.

Table 6-4. Range of Score colour coding.

Range of Scores	Colour Code	Description
>+15		Major mitigation of impact
+11 to +15		Moderate mitigation of impact
+6 to +10		Minor mitigation of impact
+1 to +5		Negligible mitigation of impact
0		No alteration of impact
-5 to -1		Negligible additional impact
-10 to -6		Minor additional impact
-15 to -11		Moderate additional impact
<-15		Major additional impact

6.3.4 Step 4: Total Impact Mitigation Scores

The Total Impact Mitigation scores, which are the totals of the mean environmental compartment scores for each response option, are located on the bottom row of the Comparative Risk Matrix (Table 6-5) presented in the following section. This overall score is a qualitative prediction of how each response option might mitigate the overall impacts when compared to natural attenuation or no intervention for a specific scenario. IPIECA et al. (2017) provides guidelines on using the finalized comparative risk matrix.

6.4 Risk Assessment Results

A single Comparative Risk Matrix (Table 6-5) for the response options was generated for the ‘EL 1144-Summer’ scenario, taking into consideration the resources of concern identified for the CNOOC SIMA GAI. The ‘EL 1144-Summer’ spill scenario was used because it posed some of the greatest challenges from an emergency response perspective, and sensitive, threatened or endangered species were predicted to be relatively more abundant in the study area during that time of the year. Results for the ‘EL 1144-Summer’ scenario were then reviewed and briefly compared to the other three spill scenarios initially considered during the selection of the primary spill scenario.

Table 6-5. Relative Impact Mitigation Scores.

Environmental Compartment	ROC/ROC Constituent	Spatial Scale	Response Options											
			Natural Attenuation		Shoreline Protection and Recovery		On-water Mechanical Recovery		*In Situ* Burning (ISB)		Surface Dispersant Application (SDA)		SDA+ Subsea Dispersant Injection (SDA+SSDI)	
			Potential Relative Impact	**Numerical Relative Impact**	**Impact Modification Factors**	**Relative Impact Mitigation Score**	**Impact Modification Factors**	**Relative Impact Mitigation Score**	**Impact Modification Factors**	**Relative Impact Mitigation Score**	**Impact Modification Factors**	**Relative Impact Mitigation Score**	**Impact Modification Factors**	**Relative Impact Mitigation Score**
				A	**B_1**	**Ax B_1**	**B_2**	**AxB_2**	**B_3**	**Ax B_3**	**B_4**	**AxB_4**	**B_5**	**AxB_5**
Shoreline (Newfoundland)	Algae	L	None	1	+1	+1	+1	+1	+1	+1	+1	+1	+2	+2
	Invertebrates	L	None	1	+1	+1	+1	+1	+1	+1	+1	+1	+2	+2
	Fishes	R	None	1	+1	+1	+1	+1	+1	+1	+1	+1	+2	+2
	Marine and Migratory Birds	R	Medium	3	+2	+6	+2	+6	+2	+6	+2	+6	+3	+9
	Marine Mammals	R	None	1	+1	+1	+1	+1	+1	+1	+1	+1	+2	+2
	Shoreline Compartment Average					**+2**		**+2**		**+2**		**+2**		**+3**
Ocean Surface	Marine and Migratory Birds	R	High	4	0	0	+2	+8	+2	+8	+2	+8	+3	+12
	Marine Mammals	R	Medium	3	0	0	+1	+3	+1	+3	+1	+3	+1	+3
	Sea Turtles	R	Medium	3	0	0	+1	+3	+1	+3	+1	+3	+1	+3
	Ocean Surface Compartment Average					**0**		**+5**		**+5**		**+5**		**+6**
Upper Water Column (≤20 m depth)	Phytoplankton and Zooplankton	R	Medium	3	0	0	+1	+3	+1	+3	-2	-6	+2	+6
	Ichthyoplankton and Invertebrate Eggs/Larvae	R	Medium	3	0	0	+1	+3	+1	+3	-2	-6	+2	+6
	Invertebrates	R	None	1	0	0	+1	+1	+1	+1	-1	-1	+1	+1
	Fishes	R	None	1	0	0	+1	+1	+1	+1	-1	-1	+1	+1
	Marine and Migratory Birds	R	Medium	3	0	0	+2	+6	+2	+6	-2	-6	+2	+6
	Marine Mammals	R	None	1	0	0	+1	+1	+1	+1	-1	-1	+1	+1
	Sea Turtles	R	None	1	0	0	+1	+1	+1	+1	-1	-1	+1	+1
	Upper Water Column Compartment Average					**0**		**+2**		**+2**		**-3**		**+3**

Environmental Compartment	ROC/ROC Constituent	Spatial Scale	Response Options											
			Natural Attenuation		Shoreline Protection and Recovery		On-water Mechanical Recovery		*In Situ* Burning (ISB)		Surface Dispersant Application (SDA)		SDA+ Subsea Dispersant Injection (SDA+SSDI)	
			Potential Relative Impact	Numerical Relative Impact	Impact Modification Factors	Relative Impact Mitigation Score	Impact Modification Factors	Relative Impact Mitigation Score	Impact Modification Factors	Relative Impact Mitigation Score	Impact Modification Factors	Relative Impact Mitigation Score	Impact Modification Factors	Relative Impact Mitigation Score
				A	B_1	Ax B_1	B_2	AxB_2	B_3	Ax B_3	B_4	AxB_4	B_5	AxB_5
Lower Water Column (>20 m depth)	Phytoplankton and Zooplankton	R	Medium	3	0	0	0	0	0	0	0	0	0	0
	Ichthyoplankton and Invertebrate Eggs/Larvae	R	Medium	3	0	0	0	0	0	0	0	0	0	0
	Invertebrates	R	Low	2	0	0	+1	+2	+1	+2	-1	-2	-2	-4
	Fishes	R	Low	2	0	0	+1	+2	+1	+2	-1	-2	-2	-4
	Marine Mammals	R	Low	2	0	0	+1	+2	+1	+2	-1	-2	-1	-2
	Sea Turtles	R	Low	2	0	0	+1	+2	+1	+2	-1	-2	-1	-2
	Lower Water Column Compartment Average					**0**		**+1**		**+1**		**-1**		**-2**
Seabed (benthic)	Corals and Sponges	L	Low	2	0	0	+1	+2	+1	+2	-1	-2	-3	-6
	Other Invertebrates	L	Low	2	0	0	+1	+2	+1	+2	-1	-2	-2	-4
	Fish and Invertebrate Eggs and Larvae	L	Low	2	0	0	+1	+2	+1	+2	-1	-2	-2	-4
	Fishes	L	Low	2	0	0	+1	+2	+1	+2	-1	-2	-1	-2
	Seabed (benthic) Compartment Average					**0**		**+2**		**+2**		**-2**		**-4**
Socio-economic	Fisheries	R	High	4	+2	**+8**	+2	**+8**	+1	**+4**	-2	**-8**	-3	**-12**
TOTAL					+10		+20		+16		-7		-6	

Note: L denotes Local; R denotes Regional.

6.4.1 Natural Attenuation

Under the natural attenuation scenario, the highest risks to ROCs/ROC constituents are associated with interactions between biota and the ocean's surface and the potential impacts on the commercial fisheries. Modelling has indicated that there is a low probability of shoreline and seabed oiling, and while there would be dissolution of hydrocarbons into the upper water column, it would be limited. Marine and Migratory Birds, Marine Mammals, and Sea Turtles are likely most at risk under a natural attenuation scenario given their interactions with the ocean's surface, and subsequently the oil at surface. For the Ocean Surface environmental compartment, the potential relative impacts for Marine and Migratory Birds, and Marine Mammals/Sea Turtles are high (4) and medium (3), respectively. Oiling of feathers and skin could result in hypothermia and ultimately mortality for birds. As for the commercial fisheries, surface oil slicks would affect where commercial fisheries could be prosecuted, and there would be potential for actual and/or perceived tainting of the target species. A high (4) potential relative impact has been assigned to the Fisheries ROC under the natural attenuation scenario.

6.4.2 Shoreline Protection and Recovery

Shoreline protection and recovery is defined as the placement of booms and any other mechanical diversion devices in strategic locations that will prevent oil from reaching particularly sensitive areas. Such devices may herd oil into areas where it can be recovered with skimmers or other mechanical devices. The Shoreline Protection and Recovery response method is described in Section 3.2. This response option only pertains to two environmental compartments; (1) Shoreline; and (2) Fisheries.

For the 'EL 1144-Summer' scenario, oil is predicted to potentially reach the Newfoundland shoreline in 34 days at a minimum, but the overall probability of oil reaching the shoreline is very low. Based on the low probability of shoreline contact and the predominance of rocky high-energy shoreline type, the Impact Modification Factors applied for this response option were designated a +1 for all ROCs/ROC constituents associated with the Shoreline environmental compartments, except the +2 IMF applied to Marine and Migratory Birds (seabirds, shorebirds, waterfowl) at the shoreline. In the event shoreline protection and recovery could be implemented, it might prevent oil from reaching sensitive shoreline areas, and re-floating or entraining from shoreline areas due to tidal action. It is also possible that some coastal areas that may be important for such activities as commercial lobster fishing, recreational fishing or aquaculture could be protected, therefore an IMF of +2 was assigned to Fisheries.

Based on the relative IMFs calculated for this response option, the highest mitigation of impact associated with shoreline protection and recovery is for the Shoreline environmental compartment.

The total impact mitigation score for this response action is +10.

6.4.3 On-water Mechanical Recovery

On-water mechanical recovery involves the use of booms and skimmers to redirect, contain and remove oil from the ocean's surface. This response option, discussed in more detail in Section 3.3, pertains to all six environmental compartments.

On-water mechanical recovery of surface oil in the offshore could potentially lessen the probability of oil reaching any Newfoundland shoreline, although this option typically results in the physical removal of <10% of all surface oil. Therefore, +1 IMFs were assigned to fish and fish habitat constituents (Algae, Invertebrates, and Fishes) and the Marine Mammal ROC, while a +2 IMF was assigned to the Marine and Migratory Bird ROC associated with shoreline areas since these animals are most susceptible to impact from exposure to oil.

This response option would provide most benefit to the Ocean Surface environmental compartment, specifically to the Migratory Bird, Marine Mammal and Sea Turtle ROCs. Oil could potentially coat either the feathers of marine and migratory birds or the skin of marine mammals and sea turtles, thereby resulting in sub-lethal or lethal effects. All three ROCs in the Ocean Surface compartment have been assigned either medium or high potential relative impact values under the scenario of 'no intervention'. Given the low oil encounter rate and removal efficiency associated with this response option, IMFs of +1 and +2 were assigned to the Marine Mammal/Sea Turtle ROCs and the Migratory Bird ROC, respectively.

The primary beneficial effect of on-water mechanical recovery of oil on both Upper and Lower Water Column environmental compartments is the reduction in hydrocarbons that dissolve in the water column. Based on the premise that potentially harmful concentrations of hydrocarbons in seawater would occur in the upper 10–20 m of the water column, the most susceptible ROC is Fish and Fish Habitat, specifically Phytoplankton and Zooplankton, and Ichthyoplankton and Invertebrate Eggs/Larvae which either have no or low capability of actively leaving the portion of the Upper Water Column with elevated concentrations of dissolved hydrocarbons. Marine and Migratory are also considered to be at slightly higher risk of impact due to exposure to dissolved hydrocarbons in the Upper Water Column. However, given the low oil encounter rate and removal efficiency associated with this response option, IMFs of either +1 or +2 were assigned to the ROCs/ROC constituents associated with the water column environmental compartments.

Based on the relative IMFs calculated for this response option, the highest mitigation of impact associated with on-water mechanical recovery of oil is for the Ocean Surface environmental compartment (relative IMF of +5). The removal of oil from the ocean's surface is also beneficial for the Fisheries environmental compartment, at least from a public perception. Note that most of the commercial fishing that is conducted within the SIMA GAI targets demersal species which occur at depth, well away from the accumulated oil at surface.

The total impact mitigation score for this response action is +20.

6.4.4 *In Situ* Burning

This response option is quite similar to the on-water mechanical recovery option in that oil is removed from the ocean's surface. However, since there is no need to separate collected oil from water fractions and store it for later disposal, ISB can proceed at a faster rate than on-water mechanical recovery. This option, discussed in more detail in Section 3.4, pertains to all six environmental compartments. Under optimal conditions, this response option can reduce significantly more oil from the ocean's surface that the on-water mechanical recovery option. The *in situ* burning response option requires a surface oil thickness of 2–5 mm which can be challenging under typical wind and wave conditions on the Newfoundland offshore. Weather conditions that are conducive to ISB are very unlikely to occur in the GAI during both the summer and winter seasons. Wave heights must be less than 1 m, and mean wave heights in the GAI typically exceed that height even during the summer period (see Table 2-1). The burning also leaves a residue on the ocean's surface that could enter the upper water column.

In this assessment, the superior efficiency of ISB compared to on-water mechanical recovery was deemed to be offset by the very low probability that it could be utilized. As a result, the risk mitigation scoring was found to be the same as that for mechanical recovery. Therefore, the highest mitigation of impact associated with *in situ* burning of oil is for the Ocean Surface environmental compartment (relative IMF of +5). As with the on-water mechanical removal option, the *in situ* burning of oil from the ocean's surface is also deemed beneficial for the Fisheries environmental compartment from a public perception standpoint, however, to a slightly lesser degree. Note that most of the commercial fishing that is prosecuted within the SIMA GAI targets demersal species which occur at depth, well away from the accumulated oil at surface.

The total impact mitigation score for this response action is +16.

6.4.5 Surface Dispersant Application (SDA)

This response option involves the use of aircraft and/or spray-boom fitted vessels to apply dispersants on the ocean's surface. This option, discussed in more detail in Section 3.5, pertains to all six environmental compartments.

Surface application of dispersants has a much higher oil encounter rate compared to the on-water mechanical removal and *in situ* burning response options and would therefore result in less oil at the ocean's surface. This method is also less weather dependent than the fore mentioned response options. However, more of the oil disperses into the water column, thereby increasing the chances of encounters between the hydrocarbons and the biological ROCs within the water column. The environmental compartment totals of relative impact mitigation scores for both the Upper and Lower Water Column, and Seabed are negative values, indicating potential additional impacts. Additionally, the Fisheries compartment average was assigned an IMF of -8 due to poor public perception and/or education of the use of dispersants to commercial fisheries. However, the totals of relative impact mitigation scores for the other environmental components are positive meaning less predicted impact on the ROCs/ROC constituents associated with the Shoreline and Ocean Surface.

The total impact mitigation score for this response action is -7.

6.4.6 Surface Dispersant Application in Combination with Subsea Dispersant Injection (SDA+SSDI)

This response option involves the combination of the use of aircraft and/or spray-boom fitted vessels to apply dispersants on the ocean's surface, and the injection of dispersant directly into the subsea flow of oil at the wellhead. This option, discussed in more detail in Section 3.6, pertains to all six environmental compartments.

The combination of surface and subsea dispersant application has an even higher oil encounter rate compared to surface application of dispersants only. Much of the released oil will remain submerged due to the application of dispersants at the wellhead. This method is also less weather dependent and can be conducted continuously. As previously discussed, more of the oil disperses into the water column, thereby increasing the chances of encounters between the hydrocarbons and the biological ROCs within the water column. The environmental compartment totals of relative impact mitigation scores for the Lower Water Column, and Seabed are negative values, indicating potential additional impacts. Additionally, the Fisheries compartment average was assigned and IMF of -12 due to poor public perception and/or education of the use of dispersants to commercial fisheries. However, the totals of relative impact mitigation scores for the other environmental components are positive meaning less predicted impact on the ROCs/ROC constituents associated with the Shoreline and Ocean Surface.

The total impact mitigation score for this response action is -6.

6.4.7 Impact of Alternative Scenarios on Risk Ratings

In this section, the relative impacts associated with the other three spill scenarios originally considered for assessment in this SIMA are briefly examined. See Section 5.2 for discussion of other oil spill scenarios.

6.4.7.1 EL 1144-Winter

The time period used for the stochastic modelling of the EL 1144-Winter scenario is November–April and due to the adverse weather conditions experienced during winter months, all response methods that relate to surface oil have lower encounter rates and were less efficient compared to the summer months. The primary differences in spill behaviour and environmental conditions that could influence risk scoring are as follows:

- The range of mean significant wave heights is higher (2.8–4.5 m compared to 1.7–3.1 m during the summer period [see Table 2-1]);
- The range of mean wind speeds is higher (8.5–11.7 m/s compared to 6.2–9.3 m/s during the summer period [see Table 2-1]);
- The average probability of oil reaching shoreline is 1% for both winter and summer scenarios;
- The minimum time to shoreline is 15 days compared to 34 days for the summer period;
- The range of length of shoreline with 1–50% probability of shoreline oil, on average, exceeding 1 g/m^2 is 331–1,245 km compared to 60–335 km for the summer period;
- The 90% probability contour, on average, for surface oil thickness exceeding 0.04 µm delineates an area of 2,205,000 km^2 compared to 2,532,000 km^2 for the summer period;
- The 90% probability contour for the concentration of dissolved hydrocarbons in the water column exceeding 1µg/L delineates an area of 130,900 km^2 compared to 149,700 km^2 for the summer period; and
- The relative abundances of sensitive environmental receptors (i.e., ROCs) are lower during the winter period.

It was predicted that reduced surface oil quantities would occur during the winter period due to the differences in weather conditions. Despite the EL 1144-Winter scenario being characterized by shorter shoreline oiling times and greater lengths of shoreline impacted, the probability of any oil reaching the Newfoundland shoreline is quite low. During the winter, surface oil thickness and water column dissolved hydrocarbon threshold exceedances are less than those seen during the summer. Therefore, the chances of interactions of the ROCs with surface oil and dissolved hydrocarbons in the upper water column during the winter are reduced. During the summer there are greater abundances of the ROCs/ROC constituents in the area, making risk of interaction with the oil greater compared to during the winter months.

6.4.7.2 EL 1150-Summer

The time period used for the stochastic modelling of the EL 1150-Summer scenario is May–October. The same weather conditions used for EL 1150-Summer modelling were used for EL 1144-Summer modelling, and efficiencies of the different response options affected by weather are the same. The primary differences in spill behaviour that could influence risk scoring are as follows:

- The average probability of oil reaching shoreline is about 19% compared to 1% for the EL 1144-Summer scenario;
- The minimum time to shoreline is 51 days compared to 34 days for the EL 1144-Summer scenario;
- The 90% probability contour, on average, for surface oil thickness exceeding 0.04 µm delineates an area of 2,328,000 km^2 compared to 2,532,000 km^2 for the EL 1144-Summer scenario;

- The 90% probability contour for the concentration of dissolved hydrocarbons in the water column exceeding 1µg/L delineates an area of 25,530 km^2 compared to 149,700 km^2 for the EL 1144-Summer scenario; and
- The relative abundances of sensitive environmental receptors (i.e., ROCs) are the same as those for the EL 1144-Summer scenario.

The predicted shoreline, ocean surface and water column oiling characteristics for this scenario present less risk to the ROCs than during the EL 1144-Summer scenario despite the abundances of the ROCs/ROC constituents being the same since both scenarios are during the summer period.

6.4.7.3 EL 1150-Winter

The time period used for the stochastic modelling of the EL 1150-Winter scenario is November–April. Because of more adverse weather conditions, all response methods that relate to surface oil have lower encounter rates, on a daily basis, and were found to be less efficient than during the summer season. The primary differences in spill behaviour and environmental conditions that could influence risk scoring are as follow:

- The range of mean significant wave heights is higher (2.8–4.5 m compared to 1.7–3.1 m during the summer period [see Table 2-1]);
- The range of mean wind speeds is higher (8.5–11.7 m/s compared to 6.2–9.3 m/s during the summer period [see Table 2-1]);
- The average probability of oil reaching shoreline is about 9% compared to 1% for the EL 1144-Summer scenario;
- The minimum time to shoreline is 15 days compared to 34 days for the EL 1144-Summer scenario;
- The 90% probability contour, on average, for surface oil thickness exceeding 0.04 µm delineates an area of 2,053,000 km^2 compared to 2,532,000 km^2 for the EL 1144-Summer scenario;
- The 90% probability contour for the concentration of dissolved hydrocarbons in the water column exceeding 1µg/L delineates an area of 24,620 km^2 compared to 149,700 km^2 for the summer period; and
- The relative abundances of sensitive environmental receptors (i.e., ROCs) are lower during the winter period.

The differences in weather conditions had the net effect of increasing natural oil dispersion and evaporation, which resulted in predicted reduced oil quantities on the surface during the winter period. The areas of surface oil thickness and water column dissolved hydrocarbon threshold exceedances are far less during the EL 1150-Winter scenario compared to the EL 1144-Summer scenario, thereby reducing the chances of interactions of the ROCs with surface oil and dissolved hydrocarbons in the upper water column during the EL 1150-Winter scenario. Another important difference between EL 1144-Summer and EL 1150-Winter is the far greater abundances of the majority of the ROCs/ROC constituents (i.e., Phytoplankton and Zooplankton, Invertebrates, Fishes, Marine Mammals, and Sea Turtles) during the summer period, making risk of interaction with the oil greater during the EL 1144-Summer scenario. It should be noted however, that Marine and Migratory Seabirds may also be in high abundance during the EL 1150-Winter scenario, though not to the degree expected in the EL 1144-Summer scenario.

6.4.7.4 Summary

The comparisons of the other three spill scenarios originally considered for assessment in this SIMA with the EL 1144-Summer scenario justify the choice of the EL 1144-Summer scenario as the worst-case scenario involving a Tier 3 spill due to an uncontrolled blowout at a potential deep-water drilling site in the northern Flemish Pass.

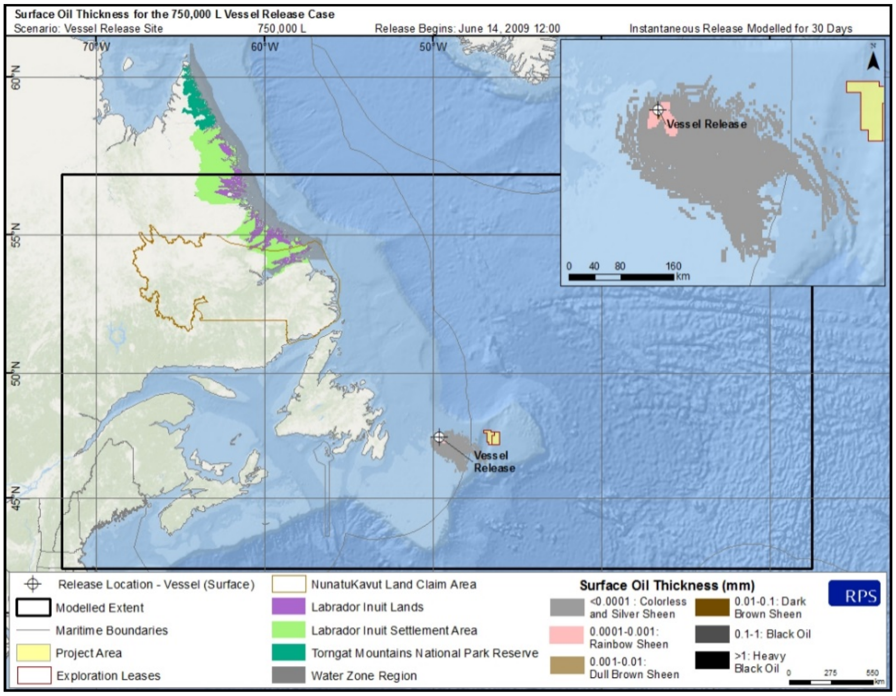
6.5 Consideration of a Smaller Tier 1 Scenario

RPS (2018) conducted deterministic analyses (30-day simulations) of two 'batch' spill scenarios (100 L and 1,000 L of marine diesel) at the EL 1144 hypothetical release location, and a 'vessel collision' scenario that involves the release of 750,000 L of marine diesel at a location between St. John's and the EL 1144 hypothetical release location. All three scenarios are considered to be Tier 1 spills. Although the marine diesel release associated with the 'vessel collision' scenario is not insignificant, the volume released is still relatively small compared to the Tier 3 scenarios assessed in Section 5.2.

Due to the relatively small release volumes associated with all three scenarios and the size of the concentration gridding (1 km x 1 km), the predicted concentrations of dissolved hydrocarbons were of very low concentrations. Surface oil thickness of 0.0001–0.001 mm (i.e., rainbow sheen) for the 'vessel collision' scenario was predicted to extend ~50 km to the southwest of the release location, while surface oil thickness of <0.0001 mm (i.e., silver sheen) was predicted to extend ~300 km to the southwest of the release location (Figure 6-2).

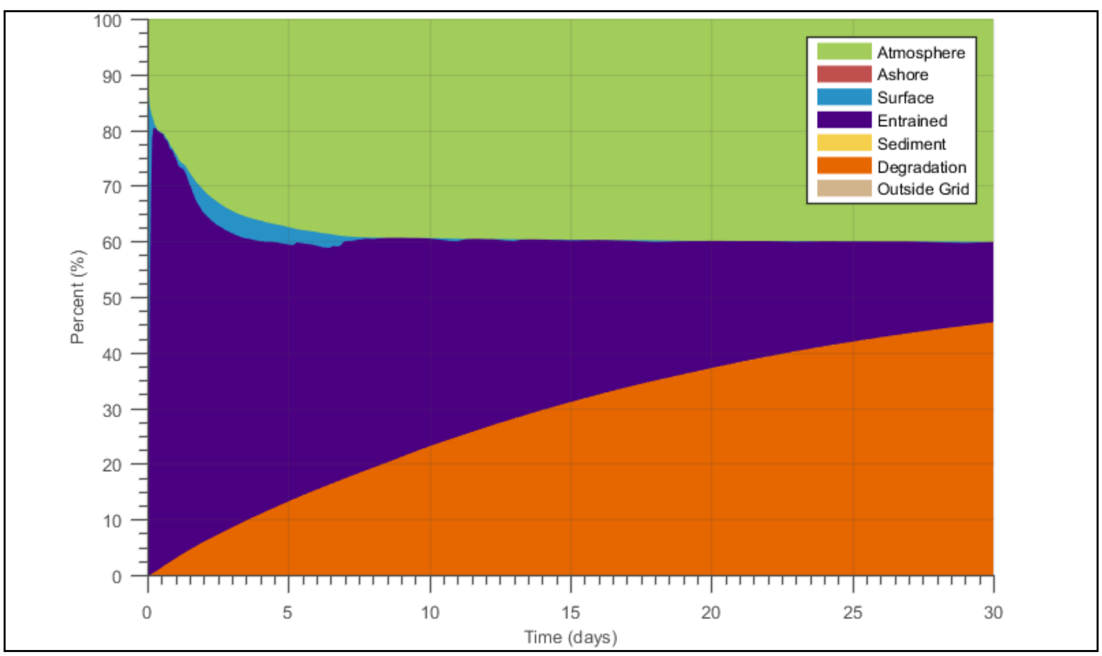
The release of 750,000 L of marine diesel was not predicted to result in any oil contacting shorelines. At the end of the 30-day simulation for the two batch spill scenarios and the 'vessel collision' scenario, the following predictions were made (Figure 6-3).

- <0.1% of the released marine diesel remained on surface;
- 63–76% evaporated into the atmosphere;
- 8–14% entrained in the water column;
- <0.01% adhered to suspended sediment;
- 16–45% degraded; and
- 0% made contact with shorelines.



Source: RPS (2018).

Figure 6-2. Surface oil thickness resulting from the release of 750,000 L marine diesel during the vessel collision scenario.



Source: RPS (2018).

Figure 6-3. Mass balance plots of the release of 750,000 L marine diesel during the vessel collision scenario.

For the purposes of this SIMA, the following assumptions have been made regarding available on-site Tier 1 response capabilities in the Newfoundland and Labrador offshore (Table 6-6).

Table 6-6. Available on-site Tier 1 response capabilities.

Response Option	Assumed On-site Tier 1 Capability
Natural Attenuation	Conduct aerial monitoring of the spill and conduct surveillance on any resources that may be impacted.
On-Water Mechanical Recovery	Use of sorbent boom and Full Tier 1 Response Kit. Single vessel side sweep systems available through mutual aid and other support vessels in region.
In Situ Burn	Not applicable for Tier 1 batch spill.
Surface Dispersant Application	This is currently not an option locally. Regulatory approval would be required to use any volume of dispersants and there is currently no vessels equipped to deploy dispersants.
Aerial Application of Dispersant	Not applicable for Tier 1 surface spill.
Subsea Dispersant Injection	Not applicable for Tier 1 surface spill.

Although the marine diesel release associated with the 'vessel collision' scenario is not insignificant, the volume released is still relatively small compared to the Tier 3 scenarios assessed in Section 5.2. As indicated in Table 6-6, only three of the six response options are relevant to the Tier 1 spill: (1) natural attenuation; (2) on-water mechanical recovery; and (3) surface dispersant application.

Despite mechanical recovery operations being somewhat limited at higher sea states, surface dispersant spraying using a vessel or platform is a response option that could be rapidly deployed, and therefore has the greatest potential for removing significant amounts of oil from the water surface in these conditions.

Because of the ephemeral nature of smaller spills, there is reduced potential for Fish and Fish Habitat, Marine Mammal or Sea Turtle ROCs coming into contact with the spill. However, Marine and Migratory Birds in the immediate vicinity of the spill could be affected. Due to the relatively small spill volume, impacts to the Upper and Lower Water Column and Seabed environmental compartments are unlikely to occur, and therefore, impacts to the Fisheries ROC are also unlikely to occur.

7.0 Summary

The natural attenuation option was found to pose the highest risk for the ocean surface and socio-economic (i.e., fisheries) environmental compartments since more oil would remain at surface for a longer period of time compared to the active response options. At the shoreline and ocean surface, oil poses a higher level of risk through multiple exposure pathways including ingestion, dermal contact, and inhalation. As already indicated, the spill modelling for 'EL 1144-Summer' scenario concluded that there is a very low probability of oil reaching the Newfoundland shoreline. As for oil at the ocean's surface, marine and migratory birds, marine mammals and sea turtles are most at risk. From a socio-economic standpoint, offshore commercial fisheries would also be impacted, through both actual and perceived fish tainting. While there would be some dissolution of hydrocarbons into the upper water column under a 'no intervention' scenario, the upper 10–20 m of the water column would be most affected. Therefore, less mobile ROC constituents such as phytoplankton and zooplankton, ichthyoplankton and invertebrate eggs/larvae, would be at highest risk in the water column. While the results from the deterministic modelling analysis do show that oil may settle in the sediment, the amount which that may settle is well below the ecological thresholds.

The application of on-water mechanical recovery would result in the most reduction in risk (i.e., relative impact mitigation score of +20, Table 6-5), followed by in-situ burning of oil at the surface (with relative impact mitigation score of +16; Table 6-5), and shoreline protection and recovery (relative impact mitigation scores of +10; Table 6-5). The use of dispersants would result in a higher overall risk to ROCs in terms of the lower water column and seabed. Additionally, the use of dispersants has the greatest negative effect on fisheries compared to the other response options (i.e., relative impact mitigation scores of -8 and -11, respectively, Table 6-5).

The choice of response option will primarily depend on temporal and spatial characteristics of the spill scenario.

8.0 References

Adams, J., Sweezey, M., Hodson, P.V. 2014. Oil and oil dispersant do not cause synergistic toxicity to fish embryos, Enviro. *Tox*. Chem. 33(1):107-114.

AEA (AEA Technology). 1994. International calibration of laboratory dispersant test methods against sea trials. Oxfordshire, UK: AEA Technology.

AEA. 1995. International calibration of laboratory dispersant test methods against sea trials. Field trial report. July 1995 sea trials. Oxfordshire, UK: AEA Technology.

Aichinger Dias, L., J. Litz, L. Garrison, A. Martinez, K. Barry, and T. Speakman. 2017. Exposure of cetaceans to petroleum products following the Deepwater Horizon oil spill in the Gulf of Mexico. Endanger. Species Res. 33: 119-125.

Almeda, R., Bona, S., Foster, C.R., Buskey, E.J. 2014.Dispersant Corexit 9500A and chemically dispersed crude oil decreases the growth rates of meroplanktonic barnacle nauplii (Amphibalanusimprovisus) and tornaria larvae (Schizocardium sp.), Mar. Enviro. Res., 99:212-217,

API (American Petroleum Institute). 2017. Industry guidelines on requesting regulatory concurrence for subsea dispersant use. API Bulletin 4719 First Edition, June 2017.

Araújo, C.V.M., M. Moreira-Santos, J.P. Sousa, V. Ochoa-Herrera, A.C. Encalada, and R. Ribeiro. 14. Active avoidance from a crude oil soluble fraction by an Andean paramo copepod. Ecotoxicology 23: 1254-1259.

Bælum, J., S. Borglin, R. Chakraborty, J. L. Fortney, R. Lamendella, O. U. Mason, M. Auer, M. Zemla, M. Bill, M. E. Conrad, S. A. Malfatti, S. G. Tringe, H. Y. Holman, T. C. Hazen, and J. K. Jansson. 2012. Deep-sea bacteria enriched by oil and dispersant from the Deepwater Horizon spill. Enviro. Microbiol. 14: 2405–2416.

Bailey, S.A.B. 2019. NMR metabolomic analysis of whole blood and tissues from hatchling loggerhead sea turtles (*Caretta caretta*) experimentally exposed to crude oil and/or Corexit. Doctor of Philosophy Dissertation. Department of Fisheries, Wildlife, and Conservation Biology, North Carolina State University. Raleigh, North Carolina. 47 p. + appendix. Available at: https://repository.lib.ncsu.edu/bitstream/handle/1840.20/36678/etd.pdf?sequence=1.

Balmer, B.C., G.M. Ylitalo, L.E. McGeorge, K.A. Baugh, D. Boyd, K.D. Mullin, P.E. Rosel, C. Sinclair, R.S. Wells, E.S. Zolman, and L.H. Schwacke. 2015. Persistent organic pollutants (POPs) in blubber of common bottlenose dolphins (*Tursiops truncatus*) along the northern Gulf of Mexico coast, USA. Science of the Total Environment 527-528: 306-312.

Barron, M.G., M.G. Carls, J.W. Short and S.D. Rice. 2003. Photoenhanced toxicity of aqueous phase and chemically dispersed weathered Alaska north slope crude oil to Pacific herring eggs and larvae. Enviro. Tox. Chem., 22(3):650–660.

Beazley, L.L., E.L. Kenchington, F.J. Murillo, and M. del Mar Sacau. 2013. Deep-sea sponge grounds enhance diversity and abundance of epibenthic megafauna in the northwest Atlantic. ICES Journal of Marine Science 70(7):1471-1490.

Beirao, J., L. Baillon, M.A. Litt, and C.F. Purchase. 2018. Chemically-dispersed crude oil and dispersant affects sperm fertilizing ability, but not sperm swimming behaviour in capelin (*Mallotus villosus*). Enviro. Poll. 241:521-528.

Beirao, J., L. Baillon, M.A. Litt, V.S. Langlois, and C.F. Purchase. 2019. Impact of crude oil and the dispersant Corexit™ EC9500A on capelin (*Mallotus villosus*) embryo development. Mar. Enviro. Res. In Press.

Bejarano, A.C., W.W. Gardiner, M.G. Barron, and J.Q. Word. 2017. Relative sensitivity of Arctic species to physically and chemically dispersed oil determined from three hydrocarbon measures of aquatic toxicity. Mar. Poll. Bull. 122(1-2), 316-322.

Bence, A.E. and W.A. Burns. 1995. Fingerprinting hydrocarbons in the biological resources of the *Exxon Valdez* spill area. Pp. 84-140. In: P.G. Wells, J.N. Butler and J.S. Hughes (eds.). *Exxon Valdez* Oil Spill: Fate and Effects in Alaskan Waters. ASTM STP 1219. American Society for Testing and Materials, Philadelphia, PA. 965 pp.

Bennison, A., and M. Jessopp. 2015. At-sea surveys confirm a North Atlantic biodiversity hotspot. Bird Study 62:262-266.

Beyer, J., H.C. Trannum, T. Bakke, P.V. Hodson, and T.K. Collier. 2016. Environmental effects of the Deepwater Horizon oil spill: A review. Marine Pollution Bulletin, 110(1): 28-51.

BirdLife International. 2020a. Important Bird Areas factsheet: Evlanov Seamount and Basin. Downloaded from http://www.birdlife.org on 17/04/2020.

BirdLife International. 2020b. Important Bird Areas factsheet: Atlantic, Northeast 2 - Marine. Downloaded from http://www.birdlife.org on 17/04/2020.

BirdLife International. 2020c. Important Bird Areas factsheet: Atlantic, Northeast 3 - Marine. Downloaded from http://www.birdlife.org on 17/04/2020.

BirdLife International. 2020d. Important Bird Areas factsheet: Corvo e Flora. Downloaded from http://www.birdlife.org on 17/04/2020.

BirdLife International. 2020e. Important Bird Areas factsheet: Norte do Corvo – Oceânica. Downloaded from http://www.birdlife.org on 17/04/2020.

BirdLife International. 2020f. Important Bird Areas factsheet: Norte do Corvo e Faial – Oceânica. Downloaded from http://www.birdlife.org on 17/04/2020.

Birdlife International. 2020g. IUCN Red List for Birds. http://www.birdlife.org Accessed: 17 April 2020.

Boertmann, D. 2011. Seabirds in the central North Atlantic, September 2006: further evidence for an oceanic seabird aggregation area. Marine Ornithology 39:183-188.

Bøhle, B. 1986. Avoidance of petroleum hydrocarbons by the cod (*Gadus morhua*). FiskDir. Skr. Ser. HavUnders., 18: 97-112.

Bolduc, F., F. Rousseu, C. Gjerdrum, D. Fifield, and S. Christin. 2018. Atlas of Seabirds at Sea in Eastern Canada 2006–2016. Environment and Climate Change Canada, Canadian Wildlife Service, https://open.canada.ca/data/en/dataset/f612e2b4-5c67-46dc-9a84-1154c649ab4e. Accessed: 8 March 2018.

Bossart, G.D., M. Lutcavage, B. Mealey and P. Lutz. 1995. The dermatopathologic effects of oil on loggerhead sea turtles (*Caretta caretta*). Pp. 180-181. In: L. Frink, K. Ball-Weir and C.

Smith (eds.). Wildlife and Oil Spills: Response, Research, and Contingency Plan. Tri-State Bird Rescue and Research, DE. 182 pp.

Brakstad, O.G., P.S. Daling, L.G. Faksness, I.K. Almås, S.H. Vang, L. Syslak, and F. Leirvik. 2014. Depletion and biodegradation of hydrocarbons in dispersions and emulsions of the Macondo 252 oil generated in an oil-on-seawater mesocosm flume basin. Mar. Poll. Bull., 84(1), 125–134. https://doi.org/10.1016/j.marpolbul.2014.05.027.

Brandvik, P.J., P.S. Daling, F. Leirvik, Ø. Johansen, E. Davies, and D.F. Krause. 2014. Subsea dispersant effectiveness bench-scale test-protocol development and documentation for IPIECA-OGP OSR JIP.

Bretherton L, M. Kamalanathan, J. Genzer, J. Hillhouse, S. Settaa, Y. Liang, C. M. Brown, C. Xu, J. Sweet, U. Passow, Z. V. Finkel, A. J. Irwin, P. H. Santschi, and A. Quigga. 2019. Response of natural phytoplankton communities exposed to crude oil and chemical dispersants during a mesocosm experiment. Aquat. Tox. 206: 43-53.

Brotz, L., W.W.L. Cheung, K. Kleisner, E. Pakhomov, and D. Pauly. 2012. Increasing jellyfish populations: trends in Large Marine Ecosystems. Hydrobiologia, 690 (1): 3–20.

Buhl-Mortensen, P., E. Tenningen, and A.B.S. Tysseland. 2015. Effects of water flow and drilling waste exposure on polyp behavior in *Lophelia pertusa*. Marine Biology Research 11(7): 725-373.

Burger, A. and M. Simpson. 1986. Diving depths of Atlantic Puffins and Common Murres. Auk 103: 828-830.

Butler, R.G. and D.E. Buckley. 2002. Black Guillemot (Cepphus grylle), version 2.0. In The Birds of North America (A.F. Poole and F.B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.675.

Camacho, M., P. Calabuig, O.P. Luzardo, L.D. Boada, M. Zumbado, and J. Orós. 2013. Crude Oil as a stranding cause among loggerhead sea turtles (*Caretta caretta*) in the Canary Islands, Spain (1998–2011). J. Wildlife Dis. 49(3): 637-640.

Campeão, M.E., L. Reis, L. Leomil, L. de Oliveira, K. Otsuki, P. Gardinali, ... and C.C. Thompson. 2017. The Deep-Sea Microbial Community from the Amazonian Basin Associated with Oil Degradation. Front. Microbiol., 8.

Carroll, J., F. Vikebø, D. Howell, O.J. Broch, R. Nepstad, S. Augustine, G.M. Skeie, R. Bast, and J. Juselius. 2018. Assessing impacts of simulated oil spills on the Northeast Arctic cod fishery. Marine Pollution Bulletin 126: 63-73.

Casas, J. M. and J. Paz. 1996. Recent changes in the feeding of cod (*Gadus morhua*) off the Flemish Cap, Newfoundland 1989–1993. ICES Journal of Marine Science 53: 750-756.

Catto, N.R., R.G. Hooper, M.R. Anderson, D.A. Scruton, J.D. Meade, L.M.N. Ollerhead, and U.P. Williams. 1999. Biological and geomorphological classification of Placentia Bay: a preliminary assessment. Can. Tech. Rep. Fish. Aquat. Sci. 2289. v + 35 p.

CBD (Convention on Biological Diversity). 2015. Ecologically or Biologically Significant Marine Areas – Special places in the world's oceans. The Clearing-House Mechanism of the Convention on Biological Diversity Information Submission Service. Available at https://www.cbd.int/ebsa/.

CERC (Coastal Engineering Research Center). 1984. Shore Protection Manual, Vol. I and II, Coastal Engineering Research Center, Department of the Army, Waterways Experiment Station, U.S. Army Corps of Engineers, Vicksburg, MS, 1105 p. + 134 p.

Clark, J.R., G.E. Bragin, R.J. Febbo, and D.J. Letinski. 2001. Toxicity of physically and chemically dispersed oils under continuous and environmentally realistic exposure conditions: Applicability to dispersant use decisions in spill response planning. Pp. 1249–1255 in *Proceedings of the 2001 International Oil Spill Conference*, Tampa, Florida. American Petroleum Institute, Washington, D.C.

C-NLOPB (Canada-Newfoundland and Labrador Offshore Petroleum Board). 2008. Labrador Shelf Offshore Area Strategic Environmental Assessment. Rep. by Sikumiut Environmental Management Ltd., for Canada-Newfoundland and Labrador Offshore Petroleum Board, St. John's, NL. 519 p. + appendices.

C-NLOPB. 2010. Southern Newfoundland Strategic Environmental Assessment. Rep. by LGL Limited, St. John's, NL, Oceans Limited, St. John's, NL, Canning & Pitt Associates, Inc., St. John's, NL, and PAL Environmental Services, St. John's, NL, for Canada-Newfoundland and Labrador Offshore Petroleum Board, St. John's, NL. 333 p. + appendix.

C-NLOPB. 2014. Eastern Newfoundland Strategic Environmental Assessment. Rep. by AMEC Environment & Infrastructure, for Canada-Newfoundland and Labrador Offshore Petroleum Board, St. John's, NL. 519 p. + appendices.

CNOOC (CNOOC Petroleum North America ULC). 2019. CNOOC International Flemish Pass Exploration Drilling (2018-2028) – Environmental Impact Statement Addendum (Revised) Responses to Information Requirements and Required Clarifications. 336 p. + appendices.

Coelho, G., D. Aurand, L. Essex, A. Parkin, and L. Robinson. 2011 (revised 2014). Monitoring subsurface dispersant injection during the MC252 incident, Volume 1. Ecosystem Management & Associates, Inc. Technical Report 11-05. Lusby, MD, USA.

Coelho, G.M., D.V. Aurand, G.S. Petch, and D.M. Jones. 1998. Toxicity bioassays on dispersed oil in the North Sea: June 1996 field trials. Ecosystem Management & Associates, Inc., Purcellville, VA. EM&A Report 96-02.

COSEWIC (Committee on the Status of Endangered Wildlife in Canada). 2006. COSEWIC assessment and update status report on the Ivory Gull *Pagophila eburnea* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. vi + 42 pp. (www.sararegistry.gc.ca/status/status_e.cfm).

COSEWIC. 2020. Committee on the Status of Endangered Wildlife in Canada. Accessed on 14 March 2019, 5 April 2019, and 17 April 2020 at http://cosewic.ca/index.php/en-ca/assessment-process.

Davis, J.E. and S.S. Anderson. 1976. Effects of oil pollution on breeding grey seals. Mar. Poll. Bull., 7(6):115-118.

De Guise, S., M. Levin, E. Gebhard, L. Jasperse, L. Burdett Hart, C.R. Smith, S. Venn-Watson, F. Townsend, R. Wells, B. Balmer, E. Zolman, T. Rowles, and L. Schwacke. 2017. Changes in immune functions in bottlenose dolphins in the northern Gulf of Mexico associated with the Deepwater Horizon oil spill. Endanger. Species Res. 33: 291-303.

DFLR (Department of Fisheries and Land Resources). 2018. Seafood industry year in review 2017. Department of Fisheries and Land Resources, Government of Newfoundland and Labrador. 59 p. Available at https://www.fishaq.gov.nl.ca/publications/pdf/SYIR_2017.pdf.

DFLR. 2019. Seafood industry year in review 2018. Department of Fisheries and Land Resources Government of Newfoundland and Labrador. 59 p. Available at

DFO (Fisheries and Oceans Canada). 2012. Recovery strategy for the beluga whale (*Delphinapterus leucas*) St. Lawrence Estuary population in Canada. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. x + 88 p.

DFO. 2013. Eastport marine protected areas management plan 2013–2018. Fisheries and Oceans Canada, Government of Canada. 26 p. + appendices. Available at http://www.dfo-mpo.gc.ca/oceans/mpa-zpm/eastport/index-eng.html.

DFO. 2016a. Recovery strategy for the leatherback sea turtle (*Dermochelys coriacea*) in Atlantic Canada [Proposed]. *Species at Risk Act* Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. vii + 43 p.

DFO. 2016b. Report on the Progress of recovery strategy implementation for the blue whale (*Balaenoptera musculus*), Northwest Atlantic population, in Canada for the Period 2009–2014. *Species at Risk Act* Recovery Strategy Report Series. Fisheries and Oceans Canada, Ottawa. ii + 14 p.

DFO. 2016c. Report on the progress of recovery strategy implementation for the northern bottlenose whale (*Hyperoodon ampullatus*), Scotian Shelf Population, in Atlantic Canadian Waters for the period 2010-2015. Accessed on 20 March 2019 at https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery-strategies/northern-bottlenose-whale-scotian-shelf.html.

DFO. 2017. Ocean Data Inventory (ODI): database inventory of moored current meters, thermographs and tide gauges from the East Coast of Canada, 1960 to present. Department of Fisheries and Oceans, Canada. http://www.bio.gc.ca/science/data-donnees/base/data-donnees/odi-en.php. ODI Database accessed on 1 May 2017.

DFO. 2018a. Recovery strategy for northern wolffish (*Anarhichas denticulatus*) and spotted wolffish (*Anarhichas minor*) and management plan for Atlantic wolffish (*Anarhichas lupus*) in Canada [proposed]. Fisheries and Oceans Canada, Ottawa. vii + 82 p. Available at http://www.registrelepsararegistry.gc.ca/document/default_e.cfm?documentID=1285.

DFO. 2018b. Inshore lobster. Integrated Fishery Management Plan, Lobster Fishing Areas 27-38, Scotia-Fundy Sector – Maritimes Region – 2011. Department of Fisheries and Oceans Canada, Government of Canada. Accessed on 17 April 2019 at https://www.dfo-mpo.gc.ca/fisheries-peches/ifmp-gmp/maritimes/inshore-lobster-2011-eng.html#toc1.4.

DFO. 2018c. 2018 Snow crab fishery, Newfoundland and Labrador. Accessed on 18 March 2019 at http://www.dfo-mpo.gc.ca/decisions/fm-2018-gp/atl-07-eng.htm.

DFO. 2019. Marine protected areas (MPAs), areas of interest (AOIs) and other measures. Fisheries and Oceans Canada, Government of Canada. Available at http://www.dfo-mpo.gc.ca/oceans/mpa-zpm-aoi-si-eng.html.

Dupuis, A. and F. Ucan-Marin. 2015. A literature review on the aquatic toxicology of petroleum oil: An overview of oil properties and effects to aquatic biota. DFO Can. Sci. Advis. Sec. Res. Doc. 2015/007. vi + 52 p.

Dussauze, M., Danion, M., Le Floch, S., Lemaire, P., Pichavant-Rafini, K., Theron, M. 2015. Innate immunity and antioxidant systems in different tissues of sea bass (Dicentrarchus labrax) exposed to crude oil dispersed mechanically or chemically with Corexit 9500, Ecotox. Enviro.Saf., 120:270-278.DWH Trustees (Deepwater Horizon Natural Resource Damage Assessment Trustee Council). 2016. The Deepwater Horizon Oil Spill Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. National Oceanic and Atmospheric Administration, Office of Response and Restoration. [http://www.gulfspillrestoration.noaa.gov/restoration-planning/gulf-plan/],

ECCC (Environment and Climate Change Canada). 2016. Recovery Strategy and Management Plan for the Red Knot (Calidris canutus) in Canada [Proposed]. *Species at Risk Act* Recovery Strategy Series. Environment and Climate Change Canada, Ottawa. ix + 54 pp.

ECCC-CWS (Environment and Climate Change Canada-Canadian Wildlife Service). 2018. Atlantic Colonial Waterbird Database. Accessed September 2018 at: http://data.ec.gc.ca/data/species/assess/atlantic-colonies-density-analysis/.

Egevang, C., I. J. Stenhouse, R. A. Phillips, A. Petersen, J. W. Fox, and J. R. D. Silk. 2010. Tracking of Arctic terns *Sterna paradisaea* reveals longest animal migration. Proceedings of the National Academy of Sciences, USA 107:2078-2081.

Engelhardt, F.R. 1978. Petroleum hydrocarbons in Arctic ringed seals, *Phoca hispida*, following experimental oil exposure. Pp. 614 628. In: Proceedings of the Conference on the Assessment of the Ecological Impacts of Oil Spills, 14 17 June 1978, Keystone, CO. American Institute of Biological Science.

Engelhardt, F.R. 1982. Hydrocarbon metabolism and cortisol balance in oil-exposed ringed seals, *Phoca hispida*. Comp. Biochem. Phys. C: Comparative Pharmacology 72: 133-136.

Engelhardt, R.F. 1983. Petroleum effects on marine mammals. Aquat. Toxic., 4: 199-217.

EPA (Environmental Protection Agency Office of Research and Development). 2010. Toxicity of Louisiana Sweet Crude Oil (LSC) and chemically dispersed LSC to two Gulf of Mexico aquatic test species – August 2010 and the updated report of September 2010. Retrieved from http://www.epa.gov/bpspill/dispersants-testing.html.

ESA (*Endangered Species Act)*. 2002. Consolidated Newfoundland and Labrador Regulation 57/02: Endangered Species List Regulations. (Online). Government of Newfoundland and Labrador, St. John's: Environment and Conservation, 2016. Accessed April 2019 at:

Falk, K., C.E. Pedersen, and K. Kampp. 2000. Measurements of diving depth in Dovekies (Alle alle). Auk 117(2): 522-525.

Federal Interagency Solutions Group. 2010. Oil budget calculator: Deepwater Horizon.

Fingas, M. (ed.). 2015. Handbook of oil spill science and technology. Hoboken, New Jersey: John Wiley & Sons, Inc. Fisheries and Oceans Canada. (2001). British Columbia/Canada in situ oil burning policy and decision guidelines. Department of Fisheries and Oceans, Pacific Region. Vancouver, BC.

Fingas, M.F., D.A. Kyle, N. Laroche, B. Fieldhouse, G. Sergy, and G. Stoodley. 1995. The effectiveness testing of oil spill-treating agents. In *The Use of Chemicals in Oil Spill Response*. ASTM STP1252. American Society of Testing and Materials, Philadelphia, PA, pp. 286-298.

Fiorello, CV, K. Freeman, B.A. Elias, E. Whitmer, M.H. Ziccardi. 2016. Ophthalmic effects of petroleum dispersant exposure on common murres (*Uria aalge*): An experimental study. Marine Pollution Bulletin 113: 387-391.

Forbes, D.L. 1984. Coastal geomorphology and sediments of Newfoundland. In Current Research, Part B, Geological Survey of Canada. Paper 84-1B: 11-24.

Fort, J., B. Moe, H. Strøm, D. Grémillet, J. Welcker, J. Schultner, K. Jerstad, K. L. Johansen, R. A. Phillips, and A. Mosbech. 2013. Multicolony tracking reveals potential threats to little auks wintering in the North Atlantic from marine pollution and shrinking sea ice cover. Diversity and Distributions, 19: 1322-1332.

Fraser, G.S. and V. Racine. 2016. An evaluation of oil spill responses for offshore oil production projects in Newfoundland and Labrador, Canada: Implications for seabird conservation. Mar. Poll. Bull. 107:36-45.

Fraser, G.S., J. Russell, G.J. Robertson, R. Bryant, and D.A. Fifield. 2013. Prospects for the Manx Shearwater colony of Middle Lawn Island, Newfoundland, Canada. Marine Ornithology 41: 137-140.

Frasier, K.E. 2020. Chapter 25: Evaluating impacts of deep oil spills on oceanic marine mammals. Pp. 419-441 *In*: Murawski, S., (eds.). Scenarios and Responses to Future Deep Oil Spills. Springer, Cham. 542 p. DOI: 10.1007/978-3-030-12963-7_25.

Frederiksen, M., B. Moe, F. Daunt, R. A. Phillips, R. T. Barrett, M. I. Bogdanova, T. Boulinier, J. W. Chardine, O. Chastel, L. S. Chivers, S. Christensen-Dalsgaard, C. Clément-Chastel, K. Colhoun, R. Freeman, A. J. Gaston, J. González-Solís, A. Goutte, D. Grémillet, T. Guilford, G. H. Jensen, Y. Krasnov, S.-H. Lorentsen, M. L. Mallory, M. Newell, B. Olsen, D. Shaw, H. Steen, H. Strøm, G. H. Systad, T. L. Thórarinsson, and T. Anker-Nilssen. 2012. Multicolony tracking reveals the winter distribution of a pelagic seabird on an ocean basin scale. Diversity and Distributions 18:530-542.

Frederiksen, M., S. Descamps, K.E. Erikstad, A.J. Gaston, H.G. Gilchrist, D. Grémillet, K.L. Johansen, Y. Kolbeinsson, J.F. Linnebjerg, M.L. Mallory, L.A. McFarlane Tranquilla, F.R. Merkel, W.A. Montevecchi, A. Mosbech, T.K. Reiertsen, G.J. Robertson, H. Steen, H. Strøm, and T.L. Thórarinsson. 2016. Migration and wintering of a declining seabird, the thick-billed murre *Uria lomvia*, on an ocean basin scale: Conservation implications. Biological Conservation, 200: 26-35.

French, D., M. Reed, K. Jayko, S. Feng, H. Rines, S. Pavignano, T. Isaji, S. Puckett, A. Keller, F.W. French III, D. Gifford, J. McCue, G. Brown, E. MacDonald, J. Quirk, S. Natzke, R. Bishop, M. Welsh, M. Phillips, and B.S. Ingram. 1996. The CERCLA Type A natural resource damage assessment model for coastal and marine environments (NRDAM/CME). Technical Documentation. Vol. I -VI. Final Report, submitted to the Office of Environmental Policy and Compliance, U.S. Dept. of the Interior, Washington, D.C., Contract No. 14-0001-91-C-11, April 1996.

French-McCay, D. 2009. State-of-the-art and research needs for oil spill impact assessment modeling. In: Proceedings of the 32nd AMOP technical seminar on environmental contamination and response, emergencies science division, Environment Canada, Ottawa, ON, Canada, pp. 601-653. Available from: http://www.asascience.com/about/publications/pdf/2009/FrenchMcCay_AMOP09-biomodel-with-cite.pdf.

French-McCay, D.P. and J.J. Rowe. 2004. Evaluation of bird impacts in the historical oil spill cases using the SIMAP Oil Spill Model. In: Proceedings of the 27th Arctic and Marine oil Spill Program (AMOP) Technical Seminar, Emergencies Science Division, Environment Canada, Ottawa ON Canada, pp. 421-452.

French-McCay, D.P., Z. Li., M. Horn, D. Crowley, M. Spaulding, D. Mendelsohn, and C. Turner. 2016. Modeling oil fate and subsurface exposure concentrations from the deep-water horizon oil spill. Proceedings of the 39th AMOP Technical Seminar on Environmental Contamination and Response. 39:115-150.

French-McCay, D., D. Crowley, and J. Rowe. 2017. Evaluation of oil fate and exposure from a deep water blowout with and without subsea dispersant injection treatment as well as traditional response activities. Proceedings of the 2017 International Oil Spill Conference. Washington, DC, American Petroleum Institute, Paper 2017-094, 21 pp.

Garthe, S., S. Benvenuti, and W.A. Montevecchi. 2000. Pursuit plunging by northern gannets (Sula bassana) feeding on capelin (Mallotus villosus). Proc. R. Soc. Lond. B. 267: 1717-1722.

Gaston, A.J., M.L. Mallory, H.G. Gilchrist, and K. O'Donovan. 2006. Status, trends and attendance patterns of the Northern Fulmar Fulmar glacialis in Nunavut, Canada. Arctic. 59(2): 165-178.

Geraci, J.R. 1990. Cetaceans and oil: Physiologic and toxic effects. Pp. 167-197 *In*: J.R. Geraci and D.J. St. Aubin (eds.). Sea Mammals and Oil:Confronting the Risks. Academic Press, San Diego, CA. 282 p.

Geraci, J.R. and T.G. Smith. 1976. Direct and indirect effects of oil on ringed seals (*Phoca hispida*) of the Beaufort Sea. J. Fish. Res. Board Can. 33: 1976-1984.

Geraci, J.R., D.J. St. Aubin and R.J. Reisman. 1983. Bottlenose dolphins, *Tursiops truncatus*, can detect oil. Can. J. Fish. Aquat. Sci., 40**,** 1516-1522.

GNL (Government of Newfoundland and Labrador). 2018. GIS data [Natural Areas]. Department of Tourism, Culture, Industry and Innovation, Government of Newfoundland and Labrador. Available at https://www.tcii.gov.nl.ca/parks/gis_data.html.

GNL. 2019. Species at risk. Department of Fisheries and Land Resources, Government of Newfoundland and Labrador, Canada. Accessed on 14 March 2019 and 5 April 2019 at https://www.flr.gov.nl.ca/wildlife/endangeredspecies/index.html.

GoC (Government of Canada). 2018. National parks and national park reserves of Canada legislative boundaries. Government of Canada. Available at https://open.canada.ca/en/open-data.

GoC. 2019. FGP/Marine Protected Areas National (MapServer). Government of Canada. Available at https://geoportal.gc.ca/arcgis/rest/services/FGP/Marine_Protected_Areas_National/MapServer.

Goodbody-Gringley G, Wetzel DL, Gillon D, Pulster E, Miller A, et al. (2013) Toxicity of Deepwater Horizon Source Oil and the Chemical Dispersant,Corexit® 9500, to Coral Larvae. PLoS ONE 8(1): e45574.

Government of Canada. 2020. Species at Risk Public Registry. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry.html, accessed 17 April 2020.

Gramentz, D. 1988. Involvement of loggerhead turtle with the plastic, metal and hydrocarbon pollution in the central Mediterranean. Mar. Poll. Bull., 19: 11- 13.

Greenan, B.J.W., Hebert, D., Cardoso, D., Kenchington, E.L., Beazley, L. and A. van der Baaren (2016). Ocean Currents and Benthic Habitat in the Sackville Spur Region. Environmental Studies Research Fund 202. Final report for Project 2013-001SOcean and Ecosystem Sciences Division, Maritimes Region, Fisheries and Oceans Canada, Bedford Institute of Oceanography, Dartmouth, NS, Canada, 103 p.

Gregory, D. N (2004). Ocean Data Inventory (ODI): A Database of Ocean Current, Temperature and Salinity Time Series for the Northwest Atlantic (Report no. 2004/097). Canadian Science Advisory Secretariat, Department of Fisheries and Oceans Canada.

Gros, J., S. Socolofsky, A. Dissanayake, I. Jun, L. Zhao, M. Boufadel, C. Reddy, and J. Arey. 2017. Petroleum dynamics in the sea and influence of subsea dispersant injection during Deepwater Horizon. Proceedings of the National Academy of Science. www.pnas.org/cgi/doi/10.1073/pnas.1612518114.

Guillermo E.N., R.J. Pollero, A.M. Gayoso, B.A. Macdonald, and R.J. Thompson. 1997. Fatty acids as trophic markers of phytoplankton blooms in the Bahía Blanca estuary (Buenos Aires, Argentina) and in Trinity Bay (Newfoundland, Canada). Biochemical Systematics and Ecology 25(8): 739-755.

Harrison, W.G., K.Y. Børsheim, W.K.W. Li, G.L. Maillet, P. Pepin, E. Sakshaug, M.D. Skogen, and P.A. Yeats. 2013. Phytoplankton production and growth regulation in the Subarctic North Atlantic: A comparative study of the Labrador Sea-Labrador/Newfoundland shelves and Barents/Norwegian/Greenland seas and shelves. Progress in Oceanography 114: 26-45.

Harvey, J.T. and M.E. Dahlheim. 1994. Cetaceans in oil. Pp. 257-264. In: T.R. Loughlin (ed.). Marine Mammals and the *Exxon Valdez*. Academic Press, San Diego, CA. 395 pp.

Hatch, S.A., G.J. Robertson, and P.H. Baird. 2009. Black-legged Kittiwake (Rissa tridactyla), version 2.0. In The Birds of North America (A.F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.92.

Hazen, T.C., E.A. Dubinsky, T.Z. DeSantis, G.L. Andersen, Y.M. Piceno, N. Singh, and W.T. Stringfellow. 2010. Deep-sea oil plume enriches indigenous oil-degrading bacteria. Science, 330(6001), 204-208.

Hazen, T.C., R.C. Prince, and N. Mahmoudi. 2016. Marine oil biodegradation. Environ. Sci. Technol. 50(5): 2121-2129. Available at: https://response.restoration.noaa.gov/sites/default/files/SMART_protocol.pdf.

Hedd, A., W. A. Montevecchi, L. McFarlane Tranquilla, C. M. Burke, D. A. Fifield, G. J. Robertson, R. A. Phillips, C. Gjerdrum, and P. M. Regular. 2011. Reducing uncertainty on the Grand Bank: tracking and vessel surveys indicate mortality risks for common murres in the North-West Atlantic. Animal Conservation 14:630-641.

Hedd, A., I. L. Pollet, R. A. Mauck, C. M. Burke, M. L. Mallory, L. A. McFarlane Tranquilla, W. A. Montevecchi, G. J. Robertson, R. A. Ronconi, D. Shutler, S. I. Wilhelm, and N. M. Burgess. 2018. Foraging areas, offshore habitat use, and colony overlap by incubating Leach's storm-petrels *Oceanodroma leucorhoa* in the Northwest Atlantic. PLoS One 13:e0194389.

Hellou, J., G. Stenson, I-H. Ni, and J.F. Payne. 1990. Polycyclic aromatic hydrocarbons in muscle tissue of marine mammals from the Northwest Atlantic. Mar. Poll. Bull. 21(10):469-473.

Hellous, J., C. Upshall, I-H. Ni, J.F. Payne. Y.S. Huang. 1991. Polcyclic Aromatic Hydrocarbons in Harp Seals *(Phoca groenlandica)* from the Northwest Atlantic. Arch. Environ. Contam. Toxicol. 21:135-140.

Helm, R.C., D.P. Coasta, T.D. DeBruyn, T.J. O'Shea, R.C. Wells, and T.M. Williams. 2015. Overview of effects of oil spills on marine mammals. Pp. 455-475 *In*: M. Fingas (ed.). Handbook of Oil Spill Science and Technology, John Wiley & Sons, Hoboken, NJ.

Hernandez Jr., F.J., J.E. Filburn, J. Fang and J.T. Ransom. 2016. Condition of larval red snapper (Lutjanus campechanus) relative to environmental variability and the Deepwater Horizon oil spill. Environ. Res. Lett.,11 094019.

Hudson E.D., C.C. Parrish, and R.J. Helleur. 2001. Biogeochemistry of sterols in plankton, settling particles and recent sediments in a cold ocean ecosystem (Trinity Bay, Newfoundland). Marine Chemistry 76: 253-270.

Huntington, C.E., R.G. Butler, and R. Mauck. 1996. Leach's Storm-Petrel (Oceanodroma leucorhoa), version 2.0. In The Birds of North America (A. F. Poole and F. B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.233.

IBA Canada. 2018. IBA Canada Important Bird Areas. Accessed September 2018 at: https://www.ibacanada.org/.

IBA Canada. 2019. IBA Canada Important Bird Areas. Accessed April 2019 at: https://www.ibacanada.org/.

IPIECA and IOGP (Oil Gas Producers). 2015a. Response strategy development using net environmental benefit analysis: Good practice guidelines for incident management and emergency response personnel. London, UK. Retrieved from https://www.ipieca.org/resources/good-practice/dispersants-subsea-application/

IPIECA and IOGP. 2015b. Dispersants: subsea application. Good practice guidelines for incident management and emergency response personnel. London, UK. Retrieved from http://www.ipieca.org/resources/good-practice/dispersants-subsea-application-good-practice-guidelines-for-incident-management-and-emergency-response-personnel/.

IPIECA and IOGP. 2016. Controlled in-situ burning of spilled oil. Good practice guidelines for incident management and emergency response personnel. London, UK. Retrieved from http://www.oilspillresponseproject.org/wp-content/uploads/2017/01/Controlled_in-situ_burning_of_spilled_oil_2016.pdf.

IPIECA-API-IOGP. 2017. Guidelines on implementing spill impact mitigation assessment (SIMA) A technical support document to accompany the IPIECA- IOGP guidance on net environmental benefit analysis (NEBA). IOGP Report 593.

ITOPF (International Tanker Owners Pollution Federation Limited). 2011. Effects of oil pollution on fisheries and mariculture. Technical Information Paper 11. Available from: http://www.itopf.com/fileadmin/data/Documents/TIPS%20TAPS/TIP11EffectsofOilPollutiononFisheriesandMariculture.pdf.

IUCN (International Union for the Conservation of Nature). 2019. The IUCN red list of threatened species. Accessed on 14 March 2019 and 5 April 2019 at https://www.iucnredlist.org/.

Jenssen, B.M. and M. Ekker. 1991. Effects of plumage contamination with crude oil dispersant mixtures on thermoregulation in common eiders and mallards. Archives of Environmental Contamination and Toxicology, 20(3): 398-403. http://dx.doi.org/10.1007/BF01064410.

Jones, M. and S. Petch. 1995. A report on the analysis of hydrocarbons in sea waters and associated samples from trial oil spills off eastern England, July 1995. Newcastle upon Tyne, UK: University of Newcastle upon Tyne.

Karnofsky, E.B., J. Atema, and R.H. Elgin. 1989. Field observations of social behaviour, shelter use, and foraging in the lobster *Homarus americanus*. The Biological Bulletin 176(3): 239-246.

Keats, D.W., D.H. Steele, and G.R. South. 1987. The role of fleshy macroalgae in the ecology of juvenile cod (*Gadus morhua* L.) in inshore waters off eastern Newfoundland. Can. J. Zool. 65: 49-53.

Kellar, N.M., T R. Speakman, C.R. Smith, S.M. Lane, B.C. Balmer, M.L. Trego, K.N. Catelani, M.N. Robbins, C.D. Allen, R.S. Wells, E.S. Zolman, T.K. Rowles, and L.H. Schwacke. 2017. Low reproductive success rates of common bottlenose dolphins *Tursiops truncatus* in the northern Gulf of Mexico following the Deepwater Horizon disaster (2010-2015). Endanger. Species Res. 33: 143-158.

Kissin, Y.V. 1987. Catagenesis and composition of petroleum: Origin of n-alkanes and isoalkanes in petroleum crudes. Geo. Cosmo. Act., 51(9): 2445-2457.

Knudby, A., E. Kenchington, and F.J. Murillo. 2013. Modeling the distribution of *Geodia* sponges and sponge grounds in the Northwest Atlantic. PLOS ONE 8(12): e82306.

Kooyman, G.L., R.W. Davis, and M.A. Castellini. 1977. Thermal conductance of immersed pinniped and sea otter pelts before and after oiling with Prudhoe Bay crude. In: D.A. Wolfe (ed.). Fate and Effects of Petroleum Hydrocarbons in Marine Ecosystems and Organisms. New York. Pp. 151-157.

Lambert, G., D.B. Peakall, B.J.R. Philogene and F.R. Engelhart. 1982. Effect of oil and oil dispersant mixtures on the basal metabolic rate of ducks. Bulletin of Environmental Contamination and Toxicology, 29: 520-524.

Lane, S.M., C.R. Smith, J. Mitchell, B.C. Balmer, K.P. Barry, T. McDonald, C.S. Mori, P.E. Rosel, T.K. Rowles, T.R. Speakman, F.I. Townsend, M.C. Tumlin, R.S. Wells, E.S. Zolman, and L.H. Schwacke. 2015. Reproductive outcome and survival of common bottlenose dolphins sampled in Barataria Bay, Louisiana, USA, following the *Deepwater Horizon* oil spill. P. Roy. Soc. - B 282: 20151944. doi: 10.1098/rspb.2015.1944.

Laramore, S., Krebs, W., Garr, A. 2014. Effects of Macondo canyon 252 oil (Naturally and Chemically Dispersed) on larval crassostrea virginica (Gmelin, 1791), J. Shell. Res., 33(3):709-718

Laramore. S., W. Krebs., and A. Garr. 2016. Effects of exposure of pink shrimp *(Farfantepenaeus duorarum)*, larvae to Macondo Canyon 252 crude oil and the Corexit dispersant. J. Mar. Sci. Eng. 4(1)24.

Lazier, J.R.N., and D.G Wright (1993). Annual velocity variations in the Labrador Current. Journal of Physical Oceanography. 23:659–678.

Lee, K., M. Boufadel, B. Chen, J. Foght, P. Hodson, S. Swanson, and A. Venosa. 2015. Expert panel report on the behavior and environmental impacts of crude oil released into aqueous environments. Royal Society of Canada, Ottawa, ON.

Leighton, F.A. 1993. The toxicity of petroleum to birds. Environ. Rev. 1(2): 92-103.

Leighton, F.A., Y.Z. Lee, A.D. Rahimtula, P.J. O'Brien, and D.B. Peakall. 1985. Biochemical and functional disturbances in red blood cells of herring gulls ingesting Prudhoe Bay crude oil. Toxic. Appl. Pharmacol. 81(1): 25-31.

Levenson, D.H. and R.J. Schusterman. 1997. Pupillometry in seals and sea lions: ecological implications. Can. J. Zool., 75: 2050-2057.

Liu, J., S.M. Techtmann, H.L. Woo, D. Ning, J.L. Fortney, and T.C. Hazen. 2017. Rapid response of eastern Mediterranean deep sea microbial communities to oil. www.nature.com/articles/s41598-017-05958-x

Linden, O. 1976. The influence of crude oil and mixtures of crude oil/dispersants on the ontogenic development of the Baltic herring, *Clupea harengus membras* L. *Royal Swedish Academy of Sciences* 5(3):136-140.

Loughlin, T.R. (ed.). 1994. Marine mammals and the *Exxon Valdez*. Academic Press, San Diego, CA. 395 p.

Lutz, P.L. and M. Lutcavage. 1989. The effects of petroleum on sea turtles: Applicability to Kemp's ridley. Pp. 52-54. In: C.W. Caillouet and A.M. Landry (eds.) Proceedings of the First International Symposium on Kemp's Ridley Sea Turtle Biology, Conservation and Management. TAMU-SG-89'-105: 260 pp.

Mallory, M.L., S.A. Hatch, and D.N. Nettleship. 2012. Northern Fulmar (Fulmarus glacialis), version 2.0. In The Birds of North America (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.361.

Mango, F.D. 1997. The light hydrocarbons in petroleum: A critical review. Org. Geochem., 26(7), 417-440.

Martin, C.W. 2017. Avoidance of oil contaminated sediments by estuarine fishes. Marine Ecology Progress Series 576: 125-134.

Matheson, K., C. Mckenzie, R.S. Gregory, D. Robichaud, I. Bradbury, P. Snelgrove, and G.A. Rose. 2016. Linking eelgrass decline and impacts on associated fish communities to European green crab *Carcinus maenas* invasion. Marine Ecology Progress Series 548: 31-45.

Matkin, C.O., G.M. Ellis, M.E. Dahlheim and J. Zeh. 1994. Status of killer whales in Prince William Sound, 1985-1992. Pp. 141-162. In: T.R. Loughlin (ed.). Marine Mammals and the *Exxon Valdez*, Academic Press, San Diego, CA. 395 pp.

Matkin, C.O., E.L. Saulitis, G.M. Ellis, P. Olesiuk, and S.D. Rice. 2008. Ongoing population-level impacts on killer whales *Orcinus orca* following the '*Exxon Valdez*' oil spill in Prince William Sound, Alaska. Mar. Ecol. Prog. Ser. 356: 269-281.

McDonald, T.L., F.E. Hornsby, T.R. Speakman, E.S. Zolman, K.D. Mullin, C. Sinclair, P.E. Rosel, L. Thomas, and L.H. Schwacke. 2017. Survival, density, and abundance of common bottlenose dolphins in Barataria Bay (USA) following the Deepwater Horizon oil spill. Endanger. Species Res. 33: 193-209.

McFarlane Tranquilla, L., W.A. Montevecchi, A. Hedd, P.M. Regular, G.J. Robertson, D.A. Fifield, and R. Devillers. 2015. Ecological segregation among Thick-billed Murres (*Uria lomvia*) and Common Murres (*Uria aalge*) in the Northwest Atlantic persists through the nonbreeding season. Canadian Journal of Zoology, 93: 447-460.

McFarlin, K.M., R.C. Prince, R. Perkins, and M.B. Leigh. 2014. Biodegradation of dispersed oil in arctic seawater at-1 C. PloS one, 9(1), e84297.

McGenity, T.J., B.D. Folwell, B.A. McKew, and G.O. Sanni. 2012. Marine crude-oil biodegradation: a central role for interspecies interactions. Aquat. Biosyst. 8(10): 1-19.

Milton, S., P. Lutz and G. Shigenaka. 2003. Chapter 4. Oil Toxicity and Impacts on sea turtles. Pp. 35-48. In: G. Shigenaka (ed.). Oil and Sea Turtles: Biology, Planning and Response. NOAA, Seattle, WA.

Milton, S., P. Lutz, and G. Shigenaka. 2010. Oil toxicity and impacts on sea turtles in: Shigenaka, G. (ed.). Oil and sea turtles: Biology, planning, and response. National Oceanic and Atmospheric Administration, 112 pp.

Mitchelmore. C., C. Bishop, and T. Collier. 2017. Toxicological estimation of mortality of oceanic sea turtles oiled during the Deepwater Horizon oil spill. Endangered Species Research, 33: 39-50.

Montevecchi, W.A. and I.J. Stenhouse. 2002. Dovekie (Alle alle), version 2.0. In The Birds of North America (A.F. Poole and F.B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.701.

Mowbray, T.B. 2002. Northern Gannet (Morus bassanus), version 2.0. In The Birds of North America (A.F. Poole and F.B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.693.

Mullin, K.D., T. McDonald, R.S. Wells, B.C. Balmer, T. Speakman, C. Sinclair, E.S. Zolman, F. Hornsby, S.M. McBride, K.A. Wilkinson, and L.H. Schwacke. 2017. Density, abundance, survival, and ranging patterns of common bottlenose dolphins (*Tursiops truncatus*) in Mississippi Sound following the Deepwater Horizon oil spill. PLoS One 12: e0186265.

NAFO (Northwest Atlantic Fisheries Organization). 2019a. Conservation and enforcement measures 2019. 82 p. + annexes. Available at https://www.nafo.int/Fisheries/Conservation.
NAFO. 2019b. Vulnerable Marine Ecosystems (VME) closures. Available at https://www.nafo.int/Fisheries/VME.
NAFO. 2019c. Fishing in the NAFO regulatory area. Available at https://www.nafo.int/Fisheries.
Naile, J. 2016. Subsea dispersant injection research program overview of toxicity and biodegradation findings. Presented at Clean Gulf Conference 2016, Tampa, FL, USA.
Nexen (Nexen Energy ULC). 2018. Nexen Energy ULC Flemish Pass Exploration Drilling Project (2018-2028) Environmental Impact Statement [Final Report]. Amec Fw TF1693501. Rep. by Amec Foster Wheeler Environment & Infrastructure, St. John's, NL, for Nexen Energy ULC, St. John's, NL. 1097 p. + appendices.
NL Fisheries and Land Resources. 2020. Species at Risk. https://www.flr.gov.nl.ca/wildlife/endangeredspecies/index.html, accessed 17 April 2020.
NOAA (National Oceanic and Atmospheric Administration). 2010. *Characteristics of Response Strategies: A Guide for Spill Response Planning in Marine Environments* was originally a joint effort between NOAA and the USCG. Seattle, WA, USA. 76 p.
NOAA 2012. Technical Report NOS OR&R 27. Joint analysis group, Deepwater Horizon oil spill: Review of subsurface dispersed oil and oxygen levels associated with the Deepwater Horizon MC252 spill of national significance. Silver Spring, MD, USA.
NRC. 2005. Oil spill dispersants efficacy and effects. National Academy Press. Washington DC.
OSAT (Operational Science Advisory Team). 2010. Unified Area Command summary report for sub-sea and sub-surface oil and dispersant detection: sampling and monitoring. Washington, DC: US Coast Guard.
OSRL (Oil Spill Response Limited). 2013. Assuring good practice in dispersant application: Effectiveness monitoring. Retrieved from
OSRL. 2017. Technical information sheet global dispersant stockpile. Retrieved from https://www.oilspillresponse.com/services/member-response-services/global- dispersant-stockpile.
Parrish, C.C., R.J. Thompson, and D. Deibel. 2005. Lipid classes and fatty acids in plankton and settling matter during the spring bloom in a cold ocean coastal environment. Mar. Ecol. Prog. Ser. 286: 57-69.
Pasparakis, C., A.J. Esbaugh, W. Burggren, and M. Grosell. 2019. Physiological impacts of Deepwater Horizon oil on fish. Comparative Biochemistry and Physiology, Part C 224: 108558. 29 p.
Payne, J.R., G.D. McNabb Jr., J.R. Clayton Jr. 1991. Oil-weathering behavior in Arctic environments. Polar Research 10(2): 631-662.
Peiffer, R.F. and J.H. Cohen. 2015. Lethal and sublethal effects of oil, chemical dispersant, and dispersed oil on the ctenophore *Mnemiopsis leidyi*. Aquatic Biology 23: 237-250.
Pepin, P., E. Colbourne, and G. Maillet. 2011. Seasonal patterns in zooplankton community structure on the Newfoundland and Labrador Shelf. Progress in Oceanography 91(3): 273-285.

Peterson, C.H., S.D. Rice, J.W. Short, D. Esler, J.L. Bodkin, B.E. Ballachey, and D.B. Irons. 2003. Long-term ecosystem response to the *Exxon Valdez* oil spill. Science 302: 2082-2086.

Piatt, J.F. and D.N. Nettleship. 1985. Diving depths of four alcids. Auk 102: 293-297.

Prince, R.C. 2015. Oil Spill Dispersants: Boon or Bane? Environmental Science and Technology, 49: 6376-6384.

Robert, M., R. Benoit, and J.P.L Savard. 2000. COSEWIC status report on the Barrow's Goldeneye *Bucephala islandica* in Canada, in COSEWIC assessment and status report on the Barrow's Goldeneye *Bucephala islandica* in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. 1-65 pp.

Robertson, G.J. 2002. Current status of Manx Shearwater (*Puffinus puffinus*) colony on Middle Lawn Island, Newfoundland. Northeastern Naturalist 9:317-324.

Røy, H., J. Kallmeyer, R.R. Adhikari, R. Pockalny, B.B. Jørgensen, and S. D'Hondt. 2012. Aerobic microbial respiration in 86-million-year-old deep-sea red clay. Science, 336(6083), 922-925.

RPS. 2018. Trajectory Modelling in Support of the Nexen Energy ULC Flemish Pass Exploration Drilling Project (2018-2028). Appendix G of Flemish Pass Exploration Drilling Project (2018-2028) – Environmental Impact Statement. 84 p.

RPS. 2019. Trajectory Modelling in Support of the Nexen Energy ULC Flemish Pass Exploration Drilling Project (2018-2028) Relief Well Modelling. 94 p.

Rubega, M.A., D. Schamel, and D.M. Tracy. 2000. Red-necked Phalarope (*Phalaropus lobatus*), version 2.0. In The Birds of North America (A.F. Poole and F.B. Gill, Editors). Cornell Lab of Ornithology, Ithaca, NY, USA. https://doi.org/10.2173/bna.538.

SARA (*Species at Risk Act)*. 2002. Consolidated Government of Canada Bill C-5, S.C. 2002, c. 29. (Online). Accessed April 2019 at: http://laws.justice.gc.ca/eng/acts/S-15.3/index.html

SARA. 2019. Welcome to the Species at Risk Public Registry. Government of Canada. Accessed April 2019 at: http://www.sararegistry.gc.ca/default.asp?lang=en&n=24F7211B-1.

Seaconsult Ltd. (1998) Physical Environmental Data for Production Systems at Terra Nova. Report prepared for Petro-Canada Inc.

Sergeant, D.E. 1991. Harp seals, man and ice. Can. Spec. Public. Fish. Aquat. Sci. 114:1-153.

Schwacke, L.H., C.R. Smith, F.I. Townsend, R.S. Wells, L.B. Hart, B.C. Balmer, T.K. Collier, S. De Guise, M.M. Fry, L.J. Guillette, Jr., S.V. Lamb, S.M. Lane, W.E. McFee, N.J. Place, M.C. Tumlin, G.M. Ylitalo, E.S. Zolman, and T.K. Rowles. 2014. Health of common bottlenose dolphins (*Tursiops truncatus*) in Barataria Bay, Louisiana, following the Deepwater Horizon oil spill. Envir. Sci. Tech. 48(1): 93-103.

Sidorovskaia, N.A., A.S. Ackleh, C.O. Tiemann, B. Ma, J.W. Ioup, and G.E. Ioup. 2016. Passive acoustic monitoring of the environmental impact of oil exploration on marine mammals in the Gulf of Mexico. Pp. 1007-1014 *In:* A.N. Popper and A. Hawkins (eds.). The effects of noise on aquatic life II. Springer, New York, NY. 1292 p.

Sittler, B., A. Aebischer, and O. Gilg. 2011. Post-breeding migration of four Long-tailed Skuas (*Stercorarius longicaudus*) from North and East Greenland to West Africa. Journal of Ornithology 152:375-381.

SL Ross (SL Ross Environmental Research Ltd). 2017. Spill Probability Assessment for Nexen Energy ULC Flemish Pass Exploration Drilling Environmental Assessment. Appendix F of Flemish Pass Exploration Drilling Project (2018-2028) – Environmental Impact Statement. 13 p.

Slaughter, A., G. Coelho, and J. Staves. 2017. Spill Impact Mitigation Assessment in Support of BP Canada Energy Group ULC Scotian Basin Exploration Project. Sponson Group Inc. Technical Project Report 17-03. Mansfield, TX, USA.

Smith, C.R., T.K. Rowles, L.B. Hart, F.I. Townsend, R.S. Wells, E.S. Zolman, B.C. Balmer, B. Quigley, M. Ivancčić, W. McKercher, M.C. Tumlin, K.D. Mullin, J.D. Adams, Q. Wu, W. McFee, T.K. Collier, and L.H. Schwacke. 2017. Slow recovery of Barataria Bay dolphin health following the Deepwater Horizon oil spill (2013-2014), with evidence of persistent lung disease and impaired stress response. Endanger. Species Res. 33: 127-142.

Smultea, M.A. and B. Würsig. 1995. Behavioral reactions of bottlenose dolphins to the Mega Borg oil spill, Gulf of Mexico 1990. Aquatic Mamm., 21: 171-181.

Soulliere, C.E. and P.W. Thomas. 2009. Harlequin Duck Threat Assessment, Eastern Population. Canadian Wildlife Service Technical Report Series No. 491. St. John's, NL.

Spraker, T.R., L.F. Lowry and K.J. Frost. 1994. Gross necropsy and histopathological lesions found in harbor seals. Pp. 281-311 In: T.R. Loughlin (ed.). Marine Mammals and the *Exxon Valdez*, Academic Press, San Diego, CA. 395 pp.

Squires, H.J. 1957. Squid, *Illex illecebrosus* (LeSueur), in the Newfoundland Fishing Area. J. Fish. Res. Brd of Can. 14(5): 693-728.

St. Aubin, D.J. 1990. Physiological and toxic effects on pinnipeds. Pp. 103 *In*: J.R. Geraci and D.J. St. Aubin (eds.). Sea Mammals and Oil: Confronting the Risks, Academic Press, San Diego, CA.

St. Aubin, D.J., J.R. Geraci, T.G. Smith and T.G. Friesen. 1985. How do bottlenose dolphins, *Tursiops truncatus*, react to oil films under different light conditions? Can. J. Fish. Aquat. Sci., 42: 430-436.

Stacy, N.I., C.L. Field, L. Staggs, R.A. Maclean, B.A. Stacy, J. Keene, D. Cacela, C. Pelton, C. Cray, M. Kelley, S. Holmes, and C.J. Innis. 2017. Clinicopathological findings in sea turtles assessed during the Deepwater Horizon oil spill response. Endanger. Species Res. 33: 25-37.

Strøm-Kristiansen, T., J.N. Hokstad, A. Lewis, and P.J. Brandvik. 1997. NOFO 1996 oil on water exercise – analysis of sample material. SINTEF Data report number STF66 A97050. Trondheim, Norway.

Stubblefield, W.A., G.A. Hancock, H.H. Prince, and R.K. Ringer. 1995a. Effects of naturally weathered Exxon Valdez crude oil on mallard reproduction. Env. Toxicol. Chem., 14(11), 1951-1960.

Stubblefield, W.A., G.A. Hancock, W.H. Ford, and R.K. Ringer. 1995b. Acute and subchronic toxicity of naturally weathered Exxon Valdez crude oil in mallards and ferrets. Environmental toxicology and chemistry, 1411):1941-1950. Technical Documentation. A Report by the Oil Budget Calculator Science and Engineering Team. Retrieved from http://www.noaanews.noaa.gov/stories2010/PDFs/OilBudgetCalc_Full_HQ-Print_111110.pdf.

Techtmann, S.M., M. Zhuang, P. Campo, E. Holder, M. Elk, T.C. Hazen, and J.W. Santo Domingo. 2017. Corexit 9500 enhances oil biodegradation and changes active bacterial community structure of oil-enriched microcosms. Appl. Env. Microbiol., 83(10), e03462-16.

Thomas, P.W. 2008. Harlequin Ducks in Newfoundland. Pp. 44-49 *in* G.J. Robertson, P.W. Thomas, J-P.L. Savard, and K.A. Hobson (Eds.). Harlequin Ducks in the northwest Atlantic. Waterbirds 31 (Special Publication 2).

Tremblay J, E. Yergeau, N. Fortin, S. Cobanli, M. Elias, T.L. King, K. Lee, and C.W. Greer. 2017. Chemical dispersants enhance the activity of oil- and gas condensate-degrading marine bacteria. ISME J. 2017 Aug 11. doi: 10.1038/ismej.2017.129.

Valentine, D.L., I. Mezic, S. Macesic, N. Crnjaric-Zic, S. Ivic, P.J. Hogan, V.A. Fonoberov, and S. Loire. 2011. Dynamic autoinoculation and the microbial ecology of a deepwater hydrocarbon irruption. Proceedings of the National Academy of Science. https://doi.org/10.1073/pnas.1108820109.

van Bemmelen, R., B. Moe, S. A. Hanssen, N. M. Schmidt, J. Hansen, J. Lang, B. Sittler et al. 2017. Flexibility in otherwise consistent non-breeding movements of a long-distance migratory seabird, the long-tailed skua. Marine Ecology Progress Series 578:197-211.

Vander Zanden, H.B., A.B. Bolten, A.D. Tucker, K.M. Hart, M.M. Lamont, I. Fujisaki, K.J. Reich, D.S. Addison, K.L. Mansfield, K.F. Philips, M. Pajelo, and K.A. Bjorndal. 2016. Biomarkers reveal sea turtles remained in oiled areas following the Deepwater Horizon oil spill. Ecological Applications, 26(7): 2145-2155.

Vargo, S., P. Lutz, D. Odell, E. Van Vleet, and G. Bossart. 1986. Study of the effects of oil on marine turtles. Final report to Minerals Management Service MMS Contract No. 14-12-0001-30063. 181 pp.

Venn-Watson S, K.M. Colegrove, J. Litz, M. Kinsel, K. Terio, J. Saliki, S. Fire, R. Carmichael, C. Chevis, W. Hatchett, J. Pitchford, M. Tumlin, C. Field, S. Smith, R. Ewing, D. Fauquier, G. Lovewell, H. Whitehead, D. Rotstein, W. McFee, E. Fougeres, and T. Rowles. 2015. Adrenal gland and lung lesions in Gulf of Mexico common bottlenose dolphins (*Tursiops truncatus*) found dead following the Deepwater Horizon oil spill. PloS ONE 10(5): e0126538. doi:10.1371/journal.pone.0126538.

Vignier, J., L. Donaghy, P. Soudant, F.L.E. Chu, J.M. Morris, M.W. Carney, C. Lay, M. Krasnec, R. Robert, and A.K. Volety. 2015. Impacts of the *Deepwater Horizon* oil spill and associated dispersant on early development of the eastern oyster *Crossostrea virgnica*. Mar. Poll. Bull. 100(1): 426-437.

Ward, E.J., K.L. Oken, K.A. Rose, S. Sable, K. Watkins, E.E. Holmes, and M.D. Scheuerell. 2018. Applying spatiotemporal models to monitoring data to quantify fish population responses to the Deepwater Horizon oil spill in the Gulf of Mexico. Environ. Monit. Assess. 190: 530. https://doi.org/10.1007/s10661-018-6912-z.

Watanabe, S., A. Metaxas, J. Sameoto, and P. Lawton. 2009. Patterns in abundance and size of two deep-water gorgonian octocorals, in relation to depth and substrate features off Nova Scotia. Deep-Study Research Part I 56: 2235-2248.

Weimerskirch, H. and P.G. Sagar. 1996. Diving depths of Sooty Shearwaters Puffinus griseus. Ibis. 138:786-794.

Wells, N.J., G.B. Stenson, P. Pepin, and M. Koen-Alonso. 2017a. Identification and descriptions of Ecologically and Biologically Significant Areas in the Newfoundland and Labrador Shelves Bioregion. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/013. v + 87 p.

Wells, R.S., L.H. Schwacke, T.K. Rowles, B.C. Balmer, E. Zolman, T. Speakman, F.I. Townsend, M.C. Tumlin, A. Barleycorn, and K.A. Wilkinson. 2017b. Ranging patterns of common bottlenose dolphins *Tursiops truncatus* in Barataria Bay, Louisiana, following the Deepwater Horizon oil spill. Endanger. Species Res. 33: 159-180.

White, N.D., C. Godard-Codding, S.J. Webb, G.D. Bossart, and P.A. Fair. 2017. Immunotoxic effects of in vitro exposure of dolphin lymphocytes to Louisiana sweet crude oil and Corexit. Journal of Applied Toxicology, 37(6): 676-682.

Whitmer, E.R., B.A. Elias, D.J. Harvey, M.H. Ziccardi (2018) An experimental study of the effects of chemically dispersed oil on feather structure and waterproofing in Common Murres (*Uria aalge*) Journal of Wildlife Diseases, 54(2): 315-328.

Wiese, F.K. and P.C. Ryan. 2003. The extent of chronic marine oil pollution in southeastern Newfoundland waters assessed through beached bird surveys 1984–1999. Mar. Poll. Bull. 46:1090-1101.

Wilhelm, S.I., J. Mailhiot, J. Arany, J.W. Chardine, G.J. Robertson, and P.C. Ryan. 2015. Update and trends of three important seabird populations in the western North Atlantic using a geographic information system approach. Marine Ornithology, 43: 211-212.

Wilhelm, S.I., A. Hedd, G.J. Robertson, J. Mailhiot, P.M. Regular, P.C. Ryan, and R.D. Elliot. 2019. The world's largest breeding colony of Leach's Storm-petrel (*Hydrobates leucorhous*) has declined. Bird Conservation International,1-18. Doi:10.1017/S0959270919000248.

Wilkin, S.M., T.K. Rowles, E. Stratton, N. Adimey, C.L. Field, S. Wissmann, G. Shigenaka, E. Fougeres, B. Mase, and M.H. Ziccardi. 2017. Marine mammal response operations during the Deepwater Horizon oil spill. Endanger. Species Res. 33: 107-118.

Wilson, KW. 1977. Acute toxicity of oil dispersants to marine fish larvae. MarBiol. 40:65-74.

Wise, C.F., J.T.F. Wise, S.S. Wise, W.D. Thompson, J.P. Wise Jr., J.P. Wise Sr. 2014. Chemical dispersants used in the Gulf of Mexico oil crisis are cytotoxic and genotoxic to sperm whale skin cells. Aquat. Tox. 152:335-340.

Wise, J.P., Jr., J.T.F. Wise, C.F. Wise, S.S. Wise, C. Gianios Jr., H. Xie, R. Walter, M. Boswell, C. Zhu, T. Zheng, C. Perkins, and J.P. Wise Sr. 2018b. A three year study of metal levels in skin biopsies of whales in the Gulf of Mexico after the Deepwater Horizon oil crisis. Comparative Biochemistry and Physiology C Toxicology and Pharmacology, 205: 15-25.

Wroblewski, J.S., L.K. Kryer-Hann, D.A. Methven, and R.L. Haedrich. 2007. The fish fauna of Gilbert Bay, Labrador: a marine protected area in the Canadian subarctic coastal zone. J. Mar. Biol. Ass. U.K. 87: 575-587.

Wu, D., Z. Wang. B. Hollebone, S. McIntosh, T. King, and P.V. Hodson. 2012. Comparative toxicity of four chemically dispersed and undispersed crude oils to rainbow trout embryos. Enviro.Tox. Chem. 31(4):54–765.

Würsig, B. 1990. Cetaceans and oil: Ecologic perspectives. Pp. 129-1653. In: J.R. Geraci and D.J. St. Aubin (eds.). Sea Mammals and Oil: Confronting the Risks, Academic Press, San Diego, CA.

Ylitalo, G. M., T. K. Collier, B. F. Anulacion, K. Juaire, R. H. Boyer, D. A. M. da Silva, J. L. Keene, and B. A. Stacy. 2017. Determining oil and dispersant exposure in sea turtles from the northern Gulf of Mexico resulting from the Deepwater Horizon oil spill. Endang. Sp. Res. 33:9-24.

Personal Communication

Lang, C.	Registrar of Aquaculture, Aquaculture Licensing Administrator, Department of Fisheries and Land Resources, 26 March 2019.
Pierce, C.	Ecosystems Geomatics Technician, Protected Areas Establishment Branch, Parks Canada, 28 September 2018.
Sullivan, D.	CW-Health, Safety and Environment Lead-Deepwater, CNOOC International. March 2019
Wells, N.	Biologist, Aquatic Resources Division, DFO, 4 February 2019.

Appendix A - Appearance of Oil on the Water Surface

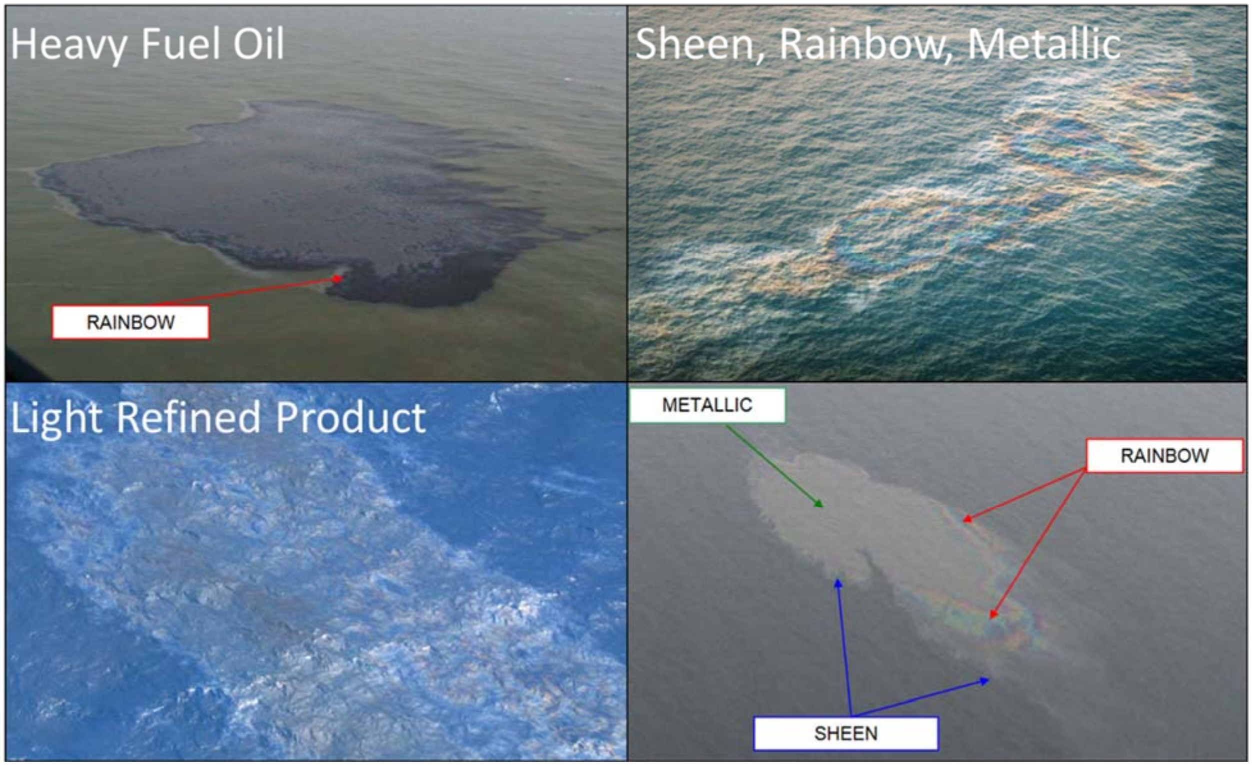


Figure A-1. Aerial surveillance images of released oil in the environment as examples of different visual appearances based on surface oil thickness and product type (Bonn Agreement 2011 *in* RPS 2019)