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ASSESSMENT OF THE EFFECTIVENESS OF MITIGATION MEASURES IN REDUCING THE POTENTIAL IMPACTS OF OIL AND GAS EXPLORATION AND PRODUCTION ON AREAS WITH DEFINED BENTHIC CONSERVATION OBJECTIVES

Figure 1. Map of the Department of Fisheries and Oceans' (DFO) six administrative regions.

Context:

Oceans Management is seeking national guidance and advice on the effectiveness of existing mitigation measures in reducing the potential impacts of oil and gas exploration and production activities in Canadian waters, including seismic surveys and drilling, on areas with defined benthic conservation objectives (such as Marine Protected Areas (MPAs) and other effective area-based conservation measures (OEABCMs)). The majority of MPAs established under the Oceans Act and OEABCMs (i.e. Fisheries Act closures that meet Government of Canada criteria for OEABCMs) have conservation objectives for benthic components (benthic species, features, and/or habitats). Corals and/or sponges are a conservation focus for the majority of existing OEABCMs.

By their nature, areas with defined benthic conservation objectives, including MPAs and OEABCMs, require a high(er) degree of risk aversion than areas with no defined conservation objectives. Addressing impacts on these areas should be based on the precautionary approach and the ecosystem approach. With this in mind, it is important to consider impacts not only on the physical location of the

benthic species and/or habitats that are defined in benthic conservation objectives for a particular area, but also to their associated ecosystem structures and functions, within the entirety of the area.

Exploration and seismic activities may have a larger geographic scope than when a significant discovery license is issued and activities become more focused on a specific target area.

This review only addresses direct routine planned oil and gas exploration and production activities, excluding accidental events, ancillary activities related to the industry (e.g., cables, boat traffic, etc.), and decommissioning. Therefore, the following potential impacts were considered out of scope: chronic and catastrophic accidental spills, discussion of potential impacts on benthic components that are not defined in conservation objectives, and potential impacts on pelagic conservation objectives or potential impacts on the pelagic zone, although it was acknowledged through discussions at the meeting that coupling between the benthic and pelagic zones can be important to ecosystem function.

This Science Advisory Report is from the June 26-28, 2018 National Peer Review Meeting on the assessment of the effectiveness of mitigation measures in reducing the potential impacts of oil and gas exploration and production on areas with defined benthic conservation objectives. The meeting brought together national and international experts from Fisheries and Oceans Canada, other federal departments, academia, non-governmental organizations, regulators and industry to provide science advice on mitigation measures that can be used to reduce the impacts of oil and gas exploration and production on areas with defined benthic conservation objectives. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule *as they become available.*

SUMMARY

- The focus of this review was on the potential effects of oil and gas exploration and production activities, and their mitigation, in the context of potential impacts to benthic species, features and habitats (including habitat functionality) in areas with defined benthic conservation objectives.
- Accidental events (i.e., spills and blowouts) were beyond the scope of this review, which focuses on planned routine activities and discharges associated with offshore exploration and production.
- Areas with benthic conservation objectives are those where a higher vulnerability to anthropogenic activities is often inferred, or where vulnerability has been explicitly identified. Therefore, a lower threshold of impact and a higher expectation of mitigation may be more appropriate for them.
- Based on the above, oil and gas exploration and production activities within habitats with defined benthic conservation objectives should be managed with higher risk aversion than activities in areas without these habitats. Beyond the placement of infrastructure to prevent direct destruction of individuals and/or individual colonies of species in areas with defined benthic conservation objectives, current management practices do not distinguish between areas with and without defined benthic conservation objectives in terms of the habitat-scale features and processes that they support.
- Aside from the benthic species, features or habitat(s) that may be directly affected by oil and gas exploration and production activities, there is also a need to understand what the potential impacts could be at the community level (e.g., food web and ecological linkages) as well as the cumulative impacts within areas with benthic conservation objectives. Impacts to benthic species, features or habitats may also have consequences for pelagic species that depend on them directly or indirectly. The benthic conservation objectives associated with each area will point to what level of consideration is needed (e.g., habitat, ecosystem structure and function, features, etc.).
- The activities of oil and gas exploration, development, and production are likely to overlap with areas with defined benthic conservation objectives. The significance of those impacts should be determined on a case-by-case basis to account for site-specific ecology and environmental conditions.
- Seismic surveys typically occur across a large geographic scale; therefore, seismic surveys may result in similar impacts between sites and across a larger geographic area in comparison with drill based exploration or production which have a smaller geographic footprint, and their impacts may be more variable and site-specific.
- The suite of activities, as well as their spatial and temporal footprint, varies significantly between oil and gas exploration and development operations. Exploration operations include seismic activities (usually over a larger geographic scale), along with a very short period of exploratory drilling (short duration – usually single well). Development and production operations, which can include drilling, tend to be more geographically focused but can extend for tens of years. Therefore, potential impacts and mitigations to oil and gas operations phases will also vary.
- Mitigation measures are ideally identified and implemented in accordance with the widely-accepted “mitigation hierarchy” of: (1) avoid; (2) mitigate; and (3) offset (recognizing that offsetting will not generally be compatible with benthic conservation objectives). The optimal

mitigation measure avoids the impact entirely by eliminating the possibility of interaction between the activity and the area with the defined benthic conservation objective, thereby removing all potential pathways of effects.

- The research available for the effectiveness of mitigation measures in areas with defined benthic conservation objectives was not sufficient to provide prioritized recommendations regarding which mitigation(s) would be most effective. A case-by-case approach to development of mitigation recommendations is considered the preferred approach at this time.
- Standardization of the description and definitions relating to areas with defined benthic conservation objectives would be helpful within and across agencies.
- While a national review, most of the examples available were from the Atlantic Coast – Arctic offshore would require further review.

BACKGROUND

The Government of Canada is committed to increasing the amount of conserved coastal and marine areas in Canada to 10% by 2020, as agreed to through international Aichi Biodiversity Target 11 and domestic Biodiversity Target 1. To achieve this goal, marine protected areas (MPAs) and other effective area-based conservation measures (OEABCMs) (*Fisheries Act* closures that meet Government of Canada criteria for OEABCMs) are being established. Many MPAs and OEABCMs have defined benthic conservation objectives. Defined benthic conservation objectives can include the protection of: benthic species (fish and invertebrates); benthic habitats including benthic spawning, nursery or feeding grounds; and Significant Benthic Areas, which include communities dominated by corals and/or sponges and hydrothermal vents, or locations likely to contain them such as canyons, seamounts, etc. By their nature, areas with defined benthic conservation objectives including MPAs and OEABCMs warrant a high(er) degree of risk aversion to anthropogenic activities than areas with no defined conservation objective.

Oceans Management has requested national science advice on the effectiveness of existing mitigation measures in reducing the impacts of oil and gas exploration and production activities in Canadian waters, including seismic and drilling, on areas with defined benthic conservation objectives (such as MPAs and OEABCMs). Oceans Management sought this advice to inform policy related to oil and gas activities in areas with defined benthic conservation objectives. The advice may also be of interest to other sectors within Fisheries and Oceans Canada (DFO), other federal departments, and oil and gas industry partners.

Oil and gas operations and regulation

The three main phases of marine based oil and gas activities are exploration, development and production, and decommissioning. The exploration phase may include electromagnetic and/or seismic surveys to identify potential oil and gas reservoirs, and drilling into formations ("exploration drilling") to determine whether the identified reservoirs contain hydrocarbons. Following the determination that hydrocarbons are present in commercially-viable quantities, the development and production phase can begin. Development includes infrastructure planning and drilling of development wells, and production is the period during which a field and its associated pipelines (as applicable) and infrastructure are used to produce oil or gas. When the

field is exhausted, the wells are plugged and abandoned, and production infrastructure is decommissioned.

The lead regulators for offshore oil and gas exploration and production activities in Atlantic Canada are the Canada-Nova Scotia Offshore Petroleum Board (CNSOPB) and the Canada-Newfoundland and Labrador Offshore Petroleum Board (C-NLOPB) which are joint federal-provincial agencies reporting to federal and provincial Ministers. Rights to explore for, develop and produce offshore petroleum resources are administered by these Boards in their respective jurisdictions and require environmental assessment under the respective legislation of the Boards and/or the *Canadian Environmental Assessment Act, 2012*. Offshore oil and gas activities are also regulated by Fisheries and Oceans Canada under the *Fisheries Act, Species at Risk Act* and *Oceans Act*. For more information on oil and gas regulation please refer to the CNSOPB and C-NLOPB websites. The Arctic and Pacific Oceans are currently under moratoria for oil and gas exploration and development.

Areas with defined benthic conservation objectives

"Areas with defined benthic conservation objectives" refer to area-based management measures (such as MPAs and OEABCMs) applied to protect benthic components defined in conservation objectives. Defined benthic conservation objectives can include the protection of: benthic species (fish and invertebrates); benthic habitats including benthic spawning, nursery or feeding grounds; and Significant Benthic Areas, which include communities dominated by corals and/or sponges and hydrothermal vents, or locations likely to contain them such as canyons, seamounts, etc.

The areas in question for this review are those where a higher vulnerability to anthropogenic activities can often be inferred, or where vulnerability has been explicitly identified. Therefore, a lower threshold of impact and a higher expectation of mitigation would be more appropriate. In addition, because the areas are subject to conservation objectives, a precautionary approach and ecosystem approach are recommended within these areas. Management of activities, including oil and gas exploration and production activities, within areas with defined benthic conservation objectives should, therefore, include a higher risk aversion than management of activities in areas without these objectives. Currently, beyond ensuring that infrastructure placement does not cause direct destruction of individual organisms/colonies in these areas, current oil and gas exploration and production management practices do not distinguish between areas with and without defined benthic conservation objectives in terms of the habitat-scale features and processes that they provide.

SCOPE

The objectives of the science peer review meeting were to provide advice on the potential impacts of oil and gas exploration and production on areas with defined benthic conservation objectives and to assess the effectiveness of potential mitigation measures in the Canadian context.

A subset of activities related to oil and gas exploration and production was reviewed; including seismic surveys, controlled source electromagnetic surveys and geotechnical / geohazard surveys that may involve the placement of structures on the bottom or physical collection of bottom samples (cores/grabs), and drilling-related activities which may have direct or indirect impacts on areas with defined benthic conservation objectives.

Other activities related to oil and gas exploration and production – in particular accidental events (e.g., chronic and catastrophic spills) – but also including decommissioning, and ancillary

activities related to the oil and gas industry such as cable installation and boat traffic were not addressed. A recent review of oil spills was conducted by the Royal Society of Canada (Lee et al. 2015); however, this review did not examine oil spills in relation to areas with defined benthic conservation objectives (e.g., coral and sponge habitats). In addition, the current review focused on offshore activities, without explicitly addressing that impacts and mitigation measures are likely to be different between offshore and nearshore/estuarine environments, and will differ in Arctic environments.

This evaluation reviewed the extent and significance of oil and gas exploration and production activities in areas with defined benthic conservation objectives in Canadian waters, and the existing mitigation measures to reduce those impacts. Maps depicting a snapshot of federal areas with defined benthic conservation objectives, locations of offshore petroleum licences, and call for bid areas (areas that are presently open for bids; these areas do not guarantee issuance of exploration licences) are provided for the Canadian Atlantic (Figure 2), Arctic (Figure 3), and Pacific Ocean (Figure 4).

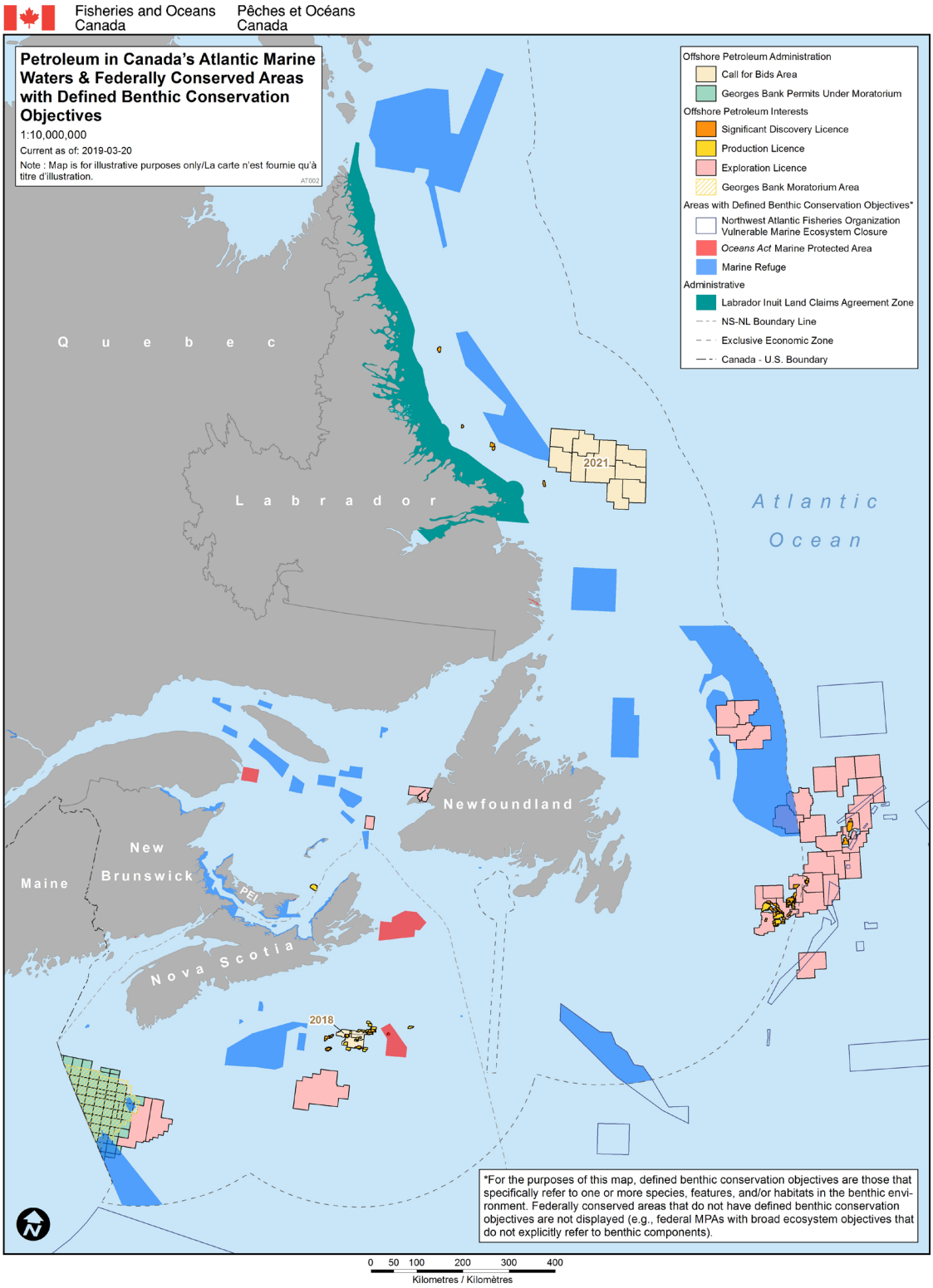

Figure 2. Map depicting federally conserved areas with defined benthic conservation objectives, locations of offshore petroleum licenses, and call for bid areas (areas that are presently open for bids; these areas do not guarantee issuance of exploration licenses), and certain administrative boundaries in Canada's Atlantic marine waters.

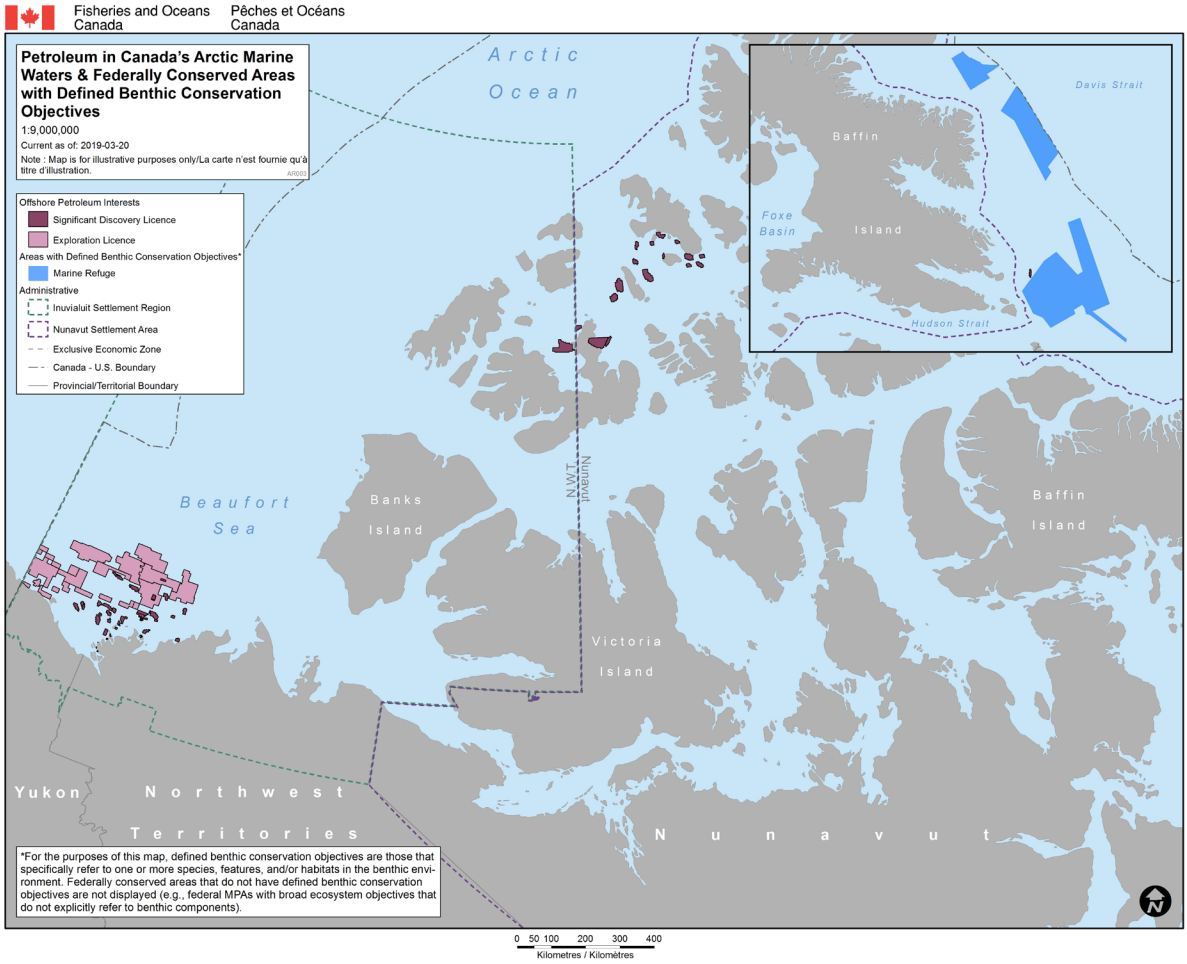

Figure 3. Map depicting federally conserved areas with defined benthic conservation objectives, locations of offshore petroleum licenses, and certain administrative boundaries in Canada's Arctic marine waters.

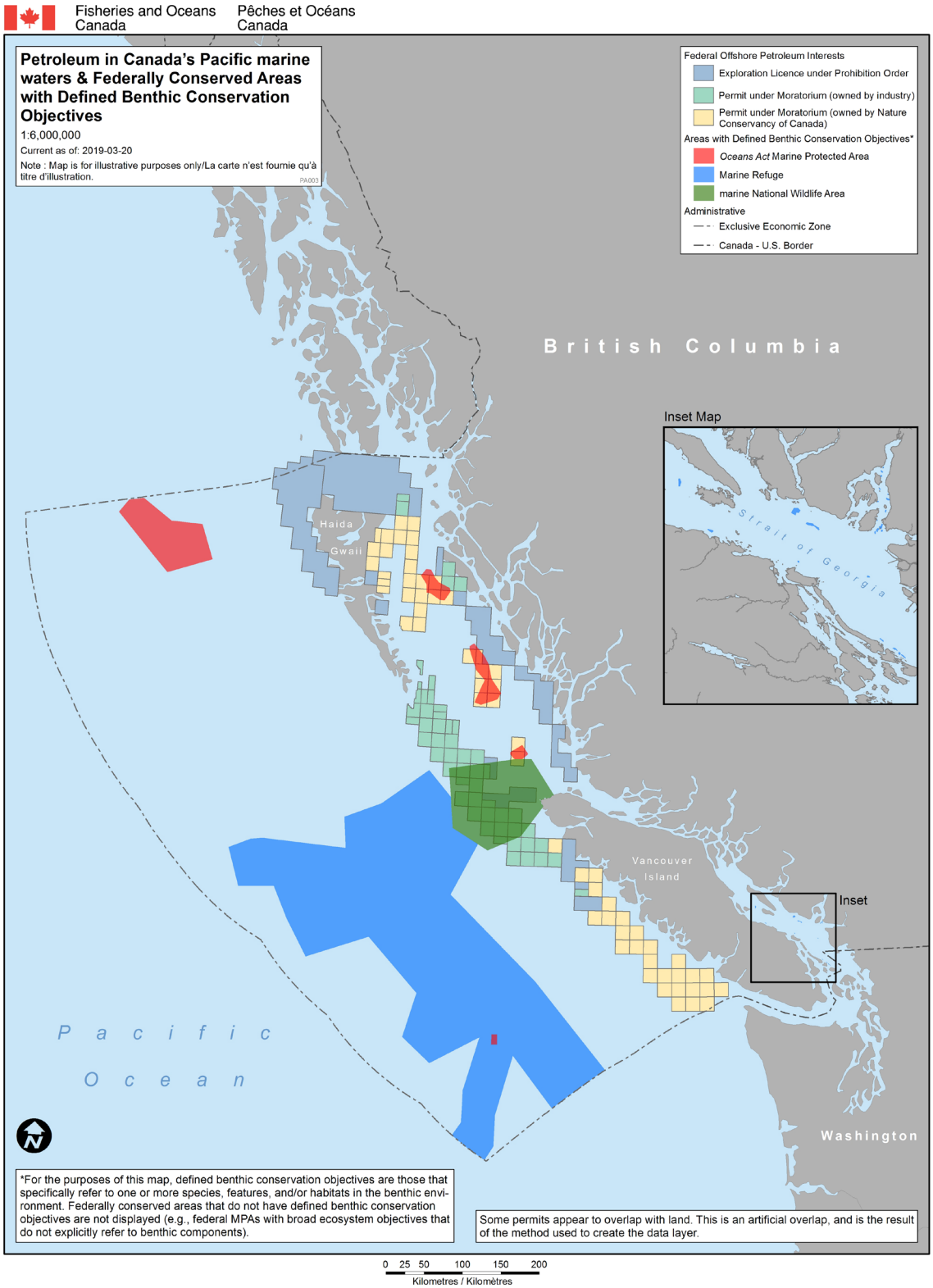

Figure 4. Map depicting federally conserved areas with defined benthic conservation objectives, locations of offshore petroleum licences, permits under moratorium (owned by Nature Conservancy of Canada), permits under moratorium (owned by industry), and certain administrative boundaries in Canada's Pacific marine waters.

ASSESSMENT

IMPACTS

Routine planned activities associated with oil and gas exploration and production include: seismic surveys; controlled source electromagnetic surveys; geotechnical / geohazard surveys that may involve the physical collection of bottom samples (e.g., cores, grab samples); exploration and/or delineation drilling, including the placement of structures on the seabed and authorized discharges (e.g., drill muds, drill cuttings and cement); and development drilling and production including placement of structures on the seabed and authorized discharges (e.g., produced water, drill muds, and drill cuttings). The time scale and footprint of specific oil and gas activities must be considered to accurately assess impacts to areas with benthic conservation objectives.

Geophysical surveys (e.g., seismic exploration, controlled source electromagnetic surveys, geotechnical / geohazard surveys), exploration drilling and development/production activities can result in underwater sound, marine discharges, and/or direct disturbance of the seafloor (e.g., placement of infrastructure on the seafloor). These effects vary in terms of nature and temporal/spatial extent depending on the type of activity and the vulnerability of the affected benthic component. For example, geophysical surveys generate underwater sound focused on a specific wellsite and are completed in a day or two, while seismic exploration surveys may be carried out over hundreds of square-kilometres over a period of months. However, within the large area covered by a seismic exploration survey the exposure to any one area within the overall survey is limited.

The main potential impacts to benthic species and habitats from exploration and delineation drilling are associated with placing infrastructure on the seabed, and depositing drill muds and cuttings at the seafloor and/or in the water column. Compared to exploration drilling, development drilling and production are generally considered to have increased risks of impacts to benthic species and habitats, with additional activities, greater seabed footprints and longer timeframes.

Development drilling and production often requires additional infrastructure such as different and/or more platforms, pipelines and flowlines. Development infrastructure may alter the habitat by introducing complex vertical hardscape (e.g., platforms) and hard substratum (e.g., pipelines and flow-lines) increasing habitat connectivity. The development and production phase also generally involves drilling several wells, with increased quantities of drill muds and cuttings and may include the introduction of produced water which typically comprises the largest waste stream volume (unless reinjected) from offshore oil and gas production.

Most studies on the impacts of oil and gas activities have been conducted in the lab or on the continental shelf and may not be reflective of impacts in deep waters as the scale and magnitude of impacts may differ. Deep-sea coral and sponge communities have been understudied by virtue of their remote locations, and are not typical of those used in previous laboratory studies. While knowledge of coral and sponge reproductive biology is limited, and the complex of species associated with the habitats they define is poorly known, it is clear that sessile and long-lived species are expected to be the most vulnerable to oil and gas activities. When examining potential effects it is also important to consider both the link of the benthos to the pelagic zone and its food chain, and water column activities on the delivery of particulate material to the benthos. In addition there are unknown impacts of sub-lethal effects on juvenile and larval stages of organisms.

Noise

For the purpose of this review 'noise' was interpreted as both seismic noise and sound associated with other exploration and production activities in varying degrees. The following activities generate sources of underwater noise that could potentially impact benthic communities: geophysical surveys (e.g., seismic surveys, electromagnetic surveys, geohazard surveys), exploration and production drilling (including use of drill rig and dynamic positioning systems) and installation of production infrastructure (e.g., pile driving, pipeline installation). While potential impacts on areas with defined benthic conservation objectives could include everything from direct mortality to sub-lethal effects (e.g., tissue and/or physiological damage); the most likely effects would be those that may elicit a behavioural response (e.g., displacement from preferred habitats, changes in movement patterns, delay or prevention of migration to spawning or feeding grounds; prevention of recruitment or settlement in preferred habitats; altered sediment reworking resulting in habitat changes).

There are few field studies on the sensitivity of different species of marine benthos to sound; most of these studies are at the individual or population level and little is known about the community level. Fish and invertebrates all have primary hearing below 500 Hz, which overlaps with the frequencies used for seismic exploration (Arthur Popper pers. comm.) Given the current state of knowledge regarding the effect of seismic surveys on marine fish or invertebrates and the fact that areas with defined benthic conservation objectives are often sensitive / vulnerable or ecologically significant, a higher level of precaution is warranted than in other areas. There is evidence to suggest that background noise in the marine environment is increasing (Cox et al. 2018). Without an understanding of the background noise present, it is impossible to know the full spectrum of noise benthic communities would be exposed to during seismic surveys.

Different types of seismic surveys (e.g., 2D, 3D, wide-azimuth) are likely to have different levels of impact due to differences in energy, duration of the survey, number of repetitions, and line spacing. Additionally, potential impacts are a function of the surrounding marine environment (e.g., depth, canyons, temperature, etc.). Studies on the impact of seismic surveys on invertebrates have not been conclusive: a recent study that showed an impact on juvenile krill (McCauley et al. 2017) has been disputed (Arthur Popper pers. comm.); another study did not detect a measurable impact of 2D seismic surveying on snow crab catch rates (Morris et al. 2018). Also, acoustic-induced particle motion could play a larger role in marine animal sensory reception than previously considered (Popper and Hawkins 2018); however, it has not been well-studied at this time.

There are potential impacts of underwater noise from drilling activities such as wellhead/conductor installation, pile driving, dynamic positioning systems and well drilling (DFO 2011). These seabed activities produce substrate vibrations that travel as compressional (longitudinal), transverse (shear) and/or surface ("ground-roll" or interface) waves. Interface waves can become trapped within the substrate/water interface where they can travel considerable (undetermined) distances, potentially affecting epifaunal and infaunal species and communities far from the source (Roberts et al. 2016). Given that marine animals living close to or within the substrate may be primarily sensitive to the particle motion component of sound future research on interface waves should be conducted to determine whether there are impacts on areas with defined benthic conservation objectives.

In general, the impact of all noise producing, activities including seismic surveys, on benthic communities will vary because the noise level, frequency and density of the activities producing the noise can vary.

Discharges

Marine discharges associated with offshore oil and gas exploration and production are managed in accordance with the Drilling and Production Regulations and an Operator's Environmental Protection Plan (EPP). The EPP uses guidance from the Offshore Waste Treatment Guidelines (NEB et al. 2010) to specify concentrations of waste material which may be discharged to the marine environment and acceptable treatment/analysis methods; however, this guidance was not designed specifically for areas with defined benthic conservation objectives. This review focused primarily on drilling fluids (muds) and cuttings, and produced water (only produced during production phase) discharges and their potential impacts on areas with defined benthic conservation objectives.

a) Drill muds and cuttings

Offshore exploration drilling typically results in the discharge of drilling wastes into the water column or at the seafloor (e.g., drilling muds, drill cuttings, cement). In accordance with the Offshore Waste Treatment Guidelines water-based muds and associated drill cuttings can be discharged to the marine environment without treatment. Whole synthetic-based muds are not permitted to be discharged to the marine environment; however, cuttings associated with synthetic-based muds are permitted for marine discharge, provided the cuttings are first treated to reduce oil on cuttings to an acceptable limit.

Coarse drill cuttings settle quickly and accumulate on the seabed; however, fine drill cuttings may remain in suspension near the seabed and be dispersed by currents and transported to depositional environments. Deposition of cuttings may result in the depletion of oxygen in sediments, alterations in sediment grain size and increased turbidity in the water column. For example, smothering of slow-moving and sessile benthic organisms (e.g., corals and sponges) is more likely to occur in low energy depositional environments and is dependent on the amount of cuttings and mud discharged. It is known that smothering has a detrimental impact on corals and sponges. Impacts on benthos could include biophysical effects (e.g., smothering, toxicity, anoxia) and behavioural effects (e.g., displacement, reduced or arrested feeding) on mobile and sessile vertebrates and invertebrates. Impacts on habitats could include changes to physical and chemical aspects of habitat (e.g., chemical properties of the sediment and sediment/water interface, substrate type including grain size, contaminant burden, current patterns).

It is important to note that there is a difference between the spatial scale of the activity footprint and the impact area (e.g., the downstream effects, including fine particulate transport). The areal extent of drilling mud deposition is similar between exploration and development drilling activities on a per well basis; however, the time scale, volume of drilling waste, number of well sites and size and depth of deposition areas increases significantly from exploration to development drilling activities. Deposition areas represent the coarser drilling mud materials; the fine materials may be transported further afield. Predictive modelling is conducted during the environmental assessment process to predict the location and extent of drill waste deposition associated with a proposed drilling program.

b) Produced water

Produced water is a mixture of formation water (existing in the reservoir), seawater (added to maintain reservoir pressure) and production chemicals (to prevent scaling and reservoir contamination). Produced water generally only occurs during the production phase and typically comprises the largest volume of waste from offshore oil and gas production (if not reinjected), with tens of thousands of barrels treated and discharged daily at sea in accordance with the Offshore Waste Treatment Guidelines. The cumulative volume of produced water often increases

over the lifetime of the field. In addition to organic and inorganic substances from the geologic formations, produced water contains various additives and treatment chemicals, seawater, dissolved organic salts, dissolved and dispersed hydrocarbons, dissolved minerals, trace metals, naturally occurring radioactive substances, and dissolved gases. Produced water processing removes a substantial amount of the dispersed oil as free oil and larger oil droplets; however, dissolved oil is more difficult to remove, and small droplets, or emulsified oil, are discharged with the water.

Composition of produced water varies by reservoir type, age and management. It is difficult to study the impacts of produced water because the characteristics are site-specific and because of the turbulent nature of plumes (released from a platform 10 to 60 m below the surface) makes them difficult to sample. In addition, produced water and its constituents undergo complex chemical and physical transformations upon discharge that significantly alter the behavior and toxicity of the component chemicals. Potential pathways of effects occur through the disruption of benthic-pelagic coupling and the delivery of contaminants to the benthic environment. Based on biological tests conducted through Environmental Effects Monitoring (EEM) programs, rapid dispersion and degradation of the plume and discharge volumes from current developments in Atlantic Canada, there is limited potential for acute toxicity to the benthos beyond the immediate discharge source. However, it is important to note that the dispersion, degradation and volume of discharge may differ in deep-water significant benthic areas.

Infrastructure

Oil and gas exploration and development activities are associated with different types of infrastructure placed on the bottom, which may include anchors, transmitters, pipelines, flowlines, and wellheads/blowout preventers. The scale of infrastructure can range from small with exploration drilling (e.g., one wellhead benthic footprint of $1m^2$) to large during the development phase. For example, production activities require additional infrastructure to develop a field compared to an isolated exploration well. The impact of infrastructure is also dependent on the type of facility in use (e.g., single wellhead approximately 1.5 m to 4 m in height and a 1 m^2 benthic infrastructure footprint) and the activity phase. Excavated drill centres for development are used to keep equipment below the reach of grounding icebergs and have been used with floating production storage and offloading platforms (FPSO) on the Grand Banks. Excavated centre dimensions are approximately 25 m x 65 m and 10 m in depth (Allen 2000). Dredge spoils from these excavations are deposited on the seafloor. There may be several drill centres and spoil piles for each FPSO operation. For example, Terra Nova has five drill centres and two spoil piles. Gravity-based structures (GBS) which are also used in the Canadian offshore have a larger footprint. For example, the Hibernia platform has an area of approximately 8825 m^2. Footprints for deep-water installations that do not require iceberg protection may be smaller.

Infrastructure associated with drilling and production platforms introduces vertical hardscapes, increasing habitat complexity relative to the natural habitat. Placing flowlines and pipelines on the seabed similarly adds hard substratum, which can support sessile epifauna, attract motile benthic organisms and/or increase habitat connectivity; while this may have positive effects for native species, it can also introduce and/or support the propagation of invasive species. The reported increased production of fauna offered by platforms and pipelines is associated with the addition of structural complexity; this is in contrast to most areas with defined benthic conservation objectives, which are already structurally complex.

Monitoring

Environmental Effects Monitoring (EEM) programs are a mandatory requirement at producing fields in Nova Scotia (NS) and Newfoundland and Labrador (NL) for the life of the field, and reports are publicly available from the C-NLOPB and CNSOPB. EEM programs may include measurements of sediment (e.g., particle size, infauna, physical and chemical characteristics), water (physical and chemical characteristics), and biota (including toxicity, benthos, fish body burden, histopathology), and vary across programs. Current EEM programs do not monitor benthic components associated with conservation objectives because to date none of the facilities have been placed in or near areas with defined benthic conservation objectives. Monitoring during the exploration phase is not designed to detect long-term effects and there is no formal EEM structure for exploratory wells, but monitoring can be designed to verify predictive dispersion modelling. In contrast, monitoring during the production phase is long term and case-specific for each development.

EEMs for production projects generally start with a pre-production baseline survey for BACI (Before-After, Control-Impact) design. EEMs are conducted on a regular schedule for the life of the producing field. The results for current operations on the continental shelf show that measured biological effects are within predictions; however, as indicated above these studies were not conducted in areas with defined benthic conservation objectives. For instance, for Terra Nova, a development field on the shelf, the EEM program determined that the highest levels of barium and some hydrocarbons (C_{10-21}) were limited spatially to within 2 km from the well site (Neff et al. 2014); however, extreme weather events may transport and disperse contaminants beyond the range of the site specific EEMs.

MITIGATION

The DFO Fisheries Protection Policy Statement (2013) describes the “mitigation hierarchy” of: (1) avoid; (2) mitigate; and (3) offset. These three factors establish a hierarchy of measures where efforts should be made to avoid impacts first. When avoidance is not possible, then efforts should be made to mitigate impacts caused by the project in question. After these actions, any residual impacts would normally require authorization and should then be addressed by offsetting; however, it is important to recognize that offsetting and compensation will not generally be compatible with benthic conservation objectives.

Oil and gas exploration and production activities within areas with defined benthic conservation objectives should be managed with greater risk aversion than activities in areas without these features. Beyond the use of initial surveys for the placement of infrastructure to prevent direct destruction of individual organisms/colonies in areas with defined benthic conservation objectives, current management practices do not distinguish between areas with and without defined benthic conservation objectives in terms of the habitat-scale features and processes that they provide. For example, remotely operated vehicle (ROV) surveys are used prior to the placement of infrastructure to ensure that no significant habitat is impacted in the local area.

Avoidance of impacts to the benthic components defined in conservation objectives and the elements of the ecosystem they depend on is the most effective mitigation measure available because it eliminates the potential for interactions between the activity and benthic components, minimizing the likelihood of serious or irreversible harm. Avoidance can have three components: spatial (move location, directional drilling), temporal (activity at a different time), and activity (reinject or skip and ship vs. discharge). Where avoidance is not feasible, other mitigation measures may be effective and would require consideration on a case-by-case basis.

Detailed understanding of the ecological functionality and processes related to areas with defined benthic conservation objectives is currently lacking, as is specific information on the impacts of oil and gas activities to these areas. Therefore the ability to assess effectiveness of specific habitat mitigation measures is rather limited. At present, avoidance of impacts, including the use of properly defined buffer zones (as informed through site-specific surveys and predictive modelling), would be the most effective way to minimize the likelihood of serious or irreversible harm, and would be consistent with the benthic conservation objectives of these areas.

Noise

A large amount of research has been focused on the impacts of noise on marine mammals; therefore, most seismic noise mitigation has been developed to minimize these impacts to marine mammals (see Statement of Canadian Practice with Respect to Mitigation of Seismic Sound in the Marine Environment). As noted above, the frequencies of noise generated by offshore oil and gas activities are well within the hearing ranges of fish and invertebrates, although the impacts are not well understood. In the absence of sufficient information on the impacts of noise to areas with defined benthic conservation objectives the precautionary approach of avoiding benthic components defined in benthic conservation objectives and the elements of the ecosystem they depend on is recommended. In some cases where the benthic component in the conservation objective has a temporal component it may be effective to apply a timing window to the noise producing activity.

Discharges (drill muds, cuttings, and produced water)

The Canadian oil and gas industry is governed by a regulatory regime that incorporates best management practices that are designed to minimize risk and effects. Operators must evaluate alternative methods of managing discharges to reduce risks to as low as reasonably practicable. The reinjection of cuttings, a method used at the Hibernia and Hebron production fields, has been shown to reduce the footprint of development drilling activities. This measure could be considered to minimize the impacts of drill cuttings to areas with defined benthic conservation objectives if deemed appropriate; however, the feasibility of this mitigation measure would depend on program- and site-specific details. Mitigation measures for discharges that are used in other countries would require consideration on a case-by-case basis to determine their applicability along with other mitigation measures already in place in Canadian waters.

Buffer zones are a potential mitigation tool to restrict potential impacts of discharges from exploration and production activities in areas with defined benthic conservation objectives. Recognizing that all oil and gas well locations have unique characteristics of sediments and ocean currents, the preferred approach would be to conduct detailed dispersion modelling at each potential exploration site and use this information along with ROV surveys to define the extent of the buffer zone required in areas with defined benthic conservation objectives. Where detailed dispersion models are not available, a recent global review (Cordes et al. 2016) suggests a minimum buffer zone for discharge infrastructure (e.g., drill centres) of 2 km for production discharge.

In addition, the delineation of habitats in areas with defined benthic conservation objectives requires high resolution mapping at the same scale as the buffer zone using ROVs or similar non-destructive techniques, together with definitions of community assemblages and characteristics (e.g., taxa to be considered, typical morphologies and spatial arrangements, etc.) based on local ecosystems. Environmental conditions and habitat suitability modelling can also be used to complement and support these habitat delineations. Current practices are based on species and features that do not reflect existing knowledge of Canadian deep sea ecosystems.

Infrastructure

A review of current information suggests corridors of 200 m for non-discharging infrastructure (e.g., pipeline corridor, anchors) (Cordes et al. 2016) in areas where benthic components (e.g., corals and sponges) are or may be present. As noted above, the delineation of habitats in areas with defined benthic conservation objectives requires high resolution mapping at the same scale as the buffer zone using ROVs or similar non-destructive techniques, together with definitions of community assemblages and characteristics based on local ecosystems.

Sources of Uncertainty

Current knowledge of the location of significant benthic areas in Canada is largely based on modelling sparse data from corals and sponges impacted by DFO science research trawls; therefore, many of the significant benthic areas identified have not been groundtruthed.

This review did not specifically consider operations in ice-covered environments; there are significant knowledge gaps in the Arctic environment. Estuarine and near shore environments were also not explicitly considered. However, many of the descriptions of activities and the operational recommendations may still be applicable.

Research into impacts of exploration and production activities in areas with defined benthic conservation objectives is limited in Canada. Many of the benthic impacts such as seismic survey noise and other noise have a high degree of uncertainty and no known impacts, as much of the research is based on propagation modelling and tank based experiments with little field-based research.

Several key knowledge gaps were identified (see Research Recommendations below for more information). For example, little investigation has been conducted on the impact of oil and gas exploration and production activities on the functioning of benthic ecosystems including benthic-pelagic coupling, and potential impacts to pelagic conservation objectives which may co-occur within areas with defined benthic conservation objectives.

Mitigation measures for exploration and production drilling are designed to mitigate direct impacts on individual organisms or colonies within areas with defined benthic conservation objectives, but they may not consider impacts at the scale of the habitat that these organisms or colonies generate. Therefore, current mitigation practices do not specifically address issues related to the ecosystem functionality, services and biodiversity provided by the benthic components in areas with defined benthic conservation objectives.

RESEARCH RECOMMENDATIONS

1. Current guidelines in relation to benthic conservation objectives are mostly based on knowledge and best practices from Norwegian oil and gas exploration and production examples, which may not be appropriate in the Canadian context. For example, *Lophelia* is a coral indicator species in Norway and has been applied to oil and gas activities in parts of Canada, but it is not a good indicator in Canadian waters. Norwegian guidelines also characterize coral aggregations as 5 colonies greater than 30 cm, which excludes Canadian sea pen fields. To provide regionally appropriate guidance, development of regionally relevant guidelines similar to those provided by the Norwegian Oil and Gas Authority (NOROG) (DNV 2013), including development of a regionally appropriate species list and criteria for setback distances is required to support determination of what level of coral and/or sponge occurrences/densities (or associated features and species) are consistent with significant concentrations in Canadian waters.

2. More research is required in order to understand the ability of individual fish and invertebrate species and their life history stages to detect and respond to the sound created by industry activities in the natural environment.

3. The potential behavioural and sub-lethal effects of oil and gas exploration and production activities on marine benthos are poorly understood for most species' life history stages and should be further studied.

4. While outside the scope of this particular science advice, research is recommended to review the extent, significance and mitigation of potential impacts of accidental events (e.g., spills and blowouts) specifically subsurface releases, and their potential impact in general, and in relation to benthic features associated with defined benthic conservation objectives in particular.

5. The majority of studies are lab-based and are directed toward shallow water environments. In Canadian waters, exploration activities have developed deep-water baseline data that can be used to compare with data collected during production to improve understanding of potential effects in deep-water environments.

6. Ecosystem-based studies are required to characterize the ecological processes and functions of benthic features associated with benthic conservation objectives, and to determine how functional roles, features and/or habitats protected through benthic conservation objectives, including community/food web dynamics, can be impacted by oil and gas related activities.

7. Research is needed to assess the effectiveness of specific technical mitigation measures in terms of reducing the amount of noise and discharges from oil and gas related activities in areas with defined benthic conservation objectives.

CONCLUSIONS

The Canadian offshore oil and gas industry is governed by a regime of best management practices that is intended to minimize risk and effects; however, these management practices have not been specifically designed to address issues related to the ecosystem functionality of areas with defined benthic conservation objectives.

Oil and gas exploration and production activities are likely to overlap with areas with defined benthic conservation objectives. While impacts are to be expected, the precise magnitude of those impacts would require a case-by-case assessment to account for site-specific ecology and environmental conditions. This review was unable to assess the general effectiveness of alternative mitigation measures in reducing the impacts from oil and gas exploration and production on areas with defined benthic conservation objectives due to the limited number of scientific studies available. However, avoidance (spatial, temporal, and/or activity) was identified as the most effective means of protecting areas with defined benthic conservation objectives.

Potential impacts and mitigations between exploration and production activities have different footprint scales (e.g., spatial, temporal, number of drilling days, etc.). Exploration may occur in multiple areas, whereas production occurs in a more focused area but over a longer duration, with a potentially larger volume of waste materials and an expected increase in cumulative impacts. In contrast, seismic surveys may result in similar impacts between sites and across a larger geographic area in comparison with drill based exploration (or production) which have a smaller geographic footprint, and their impacts may be more variable and site-specific. However, the impacts of seismic surveys may differ in intensity depending on the type of survey (e.g., 2D, 3D, wide-azimuth).

While accidental events (e.g., from minor oil spills to blowouts) may occur, they were beyond the scope of this review, which focused on routine, planned activities and discharges associated with exploration and production. Further research and advice regarding the potential impacts of oil spills is needed.

This review highlights the need for the development of a regionally appropriate species list and criteria for setback distances to support determination of what level of coral and/or sponge occurrences/densities (or associated features and species) are consistent with significant concentrations in Canadian waters. Consistent terminology for the description of species, habitats, and benthic features is also necessary within DFO and across other government departments.

OTHER CONSIDERATIONS

Cumulative effects

Cumulative effects are changes to the environment that are caused by an action in combination with other past, present and future human actions. Assessments of cumulative effects are critical to understanding the potential and relative risks associated from all activities and associated stressors within an area. These types of assessments should not only focus on likelihood of exposure to activities/stressors but rather they should also incorporate biological consequence. Cumulative effects were raised as an issue at this meeting, but they were not thoroughly addressed. Properly assessing impacts on areas with defined benthic objectives remains a difficult task, so it follows that assessing cumulative effects constitutes an even bigger challenge. To view examples of cumulative effects assessments, the reader is directed to recent Environmental Impact Statements for exploration drilling projects proposed for the Newfoundland and Labrador Offshore Area.[1] Also, the C-NLOPB[2] and CNSOPB[3] have conducted several strategic environmental assessments in Atlantic Canada. It is important to note that these examples are included for information purposes only. They have not been peer reviewed by DFO Science.

[1] https://www.ceaa.gc.ca/050/evaluations/Index?culture=en-CA
[2] http://www.cnlopb.ca/sea/
[3] https://www.cnsopb.ns.ca/environmental-assessments/public-registry-sea

LIST OF MEETING PARTICIPANTS

Name	Affiliation
Mike Chadwick	Chair
Tara Oak	Paita Environmental Consulting Inc.
Caroline Longtin	DFO Science, National Headquarters
Lesley MacDougall	DFO Science, Pacific
Lisa Setterington	DFO Science, National Headquarters
Jessica Mitchell	DFO Oceans Management, National Headquarters
Miriam O	DFO Science, Pacific
Christine Desjardins	DFO Science, Québec
Guy Cantin	DFO Science, Québec
Alice Ortmann	DFO Science, Maritimes
Michael Wambolt	DFO Fisheries Protection Program, Maritimes
Keith Clarke	DFO Science, Newfoundland and Labrador
Corey Morris	DFO Science, Newfoundland and Labrador
Stephen Snow	DFO Oceans Management, Newfoundland and Labrador
Candace Newman	Natural Resources Canada, National Headquarters
Susanna Fuller	Oceans North
Sigrid Kuehnemund	World Wildlife Fund (WWF)
Janice Ray	Canada-Nova Scotia Offshore Petroleum Board (CNSOPB)
Elizabeth Young	Canada-Newfoundland Offshore Petroleum Board (C-NLOPB)
Steve Bettles	Canadian Association of Petroleum Producers
Heather Giddens	Canadian Association of Petroleum Producers
Marina Petrovic	DFO Resource Management, National Headquarters
Jason Simms	DFO Resource Management, Newfoundland and Labrador
Evan Edinger	Memorial University
Jinshan Xu	DFO Science, Maritimes
Kent Gilkinson	DFO Science, Newfoundland and Labrador
Vonda Wareham	DFO Science, Newfoundland and Labrador
Johan Joensen	Fish, Food and Allied Workers (FFAW)
Mariano Koen-Alonso	DFO Science, Newfoundland and Labrador
M. Robin Anderson	DFO Science, Newfoundland and Labrador
Darrin Sooley	DFO Fisheries Protection Program, Newfoundland and Labrador
Nadine Templeman	DFO Science, National Headquarters
Bob Courtney	Natural Resources Canada, Geological Survey of Canada
Melissa Preston	Natural Resources Canada
Cheryl Benjamin	Canadian Environmental Assessment Agency (CEAA)
Elisabeth DeBlois	Elisabeth DeBlois Inc.
Written reviews	
Arthur Popper	University of Maryland
Kevin Hedges	DFO Science, Central and Arctic

SOURCES OF INFORMATION

This Science Advisory Report is from the June 26-28, 2018, held in St. John's, NL, entitled "Assessment of the Effectiveness of Mitigation Measures in Reducing the Potential Impacts of Oil and Gas Exploration and Production on Areas with Defined Benthic Conservation Objectives. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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APPENDIX A: GLOSSARY

Benthos: the flora and fauna found on the bottom, or in the bottom sediments, of a sea, lake, or other body of water

Corals: marine invertebrates that may exist as individual coral polyps, as diversely-shaped colonies containing many polyps of the same species, and as reefs with many colonies made up of one or more species. “Cold-water” or “deep-sea” corals obtain the energy and nutrients they need to survive by trapping tiny organisms in passing currents. Due to the continuous regeneration of new polyps, some deep-sea coral reefs have been actively growing for as long as 40,000 years.

Cumulative effects: changes to the environment that are caused by an action in combination with other past, present and future human actions

Epifauna: animals living on the surface of the seabed or a riverbed, or attached to submerged objects or aquatic animals or plants

Flowline: a pipeline that is used to transport fluids from a well to a production facility or vice versa, and includes intrafield export and all gathering lines

Hard substrate/hardscape: Sessile organisms need to attach themselves to a secure, hard base material. Sedentary organisms use hard substrate as a temporary or permanent site of residence. Hard substrate refers to hard material along the seabed (including natural and manmade substrates), while hardscape refers to hard material within the water column (e.g., drilling unit, riser, wellhead system, platform legs).

Infauna: the animals living in the sediments of the ocean floor or river or lake beds

Pipeline: a tube or system of tubes used for transporting crude oil and natural gas from the field or gathering system to shore

ROV: remotely operated vehicle

Significant benthic area: within this document, this term is used to refer to a regional habitat that contains sponges (Porifera), large and small gorgonian corals (Alcyonacea, formerly classed as Gorgonacea) and/or sea pens (Pennatulacea) as a dominant and defining feature

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Canadian Science Advisory Secretariat (CSAS)
National Capital Region
Fisheries and Oceans Canada
200 Kent Street, Ottawa, Ontario K1A 0E6

Telephone: 613-990-0293
E-Mail: CSAS-SCCS@dfo-mpo.gc.ca
Internet address: http://www.dfo-mpo.gc.ca/csas-sccs/

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