MODULE 7:

MARINE FISH AND FISH HABITAT: OVERVIEW OF POTENTIAL EFFECTS

7.1 Introduction

The Study Area and its surrounding marine environments are known to be used by a diversity of marine fish and invertebrates (Module #). The presence, abundance and distribution of particular species and associated habitat characteristics (both abiotic and biotic) vary considerably across this rather large and diverse marine environment, which transitions from relatively shallow shelf zones, through the continental slope to deep areas, all of which are used by fish and invertebrate species of commercial, cultural and ecological importance and support regionally important areas of biodiversity and marine productivity.

Marine fish and fish habitat, and the potential effects of exploratory drilling and associated activities on this Valued Component (VC), are subject to the relevant provisions of the federal *Fisheries Act* and its associated regulations, which provides protection to commercial, recreational, and Aboriginal fisheries by protecting the fish resources and habitats that support these activities. Under the *Fisheries Act*, “fish” include all parts and life stages of fish, shellfish, crustaceans and marine animals. Fish habitats include areas that fish directly or indirectly use to live, including nursery, rearing, spawning, migration and foraging areas. Certain fish species and their habitats may also be provided with legislative protection within Canadian (federal *Species at Risk Act*; *SARA*) and/or provincial (NL *Endangered Species Act*; NL *ESA*) jurisdictions or have been identified as species of conservation concern through the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (Module #).

7.2 Planned Drilling Activities and Emissions

Potential interactions between offshore exploratory drilling and associated activities and marine fish and fish habitat, and possible resulting effects on this VC, include:

- The destruction, contamination or other alteration of marine habitats and benthic organisms due to the discharge and deposition of drill cuttings and fluids, the deployment and use of other equipment, and possibly the introduction and spread of aquatic invasive species.

- Contamination of fish and invertebrates and their habitats due to other environmental discharges during planned oil and gas exploration drilling and other associated survey and support activities (e.g., deck drainage, bilge water, treated produced water).

- Attraction of marine fish to drill rigs and vessels, resulting in increased potential for injury, mortality, contamination or other interactions.

- Injury, mortality or other disturbances to marine fish and invertebrates as a result of exposure to noise within the water column during vertical seismic profiling (VSP) or other drilling related activities.

- Temporary avoidance of areas by mobile marine fish species due to underwater noise or other disturbances, which may alter their overall presence and abundance as well as disturbing movements, migration, feeding or other activities and life stages.

- Changes in the availability, distribution or quality of feed sources or habitats for fish and invertebrates as a result of drilling related activities and their associated environmental emissions.

An overview of the various effects on marine fish and fish habitat that may result from these interactions (and their interrelationships) is summarized in Table 7.1 below.

Table 7.1 Marine Fish and Fish Habitat: Potential Effects of Planned Drilling Activities and Emissions

Potential Effects	Overview
1) Change in Mortality / Injury Levels and Health	• Fish mortality, injury or health effects may occur both directly and indirectly as a result of planned offshore oil and gas drilling activities. • These may result from, for example: the discharge of drill cuttings and resulting smothering of benthic invertebrates; injury or mortality through contact with underwater noise from VSP surveys rig positioning systems or other activities; or through the contamination of fish or their habitats and food sources through emissions and discharges into the marine environment. • Increased levels of mortality, injury and health effects can have resulting implications for the overall presence, density and diversity of fish and invertebrates in a region (See #2 below).
2) Change in Presence / Abundance and Distributions (Behavioural Effects)	• Potential attraction to, or avoidance of, offshore exploratory activities (behavioral effects) can influence the overall presence, abundance and distribution of mobile fish species in an area. • Some individuals may be attracted to offshore facilities and activities due to increased food availability (including waste discharges or concentrations of certain prey species) or by underwater lighting. • Conversely, some species may avoid the area because of sensory disturbances or other environmental changes (noise, increased presence of predators). • These behavioural changes can also, in turn, have implications for mortality, injury or health (See #1 above), particularly if these disturbances occur for extended periods of time, if important and sensitive life history stages are disrupted, or if they result in displacement of individuals from important habitats or food sources (See #3 and #4 below).
3) Change in Habitat Use, Availability and Quality	• Offshore exploratory activities and their associated emissions or disturbances (drill cuttings, others) may change the physical or chemical characteristics of habitats used by marine fish and invertebrates. • Any resulting changes in the availability, extent and quality of habitats have the potential to affect the presence, abundance and health of fish that use the affected areas (See #1 and #2 above).
4) Change in Food Availability or Quality	• Offshore drilling activities and their environmental discharges can also lead to changes in the availability, quantity and quality of food sources for fish. • This can include potential decreases in food availability of quality through the various effects on species presence, abundance and health described above (See #1 and #2) as well as potential increase feeding opportunities due to organic waste released from drill rigs and vessels or other attraction effects. • These increases or decreases in food availability or quality can lead to behavioural effects that affect the presence, abundance and distribution of individuals in an area (See #2 above), as well as potentially affecting the health (See #1 above) of individuals or populations.

Table 7.2 indicates which of the various components and activities that are associated with offshore exploratory drilling and their associated emissions and disturbances are potential contributors to these effects on this VC.

Table 7.2 Potential Contributors to Effects on Marine Fish and Fish Habitat (Planned Drilling Activities and Emissions)

Potential Effects	Potential Contributors: Planned Components and Activities							Potential Contributors: Associated Emissions / Disturbances / Interactions						
	Drill Rig and Associated Equipment	Well Drilling (Exploration and Delineation)	Vertical Seismic Profiling	Other Survey Activities	Well Evaluation and Testing	Well Abandonment or Suspension	Supply and Servicing (Vessels and Aircraft Use)	Presence and Operation of Drill Rig	Lights, Heat and Noise	Underwater Noise	Air Emissions	Drill Fluids and Cuttings	Other Liquid Discharges	Other Waste Materials
1) Change in Mortality / Injury Levels and Health	●	●	●		●		●	●		●		●	●	
2) Change in Presence / Abundance and Distributions (Behavioural Effects)	●	●	●	●	●	●	●	●	●	●		●	●	
3) Change in Habitat Use, Availability and Quality	●	●						●				●	●	
4) Change in Food Availability or Quality	●	●	●					●		●		●	●	

Table 7.3 summarizes current information and knowledge from the literature and other sources on the nature and degree of these potential effects.

Table 7.3 Potential Effects on Marine Fish and Fish Habitat: Summary of Current Knowledge (Planned Drilling Activities and Emissions)

Physical Activities / Components	Potential Effects: Summary of Current Knowledge
Presence and Operation of Drill Rig	• The presence and operation of the drill rig can affect marine fish and fish habitat through anchoring/mooring and the generation of underwater light and sound emissions. • Anchoring/mooring systems (if applicable in shallower waters) can disturb benthic habitats and cause injury or mortality to benthic invertebrates including corals and sponges (Cordes et al. 2016; DNV 2013; Ragnarsson et al. 2017) but over a longer period of time may also provide additional hard substrate for colonization by invertebrates, enhancing the reef effect that may be associated with the drill rig (Page et al. 2005). • Direct impacts of infrastructure installation, including sediment resuspension and burial by seafloor anchors are typically restricted to a radius of approximately 50 m to 100 m from the installation on the seafloor (DNV 2013; Cordes et al. 2016). Recovery and recolonization of habitats is dependent on distance to source species and species densities. Recovery is often slower in deepwater environments compared to shallow water environments (Clark et al. 2016). • Operation of an offshore drill rig (including dynamic positioning and drilling activities) typically generates continuous (steady-state), non-impulsive sound that ranges from

Physical Activities / Components	Potential Effects: Summary of Current Knowledge
	approximately 130 to 190 dB re 1 µPa at 1 m with a peak frequency range of 10 HZ to 10,000 Hz (Hildebrand 2005; OSPAR 2009; MacDonnell 2017). • Due to a range in hearing capabilities and sensitivities (Hawkins and Popper 2014), and differences in physiology, ecology and adaptation (Radford et al. 2014; Carroll et al. 2017), effects from underwater sound can vary considerably by species and/or life stage of the fish exposed to the sound, and by the intensity of sound, distance from source and other factors. • There is no direct evidence of mortality to fish as a result of continuous sound associated with drilling activities, vessel traffic and other equipment used during offshore oil and gas exploration (Popper and Hastings 2009; Popper et al. 2014). • Popper et al. (2014) proposed qualitative guidelines to describe the relative risk to marine fish of potentially experiencing mortality, hearing impairment and behavioural effects from exposure to continuous (non-impulsive) sources of underwater sound and suggests that the risk of mortality and potential mortality injury is expected to be low for all fish (including eggs and larvae) when exposed to shipping and continuous sounds even at near field (tens of metres) distances (Popper et al. 2014). • Popper et al. (2014) also suggests that temporary impairment (temporary threshold shift) could occur to fish with swim bladders involved in hearing (e.g., cod, herring) when exposed to continuous (non-impulsive) sound levels of 158 dB rms over 12 hours. • Although injury may not occur, avoidance of damaging sound levels can be a costly behaviour for mobile fish in terms of lost foraging time, increased energetic costs of transiting and interrupted feeding, and less efficient foraging in areas that are not as well known (Weilgart 2018). • Behavioural responses to sound can vary considerably amongst species and likely depend on contextual variables such as location, temperature, physiological state, age, body size and school size (Kastelein et al. 2008). Behavioural responses can include changes in foraging and feeding, reproductive, anti-predatory, migratory and/or schooling behaviour (Weilgart 2018; Popper and Hawkins 2019). Some studies have demonstrated fish attraction to vessels (Røstad et al. 2006) while others have shown avoidance (de Robertis and Handegard 2013). • Masking (i.e., drowning out of sounds of interests to animals) effects can occur, particularly if the sound is in the frequency range where fish communication takes place, thereby impeding communication in fish (Slabbekoorn et al. 2010; Radford et al. 2014; Weilgart 2018). Impairment of the ability of a fish to detect and respond to biologically relevant sounds can decrease survival and fitness of individuals and populations (Radford et al. 2014; Popper and Hawkins 2019). • In addition to producing underwater sound emissions, the drill rig will also generate underwater light emissions. Artificial light from the drill rig may result in the attraction of some fish and invertebrate species and provide increased opportunities for foraging and prey capture (Keenan et al. 2007; Cordes et al. 2016). However, light from the drill rig would be quickly attenuated by surface/wave refraction and absorption. • Depending on the design of the drill rig, it may provide a surface for colonization by invertebrates, which, along with the underwater lighting and establishment of a safety (exclusion) zone around the drill rig (excluding other marine traffic and fishing activity), may enhance foraging and shelter opportunities and result in a temporary "reef effect" (aggregation of fish) (Picken and McIntyre 1989; Fabi et al. 2004; Page et al. 2005).
Vertical Seismic Profiling (VSP)	• Seismic surveys generate short duration broadband impulse sounds with high peak source levels (220-255 dB re 1 µPa at 1 m) (Nowacek et al. 2007). • Reviews of studies on the effects of seismic sound on marine life report no direct evidence of mortality of adult fish or shellfish in response to seismic sound exposure at field operating levels (DFO 2004, Payne et al. 2009; CEF 2011; Streever et al. 2016).

Physical Activities / Components	Potential Effects: Summary of Current Knowledge
	• Seismic surveys can result in physical, physiological and/or behavioural effects on fish and invertebrates (Payne et al. 2008). • Fish with connections between the inner ear and swim bladder (e.g., herring) have increased hearing sensitivity and may be more susceptible to sound pressure (Carroll et al. 2017). Organisms that rely exclusively on particle motion to detect sound (most invertebrates) are more resilient to anthropogenic sound exposure (Morley et al. 2014). Deep water species and those lacking swim bladders may be less vulnerable to effects from seismic survey activities (Boertmann and Mosbech 2011). • Sound exposure guidelines for seismic activities for fish suggest that temporary threshold shift (TTS) may occur at over 186 dB SEL_{cum}, recoverable injuries may occur between 203 and 216 dB SEL_{cum} (or 207-213 dB_{peak}), and mortality or potential lethal injuries may occur between 207 and 219 dB SEL_{cum} (207-213 dB_{peak}) (Popper at al. 2014). • Early life stages of fish (e.g., eggs, larvae, fry), which are less mobile and unable to avoid high levels of sound pressure levels are more likely to experience physiological effects (mortality, non-lethal effects) (Dalen 2007). Popper at al. (2014) suggests that exposure of eggs and larvae to sound levels >210 dB SEL_{cum} (>207 dB_{peak}) could result in mortality and/or potential mortal injury for eggs and larvae. However, it has been suggested that mortality rates caused by exposure to seismic energy are relatively low compared to natural mortality, such that the environmental effect of seismic activity on recruitment to a fish stock would be negligible (Gausland 2003; Dalen et al. 1996). • Although there are fewer studies on the effects of seismic sound on zooplankton, it has been suggested that where seismic sound causes significant mortality to zooplankton it could have greater ramifications for ecosystem structure and health (McCauley et al. 2017). • Behavioural responses of fish to underwater sound, including seismic sound, can vary greatly among species and can include a startle response, change in swimming direction, speed or depth, change in feeding behaviour and/or temporary avoidance of the area (Engås et al. 1996; McCauley at el. 2000a, 2000b; McCauley et al. 2003; Slotte et al. 2004; Fewtrell and McCauley 2012; Løkkeborg et al. 2012). Some studies have shown no measureable behavioural change at all when fish are exposed to seismic sound source arrays (Wardle et al. 2001; Peña et al. 2013). • Most studies suggest that if behavioural effects of fish to underwater sound are brief and outside a critical period, they are not expected to result in biological or physical effects (McCauley et al. 2000a, 2000b; Dalen 2007). However, the implications of measureable displacement of fish (as demonstrated in some studies measuring catch rates) are not fully understood (Streever et al. 2016). • There remain considerable gaps in the understanding of anthropogenic sound on fish and invertebrates (Popper and Hastings 2009; Hawkins et al. 2015; Carroll et al. 2017; Hawkins and Popper 2017; Weilgart 2018; Popper and Hawkins 2019).
Well Drilling and Associated Marine Discharges	• The Offshore Waste Treatment Guidelines (NEB et al. 2010) outline minimum performance targets for the management of wastes associated with drilling and production operations in Canada's offshore areas. Waste material discharged at the concentration and manner specified in the OWTG is not expected to cause significant adverse environmental effects (NEB et al. 2010). • Water-based drilling muds (WBMs) are primarily comprised of seawater, bentonite, barite, potassium chloride, and other approved chemical additives. These components are non-toxic and not likely to result in contamination (Neff 2005, 2010; Trannum et al. 2011, Bakke et al. 2013; Purser 2015). Cuttings associated with WBM use are permitted for ocean discharge.

Physical Activities / Components	Potential Effects: Summary of Current Knowledge
	• Synthetic-based drilling muds (SBMs) or non-aqueous drilling fluids (NADFs) contain similar components as WBM, but the base is a non-aqueous (water insoluble) organic base fluid. Cuttings associated with SBM use are permitted for ocean discharge once they are treated to reduce the concentration of SBM on cuttings to an acceptable level. Studies examining effects of development drilling at various producing fields on the Grand Banks have shown SBM to have relatively low toxicity with effects confined to tens of metres from cuttings piles (Payne et al. 2006; Suncor Energy 2017; Husky Energy 2019; HMDC 2019). • When WBM and SBM cuttings are discharged into the ocean, a plume is formed which dilutes rapidly as it drifts away from the discharge point with prevailing currents. Dissolved components dilute rapidly by mixing in the water column while denser particles disperse and sink through the water column (IOGP 2016). • In general, pelagic organisms are at low risk of harm from drilling discharges primarily due to the rapid rate of dilution and dispersal in the water column (Neff et al. 2000; Neff 2010). Exposure of organisms in the water column to elevated turbidity and total suspended solids concentrations is limited to those located within the discharge plume and this exposure is intermittent and brief (IOGP 2016). • Decreased light penetration caused by turbidity of the cuttings plume may temporarily decrease primary production of phytoplankton and clog the gills or digestive tract of zooplankton (IOGP 2016). However, periodic minor increases in turbidity or suspended solids do not significantly alter the primary production or phytoplankton assemblages in the vicinity of the drill rig (Neff 2010; IOGP 2016). • Drilling waste discharges have generally been shown to have only minor effects on water quality and pelagic ecosystems (Hinwood et al. 1994). Accumulation of drill fluids and cuttings on the seafloor is the primary issue of concern for effects on fish and fish habitat. The accumulation area and thickness of drill waste deposition on the seafloor is a function of the cuttings type (use of WBM or SBM), amount of drilling mud retained on the cuttings, particle size distribution in the cuttings, and physical oceanographic profile (e.g., water depth, current speed and direction) at the discharge site (IOGP 2016). • Drill cuttings discharges cause physical and chemical changes to the benthic environment and can result in the following effects: burial/smothering of benthic fauna; short-term elevations in suspended particulate matter and turbidity; changes in benthic topography and sediment grain size; direct toxicity; oxygen depletion; and sediment organic enrichment (Hurley and Ellis 2004; Smit et al. 2006, 2008; Neff 2010; Trannum et al. 2010; Gates and Jones 2012; IOGP 2016).In some cases, these changes can lead to changes in benthic macrofaunal distribution (Denoyelle et al. 2010). • Effects associated with sediment burial depend on mobility of the organism and the frequency and rate of depth of cuttings deposition (IOGP 2016). Sediment burial thresholds for benthic species can range from <1 cm to >50 cm (Kjelen-Eilertsen et al. 2004; Smit et al. 2006, 2008) depending on the taxon, size, and mobility of the organism. • Infaunal organisms with limited mobility to avoid exposure, and in particular, suspension feeding marine invertebrates, are more susceptible to effects from drilling discharges (Armsworthy et al. 2005; Cranford et al. 1999; Neff 2010). • Exposure to low concentrations of WBM has not shown to be toxic to sea scallops, polychaetes, amphipods, shrimp and various other fish species (Cranford et al. 1999; Neff 2010) although exposure to high concentrations of WBM (beyond what would be experienced in field conditions) over 96 hours to 68 days has shown sublethal effects (e.g., reduced growth rates and altered foraging behaviours) to crustaceans, scallops and haddock (Cranford et al. 1999; Neff 2010).

Physical Activities / Components	Potential Effects: Summary of Current Knowledge
	• As suspension feeding invertebrates, sponges and corals are considered sensitive to suspended sediments and WBM exposure (Neff 2010; Buhl-Mortensen et al. 2015; Edge et al. 2016; Ragnarsson et al. 2017). Some species of corals have been shown to have higher tolerance to sedimentation and drilling deposition (Gates and Jones 2012; Allers et al. 2013; Purser 2015), although sediment load and duration of discharge have been found to be important factors in the degree of disturbance of corals and sponges (Allers et al. 2013; DNV 2013; Edge et al. 2016). • Physical disturbance and discharge of drilling muds has been shown to decrease diversity and density of organisms associated with structure-forming deep sea sponges at a community level (Vad et al. 2018). • Several years of environmental effects monitoring of production projects on the Grand Banks of Newfoundland (Terra Nova, Hibernia, White Rose) have shown localized changes in sediment chemistry and grain size but found little to no evidence of sediment toxicity from drill waste discharges, and no effects on fisheries resources, as indicated by fish health assessment and taint tests (Suncor Energy 2017; Husky Energy 2019; HMDC 2019). • In general, concentrations of barium (a primary component of drilling muds) have decreased to background levels within 1000 and 3000 m from the platforms and concentrations of elevated hydrocarbon concentrations have decreased to background levels between 1000 and 5800 m from the platforms (HMDC 2019; Suncor Energy 2017; Husky Energy 2019). Biological effects, including changes in community composition, have been documented from 250 to 2000 m (Ellis et al. 2012). • The area of detection and scale of biological effects resulting from discharged SBMs were smaller, with maximum concentrations of synthetic tracers in sediment detected at distances ranging from 100 to 2000 m from the discharge location. Biological effects associated with the release of SBM cuttings were generally detected at distances of 50 to 500 m from well sites (Ellis et al. 2012; Suncor Energy 2017). • Visual surveys conducted using remotely operated vehicles after single exploration wells offshore Nova Scotia verified the zone of drill waste deposition to be generally consistent with predictive modelling, with the greatest evidence of deposition observed within 30 m (Stantec 2019) to 75 m (Stantec 2017) from the wellhead. Evidence of sediment deposition was observed out to approximately 325 m from the wellhead (Stantec 2019) and the distribution, species types, and relative numbers of macrofauna observed during post-drill surveys were similar to those observed during pre-drill surveys (Stantec 2016, 2017, 2019). • Recovery of areas of biological effect from drill cuttings can vary considerably and is influenced by the size and frequency of the disturbance (including whether cuttings piles accumulated), distance to source colonizers, and local environmental conditions (Gates and Jones 2012; Henry et al. 2017). • In some cases, abundance and species richness of bottom-dwelling fish were elevated immediately after drilling in the area where sediments were completely covered by drill cuttings, with a decrease observed to pre-drilling levels observed as the thickness of the cuttings layer decreased over time (Jones et al. 2012). • In most cases there is substantial recovery in the megabenthic community within one to four years after the discharge (Neff et al. 2000; Hurley and Ellis 2004; Jones et al. 2012; Ellis et al. 2012; Tait et al. 2016; IOGP 2016). • Less is known about the timeline for recolonization by benthic communities in deep-water environments; benthic recovery is generally expected to take longer at greater depths and in colder waters due to lower rates of metabolism and growth (Gates and Jones 2012; Cordes et al. 2016; Henry et al. 2017).

Physical Activities / Components	Potential Effects: Summary of Current Knowledge
Well Evaluation and Testing	• During formation flow testing, produced water may be discharged in small volumes (if not sent to the flare for disposal). • Water quality monitoring of produced water discharges at the Sable Offshore Energy Project (SOEP) found produced water was highly diluted within 5 m of the discharge caisson and no toxic results were observed in water column samples collected adjacent to the platform (CNSOPB 2018a). As a natural gas production project, SOEP generates less produced water and oil-in-produced water than the production of crude oil (CNSOPB 2018a) so although still an over-representation of the volumes of produced water that may be discharged during well evaluation and testing for an exploration drilling program, these environmental effects monitoring results are more applicable than those from other east coast operations.
Supply and Servicing (Vessel and Helicopter Use)	• Supply vessels will generate transitory light and sound emissions and marine discharges (e.g., deck drainage, grey/black water). • Refer to *Presence and Operation of Drill Rig* above for a general discussion of effects of continuous underwater sound emissions and light on marine fish. • There is no direct evidence of mortality to fish as a result of continuous sound associated with vessel traffic and other equipment used during offshore oil and gas exploration (Popper and Hastings 2009; Popper et al. 2014). • Studies on the effects of research vessels on marine fish have shown both attraction and avoidance behaviour to steaming and anchored vessels (Skarat et al. 2005; Røstad et al. 2006; de Robertis and Handegard 2013). • The responses and reaction thresholds of fish to vessels may vary among species and be overridden by reproductive (e.g., spawning) or other activities the fish may be engaging in at the time (Skaret et al. 2005). • Marine discharges from supply vessels would be in accordance with regulatory requirements and would be diluted rapidly in the ocean. For information on effects of oil on marine fish (which could potentially result from an unauthorized discharge), refer to *Oil Spills* below.
Well Abandonment or Suspension	• If the wellhead is removed using mechanical means (e.g., cutting), light and sound emissions from equipment may cause temporary, localized effects on fish that may be present, resulting in avoidance, attraction or no reaction from individuals (Raymond and Widder 2007). • If a mechanical cutter cannot be used, an explosive charge may be used to sever the wellhead from the seabed. Depending on the water depth and the size of the explosive charge, this could result in mortality of fish, with the risk of fish mortality decreasing with water depth of the wellhead. • Mortality of fish from explosive removal of structures has been reported as occurring at minimum radii of 12 m to 349 m with most mortality observed within 24 m to 50 m of the wellhead (Continental Shelf Associates 2003); fish without swim bladders are less vulnerable to shock wave impacts at distance (Goertner et al. 1994; Continental Shelf Associates 2003). • If the wellhead is left in place after the well is decommissioned, the structure may serve as a hard substrate on which corals, sponges, or other invertebrates may colonize (Cordes et al. 2016; Gates et al. 2017).

7.3 Unplanned Events

The accidental release of hydrocarbons or other materials into the environment has the potential to adversely affect marine fish and fish habitat in offshore and potentially nearshore areas. This can interact with and potentially affect marine fish and fish habitat in terms of habitat and food availability and quality, fish mortality, injury and health, and fish presence and abundance. The nature, magnitude, extent, duration and reversibility of potential effects of an accidental release of hydrocarbons in the marine environment on marine fish and fish habitat are largely dependent on a variety of biotic (species, life history, behaviour, resistance) and abiotic (oceanographic conditions, exposure duration, oil type, oil treatment methods) factors.

In the event of an offshore oil release, adverse effects to marine fish and fish habitat in the area at the time of the accident or malfunction are expected. Interactions with hydrocarbons would result in sublethal and lethal mortality on fish and invertebrates depending on the species-specific responses and degree of interaction. This may also may result in a decline in food availability and quality with implications for higher trophic levels. For the duration of any accidental offshore oil release, there would be reductions in availability or quality of affected marine habitats. The eventual break down of oil material in the water column and surface may become transported to benthic habitats through sinking and flocculation, and would result in contamination of subsurface environments and potential hydrocarbon interactions with sensitive coral and sponge species.

Table 7.4 summarizes current information and knowledge from the literature and other sources on the nature and degree of the potential effects of accidental events on marine fish and fish habitat.

Table 7.4 Potential Effects on Marine Fish and Fish Habitat: Summary of Current Knowledge (Unplanned Events)

Potential Accidental Event	Potential Environmental Effects: Summary of Current Knowledge
Oil Spills (Batch Spills and Blowouts)	• Oil spills can cause lethal and sublethal effects to marine fish from acute or chronic exposure to water-soluble fractions of hydrocarbons (Carls et al. 2008 Incardona et al. 2014; Lee et al. 2015; Buskey et al. 2016). • Risk of exposure of fish and invertebrates to an oil spill depends on the type of oil and volume released, the habitat affected, time of year, species physiology and life history, and general health of the stock at the time of the spill (Lee et al. 2015). • Fish (including eggs and larvae) are primarily affected by the dissolved concentrations of hydrocarbons in the water (French-McCay 2009). Pathways for exposure include respiratory uptake, direct contact, diet, or maternal transfer to eggs (Lee et al. 2015). • Fish are typically at risk from acute oil exposure within 24-48 hours following an oil spill (Lee et al. 2015). Fish kills are relatively brief and localized due to the rapid loss of low-molecular weight components of oil due to dilution and weathering (Lee et al. 2015). • Exposure of phytoplankton to oil may result in altered productivity and growth and in some cases lead to a change in community composition and increased biomass (Abbriano et al. 2011; Buskey et al. 2016). • Laboratory studies have shown lethal and sublethal (e.g., physiological, feeding fecundity, behavioural responses) effects on zooplankton (Seuront 2010; Almeda et al. 2013) from exposure to hydrocarbons. However, in most historical spills, zooplankton have demonstrated rapid recovery, likely due to short generation times and high fecundity, their ability (albeit limited) to avoid oily patches, and their recruitment from unaffected areas (Seuront 2010; Abbriano et al. 2011). • Early development stages of fish and invertebrates are more sensitive to oil than adult stages (Dupuis and Ucan-Marin 2015; Lee et al. 2015; Vikebø et al. 2015; Incardona et al. 2004, 2014). Ichthyoplankton have limited avoidance abilities and can experience

Potential Accidental Event	Potential Environmental Effects: Summary of Current Knowledge
	lethal and sublethal effects (e.g., cardiotoxicity, deformities) from exposure, although these effects may not necessarily result in population-level negative effects on larval or adult populations (Ransom et al. 2016; Carroll et al. 2018). • Phytoplankton and zooplankton play an important role in the sinking and sedimentation oil through the secretion of polymers that aggregate particulate and dissolved organic material into flocs called marine snow which then sinks to the seabed (Azam and Malfatti 2007; Passow 2012. Oiled marine snow was implicated in impacts on mesophotic and deep-sea coral communities after the Deepwater Horizon oil spill in the Gulf of Mexico (Cordes et al. 2016). • Oil spills can have long-term impacts on deep-sea benthic organisms when hydrocarbon and dispersants enter the sediments (Vad et al. 2018). Risk of exposure can be moderate to high depending on their motility and use of contaminated sediments (Yender et al. 2002). Benthic invertebrates and deepwater fish species generally have lower metabolisms, are slower growing, have longer life spans, and are therefore more susceptible to disturbances such as oil spills (Cordes et al. 2016). • Chemical dispersants break up oil slicks into very small oil droplets, promoting accelerated microbial degradation of the spilled oil. However, this can increase exposure of oil components to marine biota in the water column and the benthos (Lee et al. 2015; Cordes et al. 2016). • Although dispersants have been shown to have limited effects on oil exposure rates of fish eggs and larvae (Vikebø et al. 2015), chemically-dispersed oil has been reported to reduce larval settlement, cause abnormal development, and produce tissue degeneration in sessile invertebrates such as corals and sponges (Cordes et al. 2016).
Drill Fluids (SBM) Spills	• SBM is a dense, low toxicity fluid which sinks rapidly through the water column (Neff et al. 2000; CNSOPB 2005, 2018b). • Effects on marine fish and benthos would be similar to that describe above for Drilling and Associated Marine Discharges.

7.4 References

Abbriano, R.M., M.M. Carranza, S.L. Hogle, R.A. Levin, A.N. Netburn, K.L. Seto, S.M. Snyder and P.J.S. Franks. 2011. Deepwater Horizon oil spill: A review of the planktonic response. Oceanography 24(3): 294-301.

Allers, E., Abed, R.M.M., Wehrmann, L.M., Wang, T., Larsson, A.I., Purser, A. and D. de Beer (2013). Resistance of *Lophelia pertusa* to coverage by sediment and petroleum drill cuttings. Marine Pollution Bulletin, 74(2013): 132-140.

Almeda R, Wambaugh Z, Chai C, Wang Z, Liu Z, and E.J. Buskey. (2013) Effects of Crude Oil Exposure on Bioaccumulation of Polycyclic Aromatic Hydrocarbons and Survival of Adult and Larval Stages of Gelatinous Zooplankton. PLOS ONE 8(10): e74476. https://doi.org/10.1371/journal.pone.0074476.

Armsworthy, P.J. Cranford, P.H., Lee, K. and T.L. King. (2005) Chronic effects of synthetic drilling mud on sea scallops (Placopecten magellanicus). In: Armsworthy, P.J. Cranford, P., Lee, K. and T.L. King (eds). Offshore oil and gas environmental effects monitoring: approaches and technologies. Battelle Press.

Azam, F. and F. Malfatti. (2007) Microbial structuring of marine ecosystems. Nat Rev Micro 5:782-791.

Bakke, T., Klungsøyr, J. and S. Sanni (2013). Environmental impacts of produced water and drilling waste discharges from the Norwegian offshore petroleum industry. Marine Environmental Research, 92(2013): 154-169.

Boertmann, D. and A. Mosbech (eds.) 2011. The western Greenland Sea, a strategic environmental impact assessment of hydrocarbon activities. Aarhus University, DCE – Danish Centre for Environment and Energy, 268 pp. - Scientific Report from DCE – Danish Centre for Environment and Energy no. 22.

Buhl-Mortensen, P., Tenningen, E. 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.

Buskey, E.J., H.K. White, and A.J. Esbaugh. 2016. Impact of oil spills on marine life in the Gulf of Mexico: Effects on plankton, nekton, and deep-sea benthos.Oceanography 29(3):174–181

Carls, M.G., L. Holland, M. Larsen, T.K. Collier, N.L. Scholz and J.P. Incardona. (2008). Fish embryos are damaged by dissolved PAHs, not oil particles. Aquatic Toxicology 88(2):121-127.

Carroll, A.G., Przeslawski, R., Duncan, A., Gunning, M. and B. Bruce (2017). A critical review of the potential impacts of marine seismic surveys on fish & invertebrates. Marine Pollution Bulletin, 114(2017): 9-24.

Carroll, J., Vikebø, F., and D. Howell. (2018). Assessing impacts of simulated oil spills on the Northeast Arctic cod fishery. Mar Poll Bull 126:63-73.

CEF Consultants Ltd. (2011). Report on a Workshop on Fish Behaviour in Response to Seismic Sound held in Halifax, Nova Scotia, Canada, March 28-31, 2011, Environmental Studies Research Funds Report No. 190. Halifax, 109 p.

Clark, M.R., Althaus, F., Schlacher, T.A., Williams, A., Bowden, D.A. and A.R. Rowden (2016). The impacts of deep-sea fisheries on benthic communities: a review. ICES Journal of Marine Science, 73(Supplement 1): 51-69.

CNSOPB (Canada-Nova Scotia Offshore Petroleum Board). (2005). Investigation Report. Discharge of Synthetic Based Mud During Abandonment of the Crimson F-81 Exploration Well by Marathon Canada Petroleum ULC. Available at: https://www.cnsopb.ns.ca/sites/default/files/pdfs/Marathon_Report.pdf

CNSOPB (Canada-Nova Scotia Offshore Petroleum Board). (2018a). A Synopsis of Nova Scotia's Offshore Oil and Gas Environmental Effects Monitoring Programs. Summary Report. Updated May 2018. Available at: https://www.cnsopb.ns.ca/sites/default/files/pdfs/2018_Update_EEM_Summary_0.pdf

CNSOPB (Canada-Nova Scotia Offshore Petroleum Board). (2018b). Incident Bulletin. June 22,2018. Unauthorized Discharge of Drilling Mud. Available at: https://www.cnsopb.ns.ca/media/incident-bulletins.

Continental Shelf Associates (2003) Explosive Removal of Offshore Structures. Information Synthesis Report OCS Study MMS 2003-070.

Cordes, E.E., Jones, D.O.B., Schlacher, T.A., Amon, D.J., Bernardino, A.F., Brooke, S., Carney, R., DeLeo, D.M., Dunlop, K.M., Escobar-Briones, E.G., Gates, A.R., Génio, L., Gobin, J., Henry, L., Herrera, S., Hoyt, S., Joye, M., Kark, S., Mestre, N.C., Metaxas, A., Pfeifer, S., Sink, K., Sweetman, A.K. and U. Witte (2016). Environmental impacts of the deep-water oil and gas industry: A review to guide management strategies. Frontiers in Environmental Science, 4: 1-26.

Cranford, P.J., Gordon Jr, D.C., Lee, K., Armsworthy, S.L. and G.H. Tremblay (1999). Chronic toxicity and physical disturbance effects of water-and oil-based drilling fluids and some major constituents on adult sea scallops (*Placopecten magellanicus*). Marine Environmental Research, 48(3): 225-256.

Dalen, J. (2007). Effects of seismic surveys on fish, fish catches and sea mammals. Det Norse Veritas (DNV). Report for the Cooperation Group – Fishery Industry and Petroleum Industry Report No. 2007-0512.

Dalen, J., Ona, E., Vold Soldal, A. og Sætre, R. 1996. Seismiske undersøkeleser til havs: En vurdering av konsekvenser for fisk og fiskerier. Fisken og Havet, nr. 9 – 1996. 26 s.

Denoyelle, M., Jorissen, F.J., Martin, D., Galgani, F. and J. Miné. (2010). Comparison of benthic foraminifera and macrofaunal indicators of the impact of oil-based drill mud disposal. Mar. Poll. Bull. 60:2007-2021.

De Robertis, A. and N.O. Handegard (2013). Fish avoidance of research vessels and the efficacy of noise-reduced vessels: a review. ICES Journal of Marine Sciences, 70(1): 34-45.

DFO (Fisheries and Oceans Canada) (2004). Review of Scientific Information on Impacts of Seismic Sound on Fish, Invertebrates, Marine Turtles and Marine Mammals. Habitat Status Report 2004/002, September 2004.

DNV (Det Norske Veritas) (2013) Monitoring of drilling activities in areas with presence of cold water corals. Prepared for Norsk Olje og Gass. Project No. EP021626.

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. Adv. Sec. Res. Doc. 2015/07. vi + 52 p.

Edge, K.J., Johnston, E.L., Dafforn, K.A., Simpson, S.L., Kutti, T. and R.J. Bannister. (2016). Sublethal effects of water-based drilling muds on the deep-water sponge Geodia barretti. Environmental Pollution, 212: 525-534.

Ellis, J.I., Fraser, G. and Russell (2012). Discharged drilling waste from oil and gas platforms and its effects on benthic communities. Marine Ecology Progress Series, 456, 285-302.

Engås, A, Løkkeborg, S, Ona, E. and A.V. Soldal (1996). Effects of seismic shooting on local abundance and catch rates of cod (*G. morhua*) and haddock (*M. aeglefinus*). Canadian Journal of Fisheries and Aquatic Sciences, 53(10):2238-2249.

Fabi, G., Grati, F., Pulett, M. and G. Scarcella (2004). Effects on fish community induced by installation of two gas platforms in the Adriatic Sea. Mar Ecol. Prog. Ser. 273:187-197.

Fewtrell, J.L. and R.D. McCauley. (2012). Impact of air gun noise on the behaviour of marine fish and squid. Mar. Poll. Bull. 64:984-993.

French-McCay, D.P. 2009. State-of-the-art and research needs for oil spill impact assessment modeling. pp. 601-653. In: Proceedings of the 32nd AMOP Technical Seminar on Environmental Contamination and Response, Emergencies Science Division, Environment Canada, Ottawa, ON. Available at: http://www.asascience.com/about/publications/pdf/2009/FrenchMcCay_AMOP09-biomodel-with-cite.pdf.

Gates, A.R. and D.O.B. Jones (2012). Recovery of benthic megafauna from anthropogenic disturbance at a hydrocarbon drilling well (380m depth in the Norwegian Sea). PLOS One, 7(10).

Gates, A. R., Benfield, M. C., Booth, D. J., Fowler, A. M., Skropeta, D. & Jones, D. O.B. (2017). Deep-sea observations at hydrocarbon drilling locations: contributions from the SERPENT Project after 120 field visits. Deep-Sea Research Part II: Topical Studies in Oceanography, 137 463-479.

Gausland, I. (2003) Seismic Surveys Impact on Fish and Fisheries. Norwegian Oil Industry Association (OLF). Stavanger. March 2003.

Goertner, J.F., Wiley, M.L., Young, G.A. and W. W. McDonald. (1994) Effects of Underwater Explosions on Fish Without Swimbladders. Naval Surface Warfare Center. Weapons Research and Technology Department. February 1994.

Hawkins, A.D. and A.N. Popper (2014). Assessing the impacts of underwater sounds on fishes and other forms of marine life. Acoustics Today ,10: 30–41.

Hawkins, A.D. and A.N. Popper (2017). A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. ICES Journal of Marine Science 74(3):635-651.

Hawkins, A.D., Pembroke, A.E. and A.N. Popper (2015). Information gaps in understanding the effects of noise on fishes and invertebrates. Reviews in Fish Biology and Fisheries, 25: 39-64.

Henry, L.A., Harries, D., Kingston, P. and J.M. Roberts (2017). Historic scale and persistence of drill cuttings impacts on North Sea benthos. Mar Env Res 129:219-228.

Hildebrand, J.A (2005). Impacts of anthropogenic sound. In: Reynolds, J.E., Perrin, W.F., Reeves, R.R., Montgomery, S., and Ragen, T.J (eds.). Marine Mammal Research: Conservation Beyond Crisis. John Hopkins University Press, Baltimore, Maryland. pp.101-124.

Hinwood, J.B., Potts, A.E., Dennis, L.R., Carey, J.M., Houridis, H., Bell, R.J., Thomson, J.R., Boudreau, P., and A.M. Ayling (1994). Environmental implications of offshore oil and gas development in Australia-Drilling Activities. In: Swan, J.M, Neff, J.M. and P.C. Young (eds). Environmental Implications of Offshore Oil and Gas Development in Australia – Findings of an Independent Scientific Review. Pp. 124-207.

HMDC (Hibernia Management Development Company). 2019. Hibernia Platform (Year 10) and Hibernia Southern Extension (Year 3) Environmental Effects Monitoring Program (2016). Volume 1 – Interpretation. April 2019.

Hurley, G. and J. Ellis (2004). Environmental effects of exploratory drilling offshore Canada: environmental effects monitoring data and literature review: final report.

Husky Energy (2019). White Rose Environmental Effects Monitoring Program 2016. January 2019.

Incardona, J.P., T.K. Collier and N.L. Scholz. 2004. Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. Toxicology and Applied Pharmacology, 196: 191-205.

Incardona, J.P., L.D. Gardner, T.L. Linbo, T.L. Brown, A.J. Esbaugh, E.M. Mager, J.D. Stieglitz, B.L. French, J.S. Labenia, C.A. Laetz, M. Tagal, C.A. Sloan, A. Elizur, D.D. Benetti, M. Grosell, B.A. Block and N.L. Scholz. 2014. Deepwater Horizon crude oil impacts the developing hearts of large predatory pelagic fish. Proc. Natl. Acad. Sci. U.S.A.

IOGP (International Association of Oil and Gas Producers) (2016). Environmental Fate and Effects Of Ocean Discharge Of Drill Cuttings and Associated Drilling Fluids From Offshore Oil and Gas Operations. IOGP Report 543.

Jones, D.O.B., Gates, A.R. and B. Lausen (2012). Recovery of deep-water megafaunal assemblages from hydrocarbon drilling disturbance in the Faroe-Shetland Channel. Marine Ecology Progress Series, 461: 71-82.

Kastelein, R.A., Heul, S.V., Verboom, W.C., Jennings, N., Veen, J.V., and D. de Haan. (2008). Startle response of captive North Sea fish species to underwater tones between 0.1 and 64 kHz. Mar Eviron Res 65(5):369-77.

Keenan, S.F., Benfield, M.C. and J.K. Blackburn (2007). Importance of the artificial light field around offshore petroleum platforms for the associated fish community. Marine Ecology Progress Series, 331: 219-231.

Kjeilen-Eilertsen, G., H. Trannum, R.J. Niva, Mathijs, S., Neff, J. and G. Durell. (2004) Literature report on burial: derivation of PNEC as component in the MEMW model tool. Environmental Risk Management System Report 09B.

Lee, K., Boufadel, M. Chen, B., Foght, J. Hodson, P. Swanson, S. and A. Venosa. (2015). Expert Panel Report on the Behaviour and Environmental Impacts of Crude Oil Released into Aqueous Environments. Royal Society of Canada, Ottawa, ON. ISBN: 978-1-928140-02-3.

Løkkeborg, S., Ona, E., Vold, A. and A. Salthaug. 2012. Sounds from seismic air guns: gear-and species-specific effects on catch rates and fish distribution. Canadian Journal of Fisheries and Aquatic Sciences, 69(8): 1278-1291.

MacDonnell, J. 2017. Shelburne Basin Venture Exploration Drilling Project: Sound Source Characterization, 2016 Field Measurements of the Stena IceMAX. Document 01296, Version 3.0. Technical Report by JASCO Applied Sciences for Shell Canada Limited.

McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, C., Jenner, M.-N., Penrose, J.D. and K. McCabe (2000a). Marine seismic surveys: Analysis of airgun signals; and effects of air gun exposure on humpback whales, sea turtles, fishes and squid (Report prepared for Australian Petroleum Production Association, Sydney, Australia). Perth, Australia: Centre for Marine Science and Technology, Curtin University.

McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, M.-N., Jenner, C., Prince, R.I.T. and J. Murdoch (2000b). Marine seismic surveys - a study of environmental implications. APPEA (Australian Petroleum Production and Exploration Association) Journal, 40: 692-708.

McCauley, R.D., Fewtrell, J., Duncan, A.J., Jenner, M.-N., Jenner, C., Prince, R.I.T. and A.N. Popper (2003). High intensity anthropogenic sound damages fish ears. Journal of the Acoustical Society of America, 113(1): 638-642.

McCauley, R., Day, R. D., Swadling, K. M., Fitzgibbon, Q. P., Watson, R. A. and J.M. Semmens. (2017). Widely used marine seismic survey air gun operations negatively impact zooplankton. Nature Ecology and Evolution, 1: 1-8.

Morley, E.L., Jones, G. and A.N. Radford. (2014). The importance of invertebrates when considering the impacts of anthropogenic noise. In Proc. R. Soc. B (Vol. 281, No. 1776, p. 20132683). The Royal Society.

Neff, J.M. (2005). Composition, Environmental Fates, and Biological Effect of Water Based Drilling Muds and Cuttings Discharged to the Marine Environment: A Synthesis and Annotated Bibliography. Submitted to Petroleum Environmental Research Form and American Petroleum Institute.

Neff, J.M. (2010). Fate and effects of water based drilling muds and cuttings in cold water environments. Houston (TX): Report to Shell Exploration and Production Company.

Neff, J.M., McKelvie, S. and R.C. Ayers Jr. (2000). Environmental impacts of synthetic based drilling fluids. Report prepared for MMS by Robert Ayers & Associates, Inc. August 2000. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2000-064.

Nowacek, D.P., Thorne, L.H., Johnston, D.W., and P.L. Tyack (2007). Responses of cetaceans to anthropogenic noise. Mammal Rev., 37: 81-115.

OSPAR (OSPAR Commission) (2009). Overview of the Impacts of Anthropogenic Underwater Sound in the Marine Environment. Publication number 441/2009. 134pp. Available from: http://qsr2010.ospar.org/media/assessments/p00441_Noise_background_document.pdf.

Page, H. M., J. Dugan, and J. Childress. Role of food subsidies and habitat structure in influencing benthic communities of shell mounds at sites of existing and former offshore oil platforms. MMS OCS Study 2005-001. Coastal Research Center, Marine Science Institute, University of California, Santa Barbara, California. MMS Cooperative Agreement Number 14-35-0001-31063. 32 pages.

Passow, U., Ziervogel, K., Asper, V. and A. Diercks (2012). Marine snow formation in the aftermath of the Deepwater Horizon oil spill in the Gulf of Mexico. Environmental Research Letters, 7(3), 035301.

Payne, J.F. Andrews, C., Guiney, J. and S. Whiteway (2006). Risks associated with drilling fluids at petroleum development sites in the offshore: Evaluation of the potential for an aliphatic hydrocarbon based drilling fluid to produce sedimentary toxicity and for barite to be acutely toxic to plankton. Canadian Technical Report in Fisheries and Aquatic Sciences. 2679: 28 p.

Payne, J.F., Coady, J. and D. White (2009). Potential effects of seismic airgun discharges on monkfish eggs (*Lophius americanus*) and larvae. Environmental Studies Research Funds Report No. 170, St. John's, NL. 32p.

Payne, J. F. Andrews, C., Fancey, L., White, D. and J. Christian (2008). Potential Effects of Seismic Energy on Fish and Shellfish: An Update Since 2003. Canadian Science Advisory Secretariat Research Document 2008/060.

Peña, H., Handegard, N.O. and E. Ona (2013). Feeding herring schools do not react to seismic air gun surveys. – ICES Journal of Marine Science, doi.10.1093/icesjms/fst079.

Picken, G. B. and A.D. McIntyre (1989). Rigs to reefs in the North Sea. Bulletin of Marine Science, 44(2): 782-788.

Popper, A.N. and M.C. Hastings (2009). The effects of human-generated sound on fish. Integrative Zoology, 4: 43-52.

Popper, A.N. and A.D. Hawkins (2019). An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. Journal of Fish Biology. 2019 May;94(5):692-713.

Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D., Bartol, S., Carlson, T., Coombs, S., Ellison, W.T., Gentry, R., Halvorsen, M.B., Løkkeberg, S., Rogers, P., Southall, B.L., Zeddies, D. and W.N. Tavolga (2014). Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI," ASA S3/SC1.4 TR-2014. Springer and ASA Press, Cham, Switzerland (2014)

Purser, A. (2015). A time series study of *Lophelia pertusa* and reef megafauna response to drill cuttings exposure on the Norwegian margin. PLOS One, 10(7).

Radford, A.N., Kerridge, E. and S.D. Simpson (2014) Acoustic communication in a noisy world: can fish compete with anthropogenic noise. Behavioural Ecology 25: 1022-1030.

Ragnarsson, S.Á., Burgos, J.M., Kutti, T., van den Beld, I., Egilsdóttir, H., Arnaud-Haond, S. and A. Grehan (2017). The Impact of Anthropogenic Activity on Cold-Water Corals. Marine Animal Forests: The Ecology of Benthic Biodiversity Hotspots, 1-35.

Ransom, J.T., Filbrun, J.E., and F.J. Hernandez (2016). Condition of larval Spanish mackerel *Scomberomorus maculatus* in relation to the Deepwater Horizon oil spill. Marine Ecology Progress Series, 558, 143-152.

Raymond, E.H. and E.A. Widder (2007). Behavioural responses of two deep-sea fish species to red, far-red and white light. Marine Ecology Progress Series, 350: 291-298.

Røstad, A., Kaartvedt, S., Klejvar, T.A. and W. Melle (2006). Fish are attracted to vessels. ICES Journal of Marine Science, 63: 1431-1437.

Seuront, L. 2010. Zooplankton avoidance behaviour as a response to point sources of hydrocarbon contaminated water. Mar. Freshw. Res., 61(3): 263-270.

Skaret, G., Axelsen, B. E., Nøttestad, L., Ferno¨, A., and Johannessen, A. 2005. The behaviour of spawning herring in relation to a survey vessel. e ICES Journal of Marine Science, 62: 1061e1064.

Slabbekoorn, H., Bouton, N., van Opzeeland, I., Coers, A., Cate, C. and A.N. Popper (2010). A noisy spring: the impact of globally rising underwater sound levels on fish. Trends Ecology and Evolution, 25: 419-427. (doi:10. 1016/j.tree.2010.04.005.

Slotte, A., Hansen, K., Dalen, J. and E. Ona (2004). Acoustic mapping of pelagic fish distribution and abundance in relation to a seismic shooting area off the Norwegian coast. Fisheries Research, 67: 143-150.

Smit, M.G.D., Tamis, J.E., Jak, R.G, Karman, C.C., Kjeilen-Eilertsen, H., Trannum, H. and J. Neff (2006). Threshold levels and risk functions for non-toxic sediment stressors: burial, grain size changes and hypoxia. Summary. ERMS Report no. 9.

Smit, M.G.D., Holthaus, K.I.E., Trannum, H.C., Neff, J.M., Kjeilen-Eilertsen, G., Jak, R.G., Singsaas, I., Huiihbregts, M.A.J. and A.J. Hendriks (2008). Species sensitivity distributions for suspended clays, sediment burial and grain size change in the marine environment. Environmental Toxicology and Chemistry, 27(4): 1006-1012.

Stantec (Stantec Consulting Ltd.). (2016) Final Report: Shelburne Basin Venture Exploration Drilling Project: Cheshire L-97A Sediment Deposition Survey Report. File No. 121511210. Prepared for Shell Canada Limited. December 2016.

Stantec (Stantec Consulting Ltd.). (2017) Final Report: Shelburne Basin Venture Exploration Drilling Project: Monterey Jack E43-A Sediment Deposition Survey Report. File No. 121511210. Prepared for Shell Canada Limited. April 2017.

Stantec (Stantec Consulting Ltd.). (2019) Final Report: Scotian Basin Exploration Drilling Project: Aspy D-11A Sediment Deposition Survey Report. File No. 121413516. Prepared for BP Canada Energy Group ULC. February 2019.

Streever, B., Raborn, S.W., Kim, K.H., Hawkins, A.D. and A.N. Popper. (2016). Changes in fish catch rates in the presence of air gun sounds in Prudoe Bay, Alaska. Arctic 69(4):346-358.

Suncor Energy. 2017. Terra Nova 2014 Environmental Effects Monitoring Program Year 9. Final Revised Submission December 2017.

Tait, R.D., Maxon, C.L., Parr, T.D. and F.C. Newton III (2016). Benthos Response following petroleum exploration in the southern Caspian Sea: Relating effects of nonaqueous drilling fluid, water depth and dissolved oxygen. Marine Pollution Bulletin, 110(2016): 520-527.

Trannum, H.C., Nilsson, H.C., Schaanning, M.T. and S. Øxnevad (2010). Effects of sedimentation from water based drill cuttings and natural sediment on benthic macrofaunal community structure and ecosystem processes. Journal of Experimental Biology and Ecology, 383 (2010): 111-121.

Trannum, H.C., Nilsson, H.C., Schaanning, M.T. and K. Norling (2011). Biological and biogeochemical effects of organic matter and drilling discharges in two sediment communities. Marine Ecology Progress Series, 442: 23-36.

Vad, J., G. Kazandis, Henry, L.A., Jones, D.O.B., Tendal, O.S., Christiansen, S., Henry, T.B., and J.M. Roberts. (2018). Potential impacts of offshore oil and gas activities on deep-sea sponges and the habitats they form. Advances in Marine Biology. 79:33-60.

Vikebø, F.B., Rønningen, P., Meier, S., Grøsvik, B.E., and V.S. Lien. (2015). Dispersants have limited effects on exposure rates of oil spills on fish eggs and larvae in shelf seas. Environ Sci Technol 49(10):6061-9.

Wardle, C.S., Carter, T.J., Urquhart, G.G., Johnstone, A.D.F., Ziolkowski, A.M., Hampson, G. and D. Mackie (2001). Effects of seismic air guns on marine fish. Continental Shelf Research, 21(8-10): 1005-1027.

Weilgart, L. (2018). The Impact of Ocean Noise Pollution on Fish and Invertebrates. OceanCare and Dalhousie University. Available at: https://www.oceancare.org/wp-content/uploads/2017/10/OceanNoise_FishInvertebrates_May2018.pdf

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