4.0 Exploration/Production Activities and Associated Environmental Effects

This section describes typical oil and gas industry offshore activities, and then discusses the potential effects of these routine activities on the various VECs. Offshore activities can be categorized for discussion purposes into three phases: exploration; production; and decommissioning. This section first describes the main attributes of each phase and then describes some of the more detailed aspects, including those activities that are common to all phases (e.g., supply vessel traffic).

4.1 Exploration Phase

Offshore exploration activities that have been conducted in Newfoundland and Labrador waters include:

- Towed seismic surveys (2-D and 3-D);
- Controlled source electromagnetic surveys (CSEM; also known as resistivity mapping);
- Geohazard surveys ;
- Vertical seismic profiling (VSP); and
- Exploration and delineation drilling.

In addition to the above, on-bottom-cable (OBC) seismic surveys, that are used in very shallow water, and aeromagnetic surveys by aircraft may be conducted during exploration.

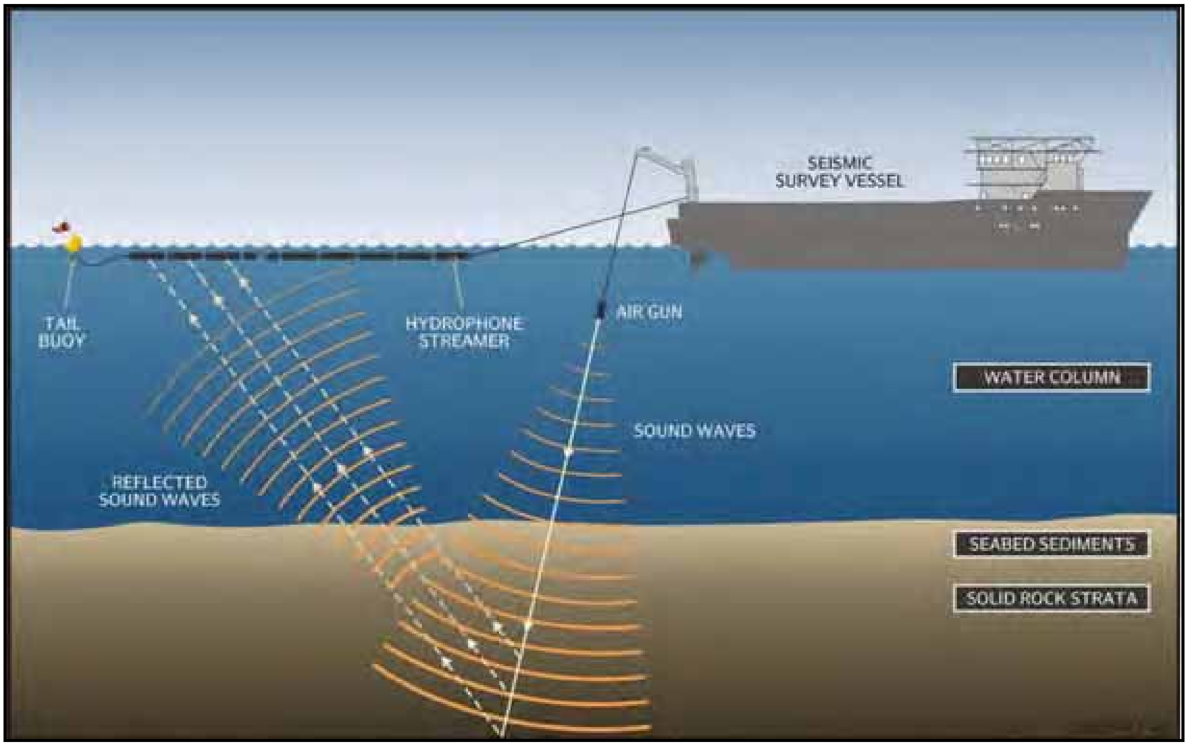
4.1.1 Geophysical Surveys

The 2-D and 3-D seismic surveys are conducted from a specialized vessel using a towed array composed of compressed air-driven “guns” (the sound source) and towed streamers (up to 8+ km in length) which contain the hydrophones (the recorders) (Figures 4.1 and 4.2). Massive amounts of positional and signal return-time data are collected over a grid pattern and analyzed. From these, a “picture” is developed of the geological layering beneath the seabed with the goal of locating potential hydrocarbon “traps”. The 2-D surveys typically cover a larger area than the finer scale 3-D surveys. The 3-D survey vessels tow more streamers over a finer grid pattern than the 2-D vessels.

Once potential targets are located, CSEM surveys might be conducted in attempts to further shed light on the nature of the contents (i.e., water or hydrocarbons). Using present technology these surveys would only be conducted in deep water (>500 m). The CSEM surveys consist of towing an electromagnetic source 20 to 50 m above the seabed in order to measure the resistivity of the seabed (Figure 4.3). Retrievable receivers are placed on the sea floor at intervals (Figure 4.4). From these data, the characteristics of the material below the trap may be extrapolated because water displays different resistivity than does petroleum hydrocarbons.

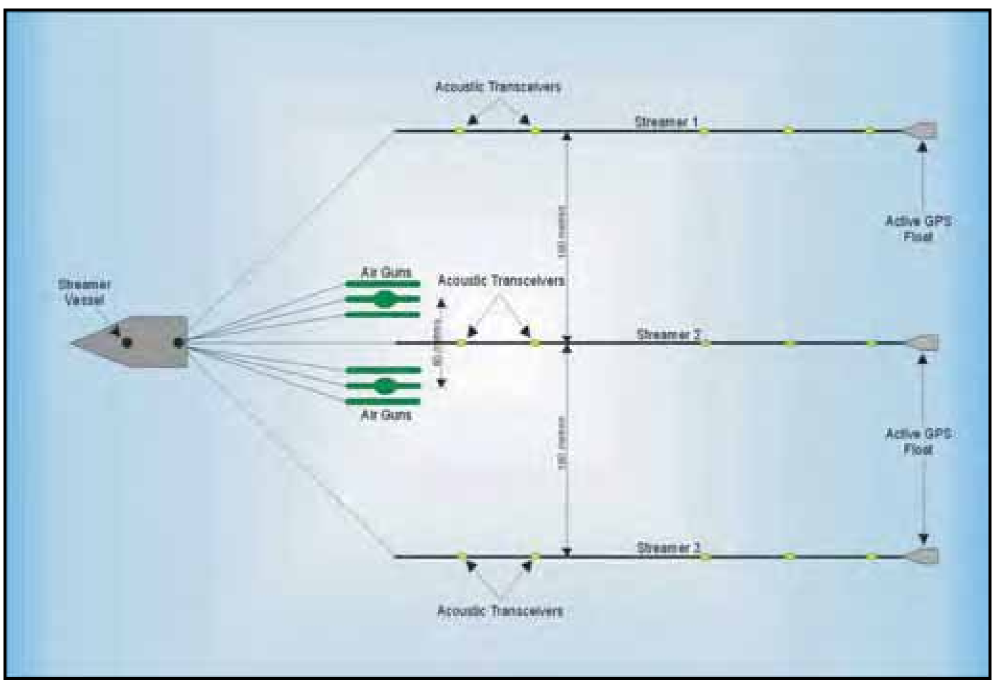
After the decision has been made to drill a well, the area is examined for geohazards such as shallow gas, unstable areas or boulder fields. The survey technology used may vary according to the potential hazards of a specific area but may consist of various echo-sounders, sonars (side scan or muti-beam), sparkers, small airgun arrays, and ROVs.

Vertical seismic profiling is conducted once some drilling has been completed. These programs use hydrophones suspended in the well at intervals (closer intervals than “checkshots”) which receive signals from external sound sources, usually airgun (s) suspended from the drill rig or a nearby supply vessel. Data are used to aid in determining the structure of a particular petroleum-bearing zone.



Source: Sikumiut (2008).

Figure 4.1. Schematic of Seismic Survey Vessel.



Source: WesternGeco (2001) *in* LGL (2003).

Figure 4.2. Typical Configuration of a Seismic Air Gun Array and Streamers.

Source: Buchanan et al. (2006).

Figure 4.3. Typical CSEM Towed Gear.

Source: Buchanan et al. (2006).

Figure 4.4. Typical CSEM Dipole Antenna (Receiver) with Anchor.

4.1.2 Exploratory Drilling

Exploration and delineation drilling may be conducted using several types of drilling platforms including anchored or dynamically-positioned (DP) semi-submersibles or drill ships, or jack-up platforms (Figures 4.5 to 4.7). The large anchors and associated heavy chain may extend out from the rig for some distance. It is also possible to drill from land using deviated drilling techniques if the target is not too far offshore. This approach has been used off the west coast of insular Newfoundland. The type of rig chosen is based on the characteristics of the well site physical environment, well site water depth; expected drilling depth and the mobility required based on well site weather and ice conditions (Canadian Association of Petroleum Producers, CAPP 2001). The most likely rig types to be used in the SEA Area are the two types of semi-submersible: anchored in water <500 m depth; and a DP semi-sub in water >500 m depth. A DP deep water drill ship may also be used. The rigs are attended by one to three supply vessels, at least one with anchor handling capabilities, if required, and offshore helicopters.

Figure 4.5. Semi-submersible Drill Rig *Glomar Grand Banks*.

Figure 4.6. Rowan Gorilla Jack-up Rig.

Figure 4.7. A Typical Drillship.

4.1.3 Potential Issues

The primary potential issues related to routine exploration activities include:

- Disturbance to marine animals (especially marine mammals) from underwater sound—airgun arrays create the strongest sound levels associated with exploration;
- Displacement or smothering of benthos by accumulation of drill mud and cuttings;
- Conflicts with commercial fisheries (especially fixed gear fisheries) from exclusion zones (see below), vessel traffic and seismic survey gear; and
- Seabird (especially Storm-Petrels) attraction and stranding on marine vessels.

A fisheries exclusion zone (FEZ) is a temporary exclusion zone typically established around a drilling platform for the duration of the 40 to 60 day drilling program; fishing is not permitted within a FEZ. Input into the development of the FEZ is solicited from stakeholders during public and fisheries consultation as part of the project-specific environmental assessment process. The FEZ around drilling operations is relatively small (0.5 km^2). If the drilling platform is an anchored rig (such as a semi-submersible), then the FEZ typically extends 500 m beyond the anchor points (which can extend up to approximately 1000 m from the centre of the drilling platform). If the drilling platform is not anchored, then the FEZ is established 500 m from the edge of the platform. Information on the FEZ is usually provided via the Fisheries Broadcast and through the Notice to Mariners.

Examples of some recent EAs conducted for exploration activities in the SEA Area include those conducted by ConocoPhillips for the Laurentian Sub-basin (Buchanan et al. 2004, 2006, 2007; Christian et al. 2005).

4.2 Production Phase

The routine production activities involve drilling and completion rigs, production platforms (bottom-founded or anchored), and the attendant vessels and helicopters. The oil or gas is processed to varying degrees on the platform and then piped to shore or offloaded to shuttle tankers. It is worthy of note that the Laurentian Sub-basin is considered a “gas play” compared to the Jeanne d’Arc Basin and vicinity projects which are primarily directed at oil.

In the Newfoundland offshore to date, the production scenarios of choice have been a gravity-based concrete structure such as Hibernia (Figure 4.8) or a floating production, storage and offloading vessel (FPSO) such as Terra Nova and White Rose (Figure 4.9). The production platforms contain processing, storage and offloading facilities, and accommodations. All of the existing platforms offload oil to tankers for transport to the oil transhipment terminal in Placentia Bay or to markets on the east coast. Production platforms are supported by a shore base and lay-down area, supply vessels, helicopters and shuttle tankers. It is anticipated that any production scenario for the SEA Area would not differ significantly from those currently used on the east coast of Canada.

Production alternatives could range from shallow water installations that pipe oil or gas ashore for processing and transportation to bottom-founded steel or concrete platforms to floating platforms that offload to tankers. There is a variety of floating production platforms including conventional semi-submersibles, FPSOs, or special deepwater platforms (e.g., spar platforms). Processing facilities can be on the platform or placed on the seabed. Subsea structures may include glory holes, flowlines and pipelines, some of which may require protection through excavation by dredges or through berms formed by rock placement.

Accidental events are probably of more concern during production than during the other phases because this phase is long term, petroleum hydrocarbons are present in large quantities, and the probability of an oil spill is greatest during loading and offloading. Accidental events are discussed in Subsection 4.6.

Figure 4.8. Hibernia GBS.

Figure 4.9. Petro-Canada FPSO. Courtesy of Petro-Canada.

The primary issues associated with routine production activities include:

- Seabed disturbance during installation of templates, glory holes, pipelines, and other structures;
- Effluents such as produced water that contain petroleum hydrocarbons (including PAHs) and are released in large quantities over a long period of time;
- Conflicts with commercial fisheries (exclusion zones and continuous traffic); and
- Seabird (especially Storm-Petrels) attraction and stranding on marine vessels.

These and other issues and potential mitigations are discussed in detail in subsequent sections.

Some local environmental assessments for offshore production include the Hibernia, Terra Nova, and White Rose EAs.

4.3 Decommissioning Phase

The operator shall ensure that, on the abandonment of any well, the seafloor is cleared of any material or equipment that might interfere with other commercial uses of the sea.

4.4 Potential Sources of Effects from Routine Activities

This section describes the sources of potential effects that are normally assessed in EAs conducted for Newfoundland and Labrador offshore waters.

4.4.1 Underwater Sound

The audibility or apparent loudness of a sound source is determined by: the radiated acoustic power (source level; the propagation efficiency; the ambient sound; and the hearing sensitivity of the subject species at relevant frequencies.

Most analyses of the effects of underwater sound are based on the Source → Path → Receiver concept. In this case, the acoustic energy originates with a "source" that generates underwater sound. Sound from the source radiates outward and travels through the water ("path") as pressure waves. Water is an efficient medium through which sounds can travel long distances. The received level decreases with increasing distance from the source. The "receiver" of these sounds is a marine animal. Whether or not the sounds are received depends upon how much propagation loss occurs between the source and the receiver, the hearing abilities of the receiving animal, and the amount of natural ambient or background sound in the sea around the receiver.

Underwater ambient sound, if it is sufficiently strong, may prevent an animal from detecting another sound through a process known as masking. Masking can occur as a result of either natural sounds (e.g., periods of strong winds or heavy rainfall) or anthropogenic sounds (e.g., ship propeller sound). The sea is a naturally noisy environment and even in the absence of anthropogenic sounds, this natural sound can "drown out" or mask weak signals from distant sources.

4.4.1.1 Source Levels

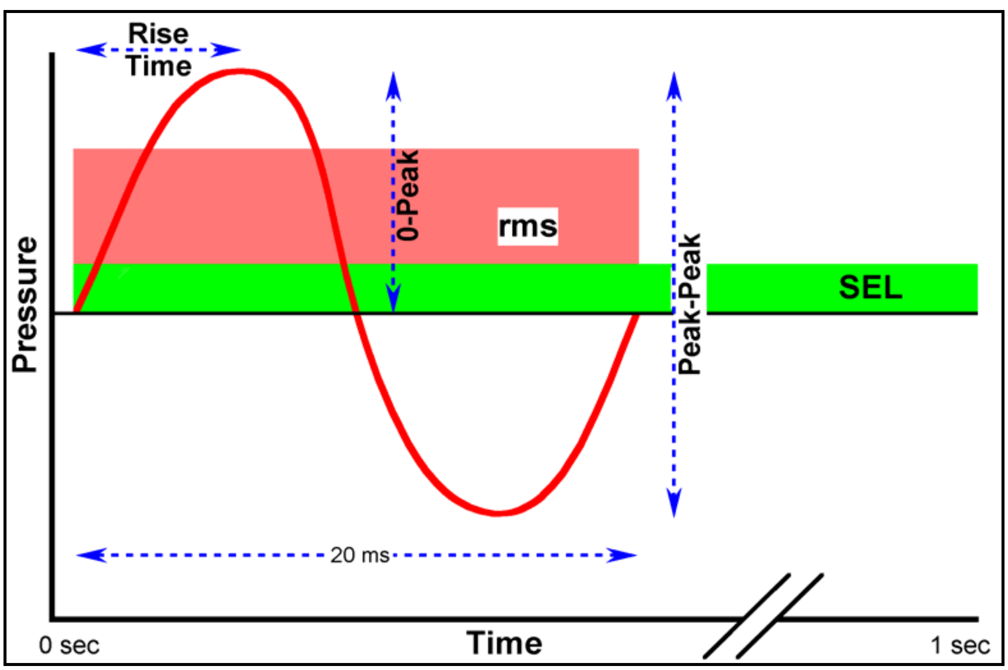
Animals, including humans, hear sounds with a complicated non-linear type of response. The ear responds logarithmically rather than linearly to received sound. Therefore, acousticians use a logarithmic scale for sound intensity and denote the scale in decibels (dB). In underwater acoustics, sound is usually expressed as a Sound Pressure Level (SPL):

$$\text{Sound Pressure Level} = 20 \log (P/P_o),$$

where P_o is a reference level, usually 1 μPa (micro-pascal). The reference level should always be shown as part of the SPL unit. A sound pressure (P) of 1000 Pascals (Pa) has an SPL of 180 dB re 1 μPa and a pressure of 500 Pa has an SPL of 174 dB. On this scale, a doubling of the sound pressure means an increase of 6 dB. In order to interpret quoted sound pressure levels one must also have some indication of where the measurement applies. SPLs are usually expressed either as a received sound level at the receiver location or the sound level "at the source." A source level is usually expressed as the SPL at one metre (1 m) from the source. If the source is large (i.e., not a point source), as is true for many industrial sources, then the source level of the large source is usually considered to be the received level 1 m from a point source emitting the same total energy as the actual large or "distributed" source.

Sound impulses, such as those often created by the offshore oil and gas industry (e.g., seismic airgun or pile-driving pulses), are composed of a positive pressure pulse followed by a negative pressure pulse. The difference in pressure between the highest positive pressure and the lowest negative pressure is the peak-to-peak pressure (p–p) (Figure 4.10). The peak positive pressure, usually called the peak or zero to peak pressure (0–p), is approximately half the peak-to-peak pressure. Thus, the difference between the two is approximately 6 dB. The average pressure over the duration of the pressure pulse can be expressed as the root mean square (rms) or average pressure. The rms pressure is usually about 10 to 12 dB lower than the peak pressure and 16 to 18 dB lower than the peak-to-peak pressure for airgun arrays (Greene 1997). To compare pulses of various types, sound pressure can be integrated over a standard unit of time, usually one second (1 s), to obtain the Sound Exposure Level (SEL). The SEL is typically 20 to 25 dB lower than the zero to peak pressure and 10 to 15 dB lower than the rms pressure.

Sound measurements are often expressed on a broadband basis, meaning the overall level of the sound over a wide range or band of frequencies. When the sound includes components at a variety of frequencies, the level at a specific frequency will be lower than the broadband sound level for some band containing that frequency. Sound signatures from underwater sources consist of measurements of the sound level at each frequency (i.e., a sound spectrum). The sound level can also be measured at specific frequencies and then summed (integrated) over groups or bands of frequencies, such as octaves or third octaves (Richardson et al. 1995).



Source: Lawson et al. (2000).

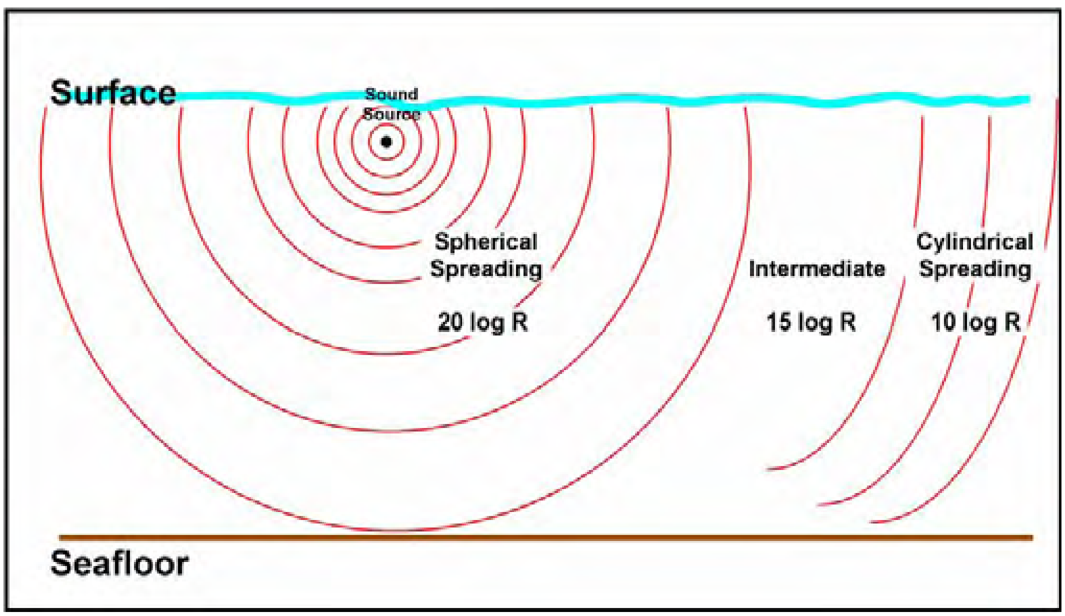
Figure 4.10. Terminology Used to Describe Sound Pressure Levels in an Acoustic Impulse (horizontal axis not drawn to scale).

4.4.1.2 Path Component

The pressure of a sound pulse diminishes with increasing distance from the source. Most of the loss in pressure is due to spreading. The diminishing of pressure with increasing distance from the source is spherical to a distance that is approximately equivalent to the water depth (Figure 4.11). In shallow water at horizontal distances much greater than bottom depth, sound propagates through a channel bounded by the bottom and the surface. For hard-bottom regions spreading is approximately cylindrical.

A simple model of acoustic spreading would use spherical spreading to distances equal to that of the bottom and then cylindrical spreading. However, for typical shallow water propagation the effect of bottom absorption results in a spreading loss of intermediate between spherical and cylindrical spreading. Which model of spreading to choose is not a simple matter of knowing the water depth, the receiver and source depth, and receiver distance, as other factors such as bottom absorption and sound speed gradients (with depth) are important.

Sound speed varies with water temperature, salinity, and pressure, and thus there can be reflection and/or refraction at water mass discontinuities, such as the seasonal thermocline. In deep (and in arctic) water, sound speed often varies with depth in a way that causes sound waves to be channeled within the water mass, resulting in low propagation loss and thus propagation over long distances. Sound propagation characteristics may change as sound travels from a source in shallow water (such as the Mississippi Delta) to a receiver in deeper water (e.g., deepwater Gulf of Mexico). Received levels are generally lower just below the surface than deeper in the water column, especially for the lower frequency components. This is a result of “pressure release at the surface” and interference effects associated with reflections of sound from the surface (Richardson et al. 1995). These and other factors complicate the estimation of transmission loss and necessitate the use of sophisticated models.



Source: Lawson et al. (2000).

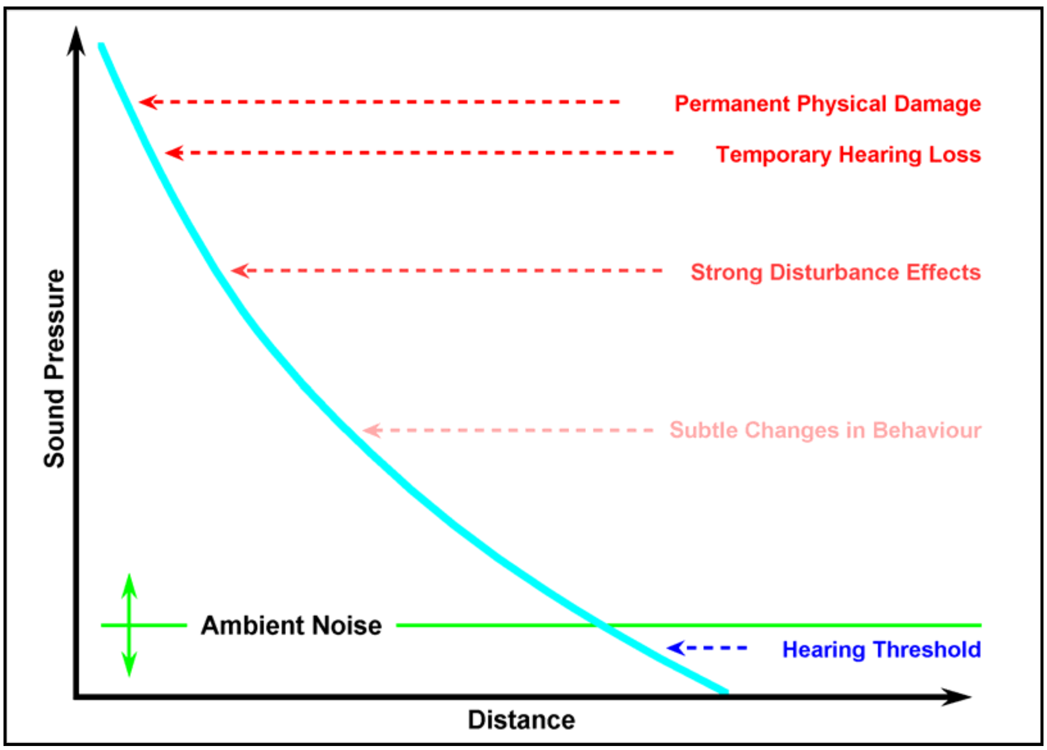
Figure 4.11. Schematic Representation of Acoustic Spreading Loss from a Sound Source as a Function of Distance and Interaction with the Seafloor.

4.4.1.3 Receiver Component

The receiver component is the most complicated and least understood component of the *Source → Path → Receiver* concept. For a fish, marine mammal or sea turtle to hear an underwater sound, the received level of the sound within a particular bandwidth relevant to the animal’s hearing processes must be greater than the absolute hearing threshold of that animal at that frequency (Davis et al. 1998). A sound with a received level below this threshold is not detectable by the animal. The hearing threshold varies with frequency and the frequencies of greatest hearing sensitivity vary among different species. Hearing thresholds, usually presented as audiograms that plot sensitivity versus sound frequency, are known for some species of fish, marine mammals and sea turtles.

A marine animal's ability to detect sounds produced by anthropogenic activities also depends on the amount of natural ambient or background sound in the waters in which it occurs. If background sound is high, then a source of anthropogenic sound will not be detectable as far away as would be possible under quieter conditions. Wind, thermal sound, precipitation, ship traffic and biological sources are all major contributors to ambient sound. However, ambient sound is highly variable on oceanic continental shelves and this probably results in significant variability in the range at which marine animals can detect anthropogenic sounds.

A hierarchy of criteria for establishing zones of influence can be derived based on ambient sound levels, absolute hearing thresholds of the species of interest, slight changes in behavior of the species of interest (including habituation), stronger disturbance effects (e.g., avoidance), temporary hearing impairment, and permanent hearing or other physical damage (Figure 4.12).



Source: Lawson et al. (2000).

Figure 4.12. Schematic Representation of the Zones of Potential Influence of Anthropogenic Sounds on Marine Animals (vertical distances among the different effects are not drawn to scale).

Underwater anthropogenic sound above a particular received level often disturbs some marine animals. However, the levels of such sound that elicit specific disturbance or other effects have not been studied in detail for many species. Generally, for man-made sounds, the levels, frequencies and types of sound that cause disturbance vary from species to species, and perhaps with area and season for a given species. Habituation (diminishing sensitivity during repeated exposures) and possibly sensitization (increasing sensitivity during repeated exposures) are additional sources of variability in responsiveness.

Disturbance is sometimes evident from changes in the behavioral patterns of the species in question. Behavioral changes can be subtle, such as a slight change in respiration rate, or conspicuous, such as movement out of an area to reduce exposure to sound. As compared with continued and undisturbed occupancy of a preferred area, displacement from a preferred area due to sound-related or visual disturbance can be considered potentially negative. However, displacement could be considered beneficial if the animal left the disturbed area before injury occurred but detrimental if it prevented the animal from performing an important life function.

Temporary threshold shift (TTS) is the lowest level of hearing effect. Brief exposures to loud sounds can temporarily increase the hearing threshold of an animal. This effect is temporary and reversible.

Additional discussion on received sound is contained in subsequent subsections concerning effects on the various VECs.

4.4.2 In-Air Sound

In-air anthropogenic sound propagation has implications for marine mammals both underwater and, in the case of pinnipeds (e.g., seals), with their ears above the water surface, and in some cases, invertebrates, fish and sea turtles. The source frequencies and intensities of sounds from various oil and gas-related activities interact with the propagation characteristics between the source and receiver to cause variation in the quality and quantity of sound reaching a receiver. Sound traveling from a source in air to a marine animal receiver underwater propagates in four ways: via a direct refracted path; via direct refracted paths that are reflected by the bottom; via a "lateral" (surface-traveling) wave; and via scattering from a rough sea surface (Urick 1972). The types of propagation vary in importance depending on local conditions, water depth, and the depth of receiver. Under calm sea conditions, airborne sound is totally reflected at larger angles and does not enter the water. However, some airborne sound may penetrate water at angles >13° from the vertical when rough seas provide water surfaces at suitable angles (Lubard and Hurdle 1976).

4.4.3 Ambient Sound

The ocean is noisy and there are varying levels of background ambient sound from physical sources such as wind, rain, sleet, ice and icebergs, thermal sources, thunderstorms, surf, tidal currents, earthquakes, volcanoes, and distant shipping. Airborne sources such as aircraft may also add to ambient sound levels. Transient sound from biological sources can also be significant. For example, blue whale calls have been recorded as far distant as 600 km (Stafford et al. 1998). Source levels as high as 232 dB re 1 µPa at 1 m (rms) have been recorded for male sperm whale (*Physeter catodon*) (Møhl et al. 2000). Some invertebrates and fish are also capable of producing sound energy, and peak source levels of 185 to 188 dB re 1 µPa at 1 m have been recorded for snapping shrimp (Au and Banks 1998).

4.4.4 Industrial Sounds

Sounds are generated by exploration, construction, production, and decommissioning phases of offshore oil and gas development.

4.4.4.1 Geophysical Surveys

Geophysical surveys include 2-D, 3-D, OBC, VSP, CSEM, geotechnical and geohazard surveys. Some of the main sound sources are described below.

Airguns--Most marine seismic surveys use airguns, singly or strung in an array. Airguns create a sound wave through the rapid release of compressed high pressure air (typically 2000 psi). Airgun arrays produce some of the strongest man-made sounds (typically short sharp pulses about 10 to 15 seconds apart) in the ocean; they produce a range of frequencies but, for the most part, frequencies emitted are low (below 120 Hz). One of the purposes of the array is to focus the sound energy toward the sea bed and thus sound energy below the array is greater than that measured horizontal to the array. Energy is often, but not always, less near the surface than at deeper depths (e.g., 3 m vs. 9 to 18 m) and less to the bow and stern of the seismic vessel (Richardson et al.

1995). Airgun arrays produce very high peak levels of sound but the energy often attenuates quickly subject to influences of bottom depth and slope, substrate characteristics, water density and other factors.

Water Guns--Water gun arrays may occasionally be used to conduct high resolution surveys. The guns create sound energy by inducing cavitation through shooting water from a cylinder. Compared to airguns of similar size, water guns produce more energy above 200 Hz (Richardson et al. 1995). To the best of our knowledge these types of arrays have not been used on the east coast.

Boomers--Boomers are used to profile the seafloor to depths below the floor of up to about 50 m and a resolution of about 0.5 to 1.0 m. Boomers are broadband energy sources operating between about 300 Hz and 10 kHz. Sound is produced by the cavitation resulting from the sudden repelling of electrically charged metal plates. A source level of 212 dB re 1 µPa at 1 m (peak) has been reported (Richardson et al. 1995).

Sparkers--Sparkers penetrate deeper into the substrate than boomers (about 200 m vs. 50 m) but at a lower resolution. Sparkers are broadband energy sources operating between 50 Hz and 4 kHz. Sparkers generate sound energy by vaporizing water using electrical power; the collapsing bubble produce omni-directional sound pulses. A source level of 221 dB re 1 µPa at 1 m peak has been reported (Richardson et al. 1995).

Vibrators--Vibrators are heavy, hydraulically-operated devices that have been used for many years for seismic surveys on land and for a few years on ice (vibroseis). Adaptations are being researched for use in the marine environment.

Sonars--Bottom-profiling and side-scan sonar surveys conducted by the offshore industry are designed to identify hazards on the seafloor. Echo sounders in use by the oil and gas industry include depth sounders, similar to those used by the fishing industry, which operate at high frequencies (12 or more kHz) and source levels of 180 dB re 1 µPa at 1 m (rms) or more (Richardson et al. 1995). Bottom profilers may operate at 0.4 to 30 kHz (source level of 200 to 230 dB re 1 µPa at 1 m, rms). Side-scan sonar pingers are mounted on “fish” that are towed behind the survey vessel. Side scans typically operate at 50 to 500 kHz with source levels around 220 to 230 dB re 1 µPa at 1 m (rms) (Richardson et al. 1995). Peak power levels for sonars can be quite high but pulse durations are usually very short (0.01 to 0.1 ms for side scan sonar) (Richardson et al. 1995). Military sonars are much more powerful and of longer pulse duration than the side scan sonars used by the oil and gas industry.

Transponders--Transponders may be used by the oil and gas industry to position drill rigs and other equipment although they are probably used less now than previously because of the availability of very precise GPS. Navigation transponders generally have frequencies about 7 to 60 kHz, source levels of 180 to 200 dB re 1 µPa at 1 m (rms) and durations of 3 to 40 ms (Richardson et al. 1995).

Explosives--Explosives provided the sound source for seismic surveys until the 1960s when they were replaced by the less environmentally intrusive airgun. Explosives have a much more rapid rise time than airguns and are the only underwater sound sources that have been clearly demonstrated to harm marine animals, particularly fish and marine mammals. At present, the use of survey explosives are very rare and may only be used in highly localized and/or specialized situations. They are discussed further under construction and decommissioning activities.

Vessel Traffic--Vessels are major contributors to background sound in the ocean. Sound levels generated by boats and ships are highly variable but generally related to type, age, size, power, load, and speed. The primary sources of sound are propeller cavitation and singing, and propulsion, pumping, compressor and generating systems, and so forth. A ship breaking ice creates additional sound from the ice but most of the increase in sound level is due to the increased load on the vessel and increased cavitation. It should be noted that vehicles such as snowmobiles and hovercraft traveling on ice may also transmit sound into the water but there are limited data on these sources.

Aircraft--The offshore industry uses helicopters for crew changes and support and fixed wing aircraft for various surveys including ice reconnaissance. Propeller-driven aircraft produce sounds audible in water with most energy at frequencies below 500 Hz (Richardson et al. 1995). Sound does not transmit well from air to water and the level and characteristics received depend on the aircraft type, speed, altitude, angle, environmental conditions, and other factors. Most sound is greatest when the aircraft is directly overhead and therefore of short duration. Helicopters are noisier than fixed wing aircraft (Richardson et al. 1995).

4.4.4.2 Drilling Sounds

Drilling of underwater wells may be conducted from a variety of platforms including land (using directional drilling), artificial islands, concrete or steel caissons, barges, semi-submersibles, drill ships, or bottom-founded jack-ups. In addition, some production platforms, floating or gravity-based also have drilling capabilities. All of these rig types likely emit different sound levels and frequencies with drillships with hull mounted machinery potentially being the noisiest type (Richardson et al. 1995). Data on drilling sound are not extensive given the different types of rigs but in general the strongest tones appear to be at low frequencies.

4.4.4.3 Production Sounds

All other factors being equal, the amount of underwater sound an anchored production or drilling platform creates is related to the area of hull or structure that contacts the water. Production systems may be mounted on artificial islands, caissons, barges, semi-submersibles or other floating configurations, concrete gravity-based structures, steel pillar mounted jack-ups, or mounted on the sea floor (subsea). A typical FPSO constructed from a ship's hull may be noisier than an anchored semi-submersible or jack-up; artificial islands would the quietest (see Richardson et al. 1995). However, in practice the amount of underwater noise created will also depend on the type and characteristics of onboard machinery such as generators, anchor tensioning devices, thrusters, and so forth.

4.4.5 Offshore Drilling

The primary effects associated with offshore drilling relate to drilling fluids or muds, and associated cuttings. Emissions and discharges are regulated and applicable guidelines are available on the C-NLOPB website. These and other potential discharges and emissions are discussed below.

Drilling Muds and Cuttings--Drilling mud is needed to convey drill cuttings out of the hole and to keep formation fluids from entering the well. Hibernia re-injects all of their cuttings but this approach is not presently feasible for the single offshore exploratory wells using existing drilling units on the East Coast. The re-injection of cuttings is more feasible with fixed platforms than floating platforms, and is also dependent on the site-specific geography. All exploratory drilling on the East Coast is conducted using either water-based drilling muds (WBM) or synthetic-based muds (SBM). Drilling off the west coast of Newfoundland has used mostly WBM, although sections of the onshore to offshore directionally drilled wells have required the use of SBM. It is debatable which type is more or less 'environmentally friendly.' For example, it can be argued that WBM is better because it is mostly water and cannot form sheens on the surface whereas some types of SBM may form one under very calm conditions. On the other hand, SBM generally stays closer to the well site and does not disperse as widely as WBM. In the case of onshore to offshore operations, used drilling fluids are normally stored in tanks at the rig site and eventually trucked to lined pits/containment areas for storage. All drilling fluids should be handled and treated in accordance with C-NLOPB policies, the *Offshore Waste Treatment Guidelines* (*OWTG*) (NEB et al. 2002), and any applicable provincial regulations.

After installation of the initial casing strings, the riser provides a conduit from the seabed to the rig that takes the drilling mud and cuttings back to the surface mud system. Once on board the rig, the drill cuttings are removed from the mud in successive separation stages and discharged. Drill mud is expensive and therefore as much mud is recovered as possible, but some mud remains with the discharged cuttings. At several stages during drilling and at the end of the drilling process, some WBM is discharged. The main component of WBM is either fresh water or seawater. The primary WBM additives include bentonite (clay) and/or barite. Other chemicals such as potassium chloride, caustic soda, soda ash, viscosifiers, filtration-control additives and shale inhibitors are added to control mud properties. Low toxicity chemicals are used for the water-based drilling mud to reduce the effect on the environment.

From the top down, a typical exploratory hole involves a conductor, surface and progressively smaller casings, perhaps as many as five. Mud and cuttings cannot be returned to the rig until the surface casing is in place and thus, mud and cuttings from the conductor and surface parts of the hole are initially discharged directly to the seabed. Once the surface casing is complete, the risers are installed, and the mud and cuttings are returned to the rig through a closed system for recycling and cleaning before cuttings and any residual mud are discharged. The discharge is treated and exits via shute below the water's surface, subject to C-NLOPB approval. The mud and cuttings are dispersed in the water column and settle on the sea floor with the heavier particles near the hole and the fines at increasing distances from the rig. The pattern of dispersal can be very irregular and in some cases it is difficult to find obvious signs of drilling after a year or so; in sheltered situations with little bottom circulation, cuttings piles may last for some years.

The conductor setting depth is site-specific and subject to C-NLOPB approval but a typical depth on the Grand Banks might be about 250 m as measured from the rotary table (i.e., measured depth, MD). The typical surface casing setting depths may be on the order of 1200 m MD. Estimated volumes of water-based mud and cuttings discharges associated with initial casings for a typical Grand Banks (White Rose area) well are shown in Table 4.1. It should be noted that the mud/cuttings from the production casing phase are passed through the solids control system that consists of shale shakers and centrifuges.

Table 4.1. Typical Mud Components and Cuttings Discharge Volume for a Grand Banks Exploration Well.

		Casing Strings		
	Unit	**Conductor**	**Surface**	**Main**
Hole Section	inch	36	16	12 1/4
DF System		Gel/SW	Gel/SW	WBM
Depth (See Note 4)	Meter (brt)	220	1200	3600
Volume Usage	bbl	897	4199	5246
Wash Out	%	50%	30%	10%
Products				
Barite	MT		58	115
Bentonite	MT	16	65	
Calcium Carbonate	kg			
Caustic	kg	116	482	138
Fluid Loss Agent	kg			2385
Inhibitor	kg			4769
Fluid Loss Agent	kg			9538
Potassium Chloride	kg			100153
Lime	kg	116	482	
Glycol Inhibitor	L			25024
Soda Ash	kg	116	482	238
Viscosifier	kg			3577
Biocide	L			72
Drilled Cuttings	kg	192032	429562	521786
Volume of Cuttings	m^3	74	165	201

Notes:
1. Three scenarios were taken into account. The 12 ¼" hole section varies in depth with each scenario.
2. 36" and 16" hole sections– Near seabed discharge.
3. WBM used for complete well.
4. All depths are measured below rotary table (brt). The rotary table is 145-m above the seafloor.

Source: Husky (2003a).

Drilling muds and cuttings, and their potential effects, were discussed in detail in the White Rose Comprehensive Study (Husky 2000) and Supplement (Husky 2001). Modeling of the fate of drill mud and cuttings discharges was conducted for the White Rose EA. The White Rose EA analyzed the effects of the discharge of drilling wastes from development drilling of 25 wells using SBM at multi-well drilling sites. As such, the White Rose scenario can be considered a 'much worse case' than the exploratory drilling of one individual well. The White Rose development drilling was deemed to create no significant effect on fish and fish habitat, the fishery, seabirds, marine mammals, or sea turtles. Additional relevant documents, not available during the White Rose EA, include: MMS (2000); CAPP (2001a,b); NEB et al. (2002, 2009); the White Rose baseline studies (Husky 2001, 2003); and Husky exploratory drilling EAs (Husky 2002, 2003a; LGL 2005) all of which discuss the discharge of mud and cuttings and associated effects. These recent reports further confirmed the conclusions of the White Rose EA that routine drilling, particularly small scale drilling, has no large effect on the marine environment of the Grand Banks. The salient points are briefly summarized in the two following sections.

In recent years, most shallow exploratory wells on the East Coast have been drilled with WBM unless unexpected, difficult or highly deviated conditions are encountered and then, with the approval of the C-NLOPB, they may use SBM (discussed in a following section). Composition of one typical WBM formulation for an exploratory program is shown in Table 4.1.

The following points are relevant to the discharge of WBM and cuttings:

- WBMs are essentially non-toxic. The main component of WBMs is seawater and the primary additives are bentonite (clay), barite and potassium chloride;
- Chemicals such as caustic soda, soda ash, viscosifiers, and shale inhibitors are added to control mud properties. All constituents are normally screened using the *Offshore Chemical Selection Guidelines for Drilling and Production Activities on Frontier Lands* (NEB et al. 2009);
- Discharge of WBM and associated cuttings is regulated by the C-NLOPB. Spent and excess WBM and cuttings can be discharged without treatment (NEB et al. 2002);
- The discharge of WBM may increase metals in sediments such as barium, arsenic, cadmium, copper, mercury, lead, and zinc, generally within 250 to 500 m of the drill site but occasionally farther (usually zinc and sometimes chromium) depending upon mud volumes and environmental conditions. However, these metals are not in a bioavailable form and few, if any, biological effects have been associated with these increases in metals from drill rig discharges (CAPP 2001b); and
- The primary effect of WBM appears to be smothering of benthos in a small area near the hole. The exact area of effect cannot be predicted because of variable coverage and animals' reactions range from simply avoiding the immediate area of deposition to direct mortality of sessile organisms. Nonetheless, the White Rose EA indicated a worst-case scenario of an area of less than 1 km^2 around each well would have a depth sufficient to result in some smothering (Husky 2000, 2001). The exploratory drilling for one well would be well below the worst-case scenario used for the White Rose EA. The benthos can be expected to recover within several months to several years after the drilling ceased, based upon the published literature (reviewed in Husky 2000, 2001; MMS 2000; CAPP 2001b). Monitoring data from other operators indicate that the actual area of smothering may be much less than predicted (Fechhelm et al. 2001; JWEL 2001; 2002).

SBMs may be used in an exploratory program, especially for long horizontal reach drilling (e.g., onshore to offshore) or in very deep water. Synthetic muds were developed to replace oil-based muds which were considered toxic, to varying degrees, and which appeared, at least partially, responsible for the longevity of cuttings piles. In general, SBM is essentially non-toxic, has the potential to biodegrade relatively rapidly (perhaps too rapidly under certain conditions, creating some localized anoxic conditions), and less mud is required than for WBM, for the same distance drilled. SBM tend to 'clump' cuttings together more than WBM thus SBM cuttings tend to disperse less and fall closer to the rig.

The following points concerning SBM are relevant to an exploratory drilling program EA on the south coast:

- For multiple wells, biological effects have been attributed to smothering under the patches of mud/cuttings from physical and/or chemical (i.e., anoxia caused by rapid biodegradation) conditions (e.g., EPA 2000);
- SBMs have been handled in a number of ways including shipping to shore, injection, and discharge; The feasibility of injection depends upon type of rig (i.e., usually only with certain bottom-founded rigs) and local geology;
- In the deepwater (500+-m), Gulf of Mexico, organic enrichment with attendant increases in biota, including fishes and crabs, has been reported after a two year multi-well drilling program (Fechhelm et al. 2001). No large cuttings piles were observed by ROV during that study;
- Biological effects are not normally found beyond about 250 to 500-m from the drilling platform (Husky 2000, 2001, 2002, 2003a; MMS 2000; CAPP 2001b; Buchanan et al. 2003; Hurley and Ellis 2004; LGL 2005). The Husky EAs (White Rose, Jeanne d'Arc Basin, and South Whale Basin) concluded a total area of impact of less than 1 km^2 from multi-well drilling based upon a modeling exercise and published literature. It can reasonably be expected that a single exploratory well would affect a much smaller area; and
- In the event that SBM must be used, the cuttings are treated prior to discharge in accordance with the *OWTG* (NEB et al. 2002). All discharges are subject to approval by the C-NLOPB and discharge of whole SBM is not permitted. Operators are expected to apply best available technology to achieve as low synthetic oil on cuttings as possible with an objective to achieve 6.9% synthetic oil on cuttings.

There are numerous synthetic fluid drilling systems. Petro-Canada claims good results with the very low toxicity, odour-free PureDrill IA-35 (Williams et al. 2002). Its formulation is contained in Table 4.2.

Table 4.2. Composition of the SBM PARADRIL-IA.

Component	**Purpose**
PureDrill IA-35	Base Fluid
NOVAMULL L	Primary Emulsifier
NOVAMOD L	Rheology Modifier
NOVATHIN L	Thinner
MI-157	Wetting Agent
HRP	Rheology Modifier
TRUVIS	Viscosity
VERSATROL	Filtration Control
ECOTROL	Filtration Control (Alternative)
LIME	Alkalinity
CALCIUM CHLORIDE	Salinity
WATER	Internal Phase
BARITE	Density

Source: Williams et al. (2002).

Discharge of Other Fluids and Solids--Other fluids associated with the drilling include cement slurry and blowout preventer (BOP) fluid. Mitigations include careful selection and use of chemicals in order to minimize any potential toxic effects. Readers are referred to the new *Offshore Chemical Selection Guidelines for Drilling and Production Activities on Frontier Lands* (NEB et al. 2009). Based on experience with previous exploratory wells, approximately 33-t (26.4-m^3) of excess cement may be released to the marine environment per well

(Husky 2000), and may smother or displace some benthos locally. If the cement remains in a pile, it will act as an artificial reef, be colonized by epifaunal animals and attract fish. BOP fluid is used in the blowout preventer stacks during drilling. The fluids are normally glycol-water mixes. Periodic testing of the blowout preventer is required by regulation. On semi-submersibles, approximately 1 m^3 of the fluid is released per test; jack-up rigs do not release BOP fluid.

Emissions and Effluents--The *OWTG* identify minimum standards for the discharge of effluents from oil and gas drilling and production facilities. [The *OWTG* are presently being revised and the new version should be available soon.] Produced water is normally associated with production activities and not drilling activities. However, in the case of produced water during exploratory or delineation wells, the produced water is shipped ashore or mixed with hydrocarbons burned in the flare. Produced water is discussed in more detail in the subsection on production activities.

Emissions and effluents possibly associated with exploration activities include:

- Atmospheric emissions;
- Domestic and sanitary waste;
- Cooling water;
- Sound; and
- Light.

Atmospheric emissions during exploration originate from flaring, fugitive emissions from storage tanks, generator exhaust, support vessel exhausts, helicopter exhaust, and so forth. Gaseous emissions from exploration and production activities include carbon dioxide (CO_2), methane (CH_4), non-methane volatile organic compounds (NMVOC), sulphur dioxide (SO_2), and nitrous oxides (NO_x) (OGP 2005). To date, atmospheric emissions from the East Coast offshore have not been of particular concern because of the distance from human settlement, the relatively small number of developments, the prevailing westerly winds, and generally strong mixing and dispersion in the windy offshore environment. However, with increasing societal focus on greenhouse gas, the prevailing onshore winds, and the potential proximity to land, atmospheric emissions may be a larger issue in the northwest part of the SEA Area than on the east coast of Newfoundland.

Drill rigs are usually in an area for a relatively short period (e.g., exploration drilling usually takes 40 to 90 days, depending on the water and well depths to be drilled). Air emissions for production activities originate from flaring, generator exhaust, support vessel exhaust, helicopter exhaust, fugitive emissions from storage tanks, and activities and equipment associated with production activities. Although, offshore air emissions have been of limited concern to date, increasing focus by society on greenhouse gases (GHG) and climate change issues, may increase its emphasis within the SEA Area.

The main sources of air emissions associated with routine activities of exploration drilling (Husky Energy 2007 *in* Sikumiut 2008) include:

- Burning of diesel fuel for power generation on the drill unit;
- Flaring during any required well testing; and
- Fugitive emissions.

Exhaust gas are emitted from diesel-powered generators on drill units and the support vessels. Exhaust gases are known to contain oxides of nitrogen, carbon dioxide, and methane emissions that compose GHG and are recorded in carbon dioxide equivalent (CO_2e). Husky Energy (2007) estimated that air emissions from a typical rig with two main engines of less than 600 horsepower each, drilling year round produced approximately 18,509.34 tonnes CO_2e per year (CO_2 [17,690.57] + N_2O [2.58] + CH_4 [0.90]).

Testing of wells is important for the determination of the reservoir and fluid conditions. Flaring activities during well testing produces air emissions in the order of 1,650 tonnes CO_2e per test (Husky Energy 2007 *in* Sikumiut

2008). Proponents may want to consider limiting flaring activities to only those tests necessary to determine reservoir parameters. Fugitive emissions from valves, seals, open ended piping release air emissions. However, this source is typically less than 1 to 2 percent of overall emissions and as such is considered negligible (Husky Energy 2007 *in* Sikumiut 2008).

All potential reduction strategies should be investigated and analyzed during the early planning and design stages of a project, when best applicable technology options can be assessed. Operators should estimate the annual quantities of GHG that would be emitted from its offshore facilities, provide a description of potential means for their reduction and reporting, and calculate and report the actual GHG emitted on an annual basis as per requirements of the *OWTG* (NEB et al. 2002). Operators of a drilling or production installation should report the type and significance of volatile organic compound (VOC) emissions in accordance with existing best management practices for oil and gas operations in Canada. Several GHG reduction technologies and strategies are most likely to be feasible if incorporated when a project is first constructed.

The air contaminants of primary concern with respect to air emissions include CO_2, carbon monoxide (CO), sulphur oxides (SO_X), NO_X and particulate matter (PM). It is estimated a typical drill unit consumes approximately 110 barrels of diesel per day. Each barrel holds approximately 42 US Gallons (159 L) of fuel. Representative emissions factors for air contaminants released to the atmosphere by source type were estimated by Husky Energy and Norsk Hydro Canada (2006) (*in* Sikumiut 2008) using US EPA AP-42 *Emission Factor Inventory* for a delineation well. The resulting data for a typical drill unit would compose less than 0.2 percent of the GHG emissions for Newfoundland and Labrador (based on 2003 greenhouse gas emissions data). These emissions are comparable to emissions from a single large container ship of the type commonly present in the Jeanne d'Arc Basin area.

Domestic and sanitary waste originates from the personnel on a vessel or drilling rig. Sewage and food wastes should be reduced through maceration to a particle size of 6 mm or less prior to discharge. Water is used to cool equipment and the cooling system may be closed (no discharge) or open (discharge), and may or may not contain biocides such as chlorine. Any concern is usually related to volume and temperature differentials between the effluent and the receiving water. The Chief Conservation Officer (C-NLOPB) may impose residual chlorine level limits for any discharged cooling water (NEB et al. 2002). The Chief Conservation Officer must also approve any other biocide agent.

Broadband noise is generated by machinery, support vessels, and aircraft. Any concerns are related to the source levels of the noise, the frequencies, and the proximity to sensitive species such as certain species of marine mammals. Marine vessel and rig lights may attract certain species of birds which may then become stranded on the structure. On the Grand Banks, storm petrels appear to be the most sensitive group in this regard because once grounded, they have difficulty becoming airborne again. Programs are presently undertaken by operators to gently capture, hold and release petrels that become stranded (Williams and Chardine nd).

4.4.6 Construction Activities

Construction activities related to the installation of production facilities may include the following:

Dredging--Dredging can produce significant sound in nearshore regions, especially in the low frequencies, but rapid attenuation occurs in the shallow water and dredging may not be detectable beyond about 25 km (Richardson et al. 1995). It also creates physical disturbance and sedimentation.

Pile-Driving--Individual pile-driving pulses have been measured in the Arctic during June and July. Underwater mean levels were 157 (flat-weighted peak) and 151 re 1 μPa at 1 m (rms) (Blackwell et al. 2003).

Many of the routine activities briefly discussed in the subsection on exploration activities also apply to this phase (e.g., vessel traffic, sound, domestic and sanitary waste, atmospheric emissions, light, etc.).

4.4.7 Production Effluents and Emissions

Effluents and emissions are regulated with the guidance of the *OWTG*. During production, petroleum must be separated from water which results in increasing amounts of produced water as the well ages. The composition of produced water varies greatly by well and age of well and may contain a wide variety of chemicals, including hydrocarbons from the formation, plus additives such as biocides. The *OWTG* specify that the 30-day weighted average of oil in discharged produced water does not exceed 30 mg/L and that the 24-hour arithmetic average of oil in produced water does not exceed 60 mg/L. It is difficult to "typify" produced water because it differs by well, region, age of well and other factors. Some composition data from the North Sea are contained in Table 4.3).

All of the routine activities previously discussed in the subsection on exploration activities also apply to the production phase (e.g., vessel traffic, drilling muds and cuttings, atmospheric emissions, domestic and sanitary waste, light, sound, etc.)

Table 4.3. Chemical Composition of Produced Water from Norwegian North Sea Platforms.

Fields	Unit	Statfjord	Gullfaks	Ekofisk 2/4B-K	Ekofisk 2/4T	Tor	Ula
Compounds							
TOC	mg/l	850	61	180		85.5	71
THC	mg/l	15	35				50
Sum Aromatics	mg/l	6.00	9.56	5.67	66.95		15
BTX	mg/l	4	5	5.41	66.90	1.1	12
Naphthalenes	mg/l	0.942	2.16	0.247	0.052	0.597	
Naphthalene	mg/l	0.261	0.398	0.157	0.038	0.073	
C1-naph	mg/l	0.35	0.629	0.062	0.012	0.17	
C2-naph	mg/l	0.199	0.584	0.018	0.002	0.204	
C3-naph	mg/l	0.132	0.55	0.010	0.0005	0.155	
Phenanthrenes	µg/l	45	90	6.26	0.28	135	
Phenanthrene	µg/l			2.09	0.08		
C1-phenanthrene	µg/l			2.43	0.12		
C2-phenanthrene	µg/l			1.74	0.08		
C3-phenanthrene	µg/l			n.d.	n.d.		
Dibenzothiophenes	µg/l	8.6	22.7	1.39	0.15	10	
Dibenzothiophene	µg/l			n.d.	n.d.		
C1-dibenzothiophene	µg/l			1.39	0.03		
C2-dibenzothiophene	µg/l			n.d.	0.12		
C3-dibenzothophene	µg/l			n.d.	n.d.		
Sum NPD	µg/l	1.00	2.27	0.254	0.055	0.74	
Acenaphtylene	µg/l			0.89	0.02		
Acenaphthene	µg/l	0.001	0.001	n.d.	0.04	0	
Fluorene	µg/l	12	11.3	n.d.	0.33	8.1	
Fluoranthene	µg/l	0.0854	0.195	n.d.	n.d.	0.24	
Pyrene	µg/l	0.0897	0.194	n.d.	0.08	0.42	
Chrysene	µg/l	0.226	0.398			0	
Benz(a)anthracene	µg/l	0.0193	0.311	n.d.	n.d.	0.23	
Benzo(a)pyrene	µg/l	0.001	0.001	n.d.	n.d.	0	
Benzo(ghi)perylene	µg/l	0.001	0.001	n.d.	n.d.	1.35	
Benzo(k)fluoranthene	µg/l	0.0197	0.0528	n.d.	n.d.	0.016	
Sum PAH 3-6 ring	µg/l	66.04	125.15	0.89	0.47	155.36	
Sum phenol	mg/l	8.3	2.7	1.03	2.65	3.62	0.09
Phenol	mg/l	5.1	0.8	0.61	0.97	2.19	0.033

Fields	Unit	Statfjord	Gullfaks	Ekofisk 2/4B-K	Ekofisk 2/4T	Tor	Ula
C1-phenol	mg/l	2.5	0.86	0.19	0.83	1.1	0.028
C2-phenol	mg/l	0.4	0.6	0.14	0.57	0.254	0.02
C3-phenol	mg/l	0.13.	0.18	0.06	0.26	0.0316	0.0006
C4-phenol	mg/l	0.026	0.1	0.03	0.02		
C5-phenol	mg/l	0.016	0.065	n.d.	n.d.		
C6-phenol	mg/l	0.013	0.11	n.d.	n.d.		
C7-phenol	mg/l	0.005	0.012	n.d.	n.d.		
Sum organic acids	mg/l	895	55	323	577	234	
Formic acid	mg/l			148	275		
Acetic acid	mg/l	732	15.6	132	267	104	9.5
Propionic acid	mg/l	106	8.9	35.2	27.4	10	1.2
Butylic acid	mg/l	39	14.1	6.35	5.18		1.5
Valeric acid	mg/l	18	8.2	1.61	2.17		0.6
Caprioic acid	mg/l	9	8.2	n.d.	0.09		
Organic acids >C6	mg/l			n.d.	n.d.		
Methanol	mg/l			6.3	33.9		
Salinity C1-	mg/l			30400		90500	40440
Amonium	mg/l	25.4	26.9				0.1
Lead	µg/l	50	50	n.d.		80	270
Copper	µg/l	2	2	20		600	20
Iron	mg/l			4		8.9	23
Barium	mg/l			28.2		42.1	12
Cr-VI	µg/l	10	10	6		0.08	40
Mercury	µg/l	1.9	1.9	n.d.			9
Zinc	µg/l	6.8	13	13		200	0.26
Cadmium	mg/l	10	10	n.d.			0.02
H2S	mg/l	0.12	0.17				
Total radioactivity	Bql						
40K	Bql						
226Ra	Bql						

Source: Røe and Johnsen (1996).

4.4.8 Decommissioning Activities

The operator shall ensure that, on the abandonment of any subsea infrastructure, the seafloor is cleared of any material or equipment that might interfere with other commercial uses of the sea.

4.5 Interactions and Potential Effects of Routine Activities

This subsection identifies potential interactions between the routine activities associated with oil and gas exploration and production and the VECs described in Section 3.0, and briefly discusses the potential effects of these interactions. A more detailed discussion of potential interactions, effects, and significance of post-mitigation residual effects would be provided in project-specific environmental assessments of proposed projects. Possible mitigations to reduce residual effects of the routine activities are discussed in the subsection on `Planning Implications`.

Only those interactions of routine activities and VECs that have the highest likelihood of potentially meaningful effects are indicated in Table 4.4. Each routine activity is then discussed within its own subsection with respect to the potential effects of its interactions with VECs.

Table 4.4. Potential Interactions of Oil and Gas Exploration and Production Routine Activities and Valued Ecosystem Components.

Routine Activity	Valued Ecosystem Component							
	Fish Habitat[1]	Fish[2]	Fisheries	Marine-associated Birds	Marine Mammals	Sea Turtles	Species-at-Risk	Potentially Sensitive Areas
Sound[3]	*	*	*	*	*	*	*	*
Drilling muds and cuttings	*	*	*	*			*	*
Bottom disturbance[4]	*	*	*				*	*
Produced water	*	*	*	*		*	*	*
Lights	*			*		*	*	*
Flaring				*			*	*
Presence of structures[5]	*	*	*	*	*	*	*	*
Liquid and solid wastes	*	*	*	*	*	*	*	*
Atmospheric emissions[6]				*	*	*	*	*
Marine vessel presence [7]			*	*	*	*	*	*

Notes:
[1] Refers to habitat for macroinvertebrates and fishes, and includes bottom substrate, coastal algal communities, plankton and benthic invertebrates
[2] Refers to macroinvertebrates and fishes
[3] Sources include seismic airguns, rig operation, marine vessels, and helicopters
[4] Refers to glory hole excavation, anchors, flowline berms, GBS, CSEM receivers
[5] Includes artificial reef effect of rigs, safety zones around rigs, anti-fouling systems, seismic streamers and airgun arrays
[6] Includes both routine and well-testing emissions
[7] Refers to physical presence of marine vessels, NOT sounds emitted by marine vessels

4.5.1 Effects of Sound

Underwater sound is discussed in detail in Subsection 4.4.1. There are numerous sound sources associated with oil and gas exploration and production activities. The one that has the highest levels of energy is the seismic airgun array. Consequently, this subsection discusses the potential effects of exposure to impulsive sound on the various VECs. The other main sources of sound (i.e., rig operation, marine vessels, and helicopters) produce continuous sound.

4.5.1.1 Fish Habitat

The components of fish habitat that could potentially be affected by exposure to sound, particularly seismic sound are zooplankton and benthic invertebrates. Zooplankton are most vulnerable to seismic sound, considering their usual position in the water column while benthic invertebrates, unless exposed to seismic sound in very shallow water areas, are usually a considerable distance from the airguns and thus receive lower energy levels. The limited information on the effects of exposure to seismic sound on marine invertebrates is discussed in the next subsection on the Fish VEC and is relevant to the invertebrate components of the Fish Habitat VEC.

4.5.1.2 Fish and Invertebrates

This subsection provides an overview of information pertaining to the sound detection capabilities of marine invertebrates and fishes, and the potential effects of exposure to seismic sound on these animals, based on the results of scientific studies of varying degrees of rigor as well as anecdotal information.

Sound Detection and Production

Many marine invertebrates and fish produce sounds. It is believed that some of these sounds are used for communication in a wide range of behavioural and environmental contexts. The behaviours most often associated with acoustic communication include territorial behaviour, mate finding, courtship and aggression. Sound production provides a means of long distance communication as well as communication when underwater visibility is poor (Zelick et al. 1999).

Rather than being pressure sensitive, invertebrates seem to be most sensitive to particle displacement, the kinetic component of sound. While the sensitivity of some marine invertebrates to particle displacement and hydrodynamic stimulation appears to be less than that of fish (e.g., decapods crustaceans), cephalopod sensitivity to particle motion appears to be comparable to fish. Decapods, for example, have an extensive array of hair-like receptors both within and upon the body surface that could potentially respond to water- or substrate-borne displacements. They are also equipped with an abundance of proprioceptive organs that could serve secondarily to perceive vibrations. Crustaceans appear to be most sensitive to sounds of low frequency (i.e., <1000 Hz) (Budelmann 1992; Popper et al. 2001). A New Zealand study investigated the responses of the planktonic stages of common coastal crabs to artificial sources of natural reef sound (Jeffs et al. 2003). The purpose of the study was to provide insight on the ability of larval and post-larval stages of coastal crustacean to find their way from the open ocean to the coast where they settle to the bottom. Results of the study provided some evidence for pelagic stages of common coastal crabs using underwater sound to aid in orientation to the coast. Hanlon and Budelmann (1987) presented a review paper on underwater sound detection by cephalopods, a group of marine animals once considered 'deaf'. Cephalopods, including octopuses, squids and cuttlefish, have external ciliated sensory cells which serve as mechanoreceptors of water-borne vibrations (Packard et al. 1990). They also have relatively sophisticated statocysts which contain calcareous statoliths and are suitable for the detection of both linear and angular acceleration. Kaifu et al. (2008) showed that the cephalopod *Octopus ocellatus* uses the statocyst to detect the particle motion component of underwater sound.

Some marine invertebrates are capable of producing underwater sound. For example, snapping shrimp (e.g., *Synalpheus paraneomeris* and *Alpheus heterochaelis*) are among the major sources of biological noise in shallow bays, harbors, and inlets, in temperate and tropical waters (Au and Banks 1998; Versluis et al. 2000). The spectrum of a snapping shrimp click (rapid closure of front claw) is very broad with only a 20 dB difference between the peak and minimum amplitudes across 200 kHz. It is believed that the rapid closure of the front claw is used to produce a high velocity water jet to stun prey. Latha et al. (2005) and Pye and Watson (2004) discuss the sounds produced by shallow- and deep-water spiny lobsters (*Panulirus* spp.) and American lobsters, respectively. Both low and high frequency sounds are produced by these crustaceans, with peak levels appearing to be lower during molting times compared to non-molting times. The purposes of sound production by lobsters are not understood.

Hearing in fishes was first demonstrated in the early 1900s through studies involving cyprinids (Parker 1903 and Bigelow 1904 *in* Kenyon et al. 1998). Since that time, numerous methods have been used to test auditory sensitivity in fishes, resulting in audiograms of over 50 species. These data reveal great diversity in fish hearing ability, mostly due to various peripheral modes of coupling the ear to some internal structures, including the swim bladder. However, the general auditory capabilities of less than 0.2% of fish species are known so far. For many years, studies of fish hearing have reported that the hearing bandwidth typically extends from below 100 Hz to approximately 1 kHz in fishes without specializations for sound detection, and up to about 7 kHz in fish with specializations that enhance bandwidth and sensitivity. A recent Environmental Studies Research Fund (ESRF) study on bluefin tuna concluded that this species probably cannot detect sound over 1000 Hz and that only very loud sounds have the potential to affect their hearing (Song et al. 2006). Recently there have been suggestions that certain fishes, including many clupeiforms (i.e., herring, shads, anchovies, etc.), may be capable of detecting ultrasonic signals with frequencies as high as 126 kHz (Dunning et al. 1992; Nestler et al. 1992). Studies on Atlantic cod, a non-clupeiform fish, suggested that this species could detect ultrasound at almost 40 kHz (Astrup and Møhl 1993). Mann et al. (2001) showed that the clupeiform fish, the American shad, is capable of detecting sounds up to 180 kHz. They also demonstrated that the gulf menhaden is also able to detect ultrasound while other species such as the bay anchovy, scaled sardine, and Spanish sardine only detect sounds with frequencies up to about 4 kHz. Nedwell et al. (2004) have recently compiled a summary of available fish audiograms.

Among fishes, at least two major pathways for sound to get to the ear have been identified. The first and most primitive is the conduction of sound directly from the water to tissue and bone. The fish's body takes up the sound's acoustic particle motion and subsequent hair cell stimulation occurs due to the difference in inertia between the hair cells and their overlying otoliths. The second sound pathway to the ears is indirect. The swim bladder or other gas bubble near the ears expands and contracts in volume in response to sound pressure fluctuations, and this motion is then transmitted to the otoliths. While present in most bony fishes, the swim bladder is absent or reduced in many other fish species. The species of fish with a swim bladder that appear to be sound pressure-sensitive via this indirect pathway to the ears are called 'hearing specialists'. These hearing specialists have some sort of connection with the inner ear, either via bony structures known as Weberian ossicles, extensions of the swim bladder, or simply a swim bladder more proximate to the inner ear. Hearing specialists' sound pressure sensitivity is high and their upper frequency range of detection is extended above those species that hear only by the previously described direct pathway. The species having only the direct pathway are known as 'hearing generalists' (Fay and Popper 1999). Typically, most fish detect sounds of frequencies up to 2000 Hz but, as indicated, others have detection ranges that extend to much higher frequencies. Fish also possess lateral lines that detect water movements. The essential stimulus for the lateral line consists of differential water movement between the body surface and the surrounding water. The lateral line is typically used in concert with other sensory information, including hearing (Sand 1981; Coombs and Montgomery 1999).

Elasmobranchs, including sharks and skates, lack any known pressure-to-displacement transducers such as swim bladders. Therefore, they presumably must rely on the displacement sensitivity of their mechanoreceptive cells. Unlike acoustic pressure, the kinetic stimulus is inherently directional but its magnitude rapidly decreases relative to the pressure component as it propagates outward from the sound source in the near field. It is believed that elasmobranches are most sensitive to low frequencies (i.e., <1 kHz) (Corwin 1981).

Potential Effects on Fish and Invertebrates

Potential effects of exposure to seismic sound on fish and invertebrates can be categorized as: pathological; physiological; and behavioural. Pathological effects include lethal and sub-lethal damage, physiological effects include temporary primary and secondary stress responses, and behavioural effects are changes in exhibited behaviours. The three categories should not be considered independently of one another. They are likely interrelated in complex ways.

Pathological

In water, acute damage to organisms exposed to seismic sound is likely related primarily to two features of the sound: received peak pressure; and time required for the pressure to rise and decay (Hubbs and Rechnitzer 1952 *in* Wardle et al. 2001). Generally, the higher the received pressure and the less time it takes for the pressure to rise and decay, the greater the chance of acute pathological effects. Considering the peak pressure and rise/decay time characteristics of seismic airgun arrays used today, the pathological zone for fish and invertebrates would be expected to be small (i.e., within a few metres of the seismic source).

Very few investigations of pathological impacts of exposure to seismic sound on marine invertebrates have been conducted to date. There are not any properly documented cases of acute mortality of juvenile or adult marine invertebrates exposed to seismic sound characteristic of typical field seismic surveys. Sub-lethal injury or damage has been observed, but as a result of repeated exposure to very high received levels of sound, a higher cumulative level than would be expected in the field under normal seismic operating conditions. Acute mortality of eggs and larvae have been demonstrated in experimental exposures but only when the eggs and larvae were exposed very close to the seismic sound sources and the received pressure levels were presumably very high.

In 2002, Christian et al. (2004) exposed adult male snow crabs, egg-bearing female snow crabs, and fertilized snow crab eggs to sound from seismic air guns under controlled field conditions near St. John's, Newfoundland and Labrador, Canada. All exposure experiments consisted of 200 discharges over a 33 minute period. Male crabs were associated with numerous exposure experiments where the mean received SPL ranged from 197 to 221 dB re 1 µPa 0-P, and the maximum received energy density ranged from 130 to 187 dB re 1 µPa2/Hz. Maximum received energy densities occurred at frequencies <260 Hz. The berried female crabs were associated with a single exposure experiment with a mean received SPL of 221 dB re 1 µPa 0-P, and a maximum received energy density of 183 dB re 1 µPa2/Hz at <50 Hz. No differences in either acute or chronic (12 weeks and 30 weeks post-exposure) mortality were observed between the treated and control animals for both male and female crabs (Christian et al. 2004). The fertilized egg masses were used in a single exposure experiment with a mean received SPL of 221 dB re 1 µPa 0-P, and a maximum received energy density of 187 dB re 1 µPa2/Hz at <50 Hz. There was a significant difference in development rate noted between the treated and control fertilized eggs. The egg mass exposed to seismic sound had a higher proportion of less-developed eggs than the control egg mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable (Christian et al. 2004). Caged egg-bearing female snow crabs were exposed to seismic sound associated with a commercial seismic survey conducted in the southern Gulf of St. Lawrence off Cape Breton, Nova Scotia, Canada in December 2003 (DFO 2004b). Crabs were exposed to seismic sound for 132 hours of survey time. The maximum SPLs measured by ocean bottom seismometers (OBS) at the survey site ranged from 152 to 192 dB re 1 µPa 0-P (140 to 178 dB re 1 µPa RMS). Definitive conclusions of this study were that exposure to the seismic sound did not cause any acute or chronic mortality of the crab, nor did it affect the survival of the embryos being carried by the females during the time of exposure. Locomotory ability of larvae that hatched after exposure did not appear to be affected either. There was some evidence of hepatopancreas and ovary bruising, detached outer membranes of oocytes, and acute soiling of gills, antennules and statocysts in the treatment crabs. However, no definitive link between these observations and exposure to seismic could be made (DFO 2004b,c). Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab (*Cancer magister*) to four discharges from a seven-air gun seismic array under five different received SPL scenarios. The mean received SPLs ranged from approximately 221 to 231 dB re 1 µPa P-P. No significant differences in survival rate between control and treatment Stage III and Stage IV larvae were noted under any of the five scenarios.

McCauley et al. (2000a,b) carried out three exposure trials with caged squid (*Sepioteuthis australis*) using a single 20 in^3 air gun. During the first trial using a fixed air gun sound source, the squid-received SPLs were at least 174 dB re 1 µPa $_{RMS}$. Trials 2 and 3 used a mobile air gun sound source resulting in a minimum to maximum received SPL range of 35 to 45 dB re 1 µPa $_{RMS}$ (<156 to >174 dB re 1 µPa $_{RMS}$). Statocysts were removed and preserved but at the time of the study report publication, results of the statocyst analyses were not available. No squid mortalities were reported as a result of the exposure trials. In 2001 and 2003, two incidents of multiple strandings of the giant squid (*Architeuthis dux*) on the north coast of Spain were reported (Guerra et al. 2004). The strandings occurred at about the same time as geophysical seismic surveys were being conducted in the Bay of Biscay. A total of nine giant squids, either stranded or moribund surface-floating, were collected at these times. Guerra et al. (2004) presented evidence of acute tissue damage in the stranded and surface-floating giant squids after conducting necropsies on seven (six females and one male) of the relatively fresh nine specimens. The authors speculated that one female with extensive tissue damage had been affected by the seismic sound. However, little is known about the impact of marine acoustic technology on cephalopods and, unfortunately, the authors did not describe the seismic sources, locations, and durations of the Bay of Biscay surveys. No evidence of relationships between the squid tissue damage and the seismic surveys was presented.

Pilot studies investigating the potential effects of exposure to seismic sound on marine invertebrates have been conducted recently by DFO (J. Payne, DFO, pers. comm.). The primary species used in these pilot studies included snow crab and American lobster. The exposure experiments were typically characterized by 50 to 200 air gun discharges and an approximate received SPL of 197 db re 1 µPa $_{0\text{-}P}$. To date, neither mortality nor gross injury has been detected as a result of exposure to seismic sound. Other marine invertebrates that have been exposed to seismic sound at the DFO (St. John's) laboratory include shrimp, ctenophores, blue mussels, sea anemones and sea cucumbers. No pathological effects on these invertebrates were observed. Bivalves in the Adriatic Sea have also been exposed to seismic energy and subsequently assessed (LaBella et al. 1996). No effects of the exposure were noted.

There are some examples of the occurrence of damage to fish ear structures as a result of exposure to seismic sound (Enger 1981; McCauley et al. 2000a,b, 2003). It must be noted that the experimental fish in these studies were caged and exposed to high cumulative levels of seismic energy, a scenario not likely to occur with noncaptive fish. Atlantic salmon were exposed within 1.5 m of underwater explosions (Sverdrup et al. 1994). Compared to airgun sources, explosive detonations are characterized by higher peak pressures and more rapid rise and decay times, and are considered to have greater potential to damage marine biota. In spite of this, no salmon mortality was observed immediately after exposure or during the seven-day monitoring period following exposure.

Studies have indicated that exposure to intense sound can affect the auditory thresholds of fish. Under certain conditions, fish have exhibited TTS, followed by complete recovery within 24 hours. Amoser and Ladich (2003) exposed two hearing specialist fish, the nonvocal goldfish (*Carassius auratus*) and the vocalizing catfish (*Pimelodus pictus*) to intense white noise (158 dB re 1 µPa; unspecified measure type) for periods of 12 and 24 hours and then tested their hearing sensitivities using auditory brainstem response (ABR) immediately following exposure and at 3, 7 and 14 days post-exposure. Hearing sensitivities were also measured prior to exposure to intense white noise. Both species exhibited loss of hearing sensitivity (maximum of 26 to 32 dB) immediately post-exposure, the greatest loss occurring at the most sensitive frequencies. The catfish exhibited the highest maximum loss of hearing sensitivity. While the goldfish hearing sensitivity returned to normal within three days of exposure, the catfish hearing sensitivity took 14 days to return to normal. Smith et al. (2004) found that goldfish had significant threshold shift after only 10 minutes of exposure to white noise (160 to 170 dB re 1 µPa; unspecified measure type) and that these shifts increased linearly up to approximately 28 dB after 24 hours of exposure to the noise. Threshold shifts did not increase beyond the 24-hour exposure time. After 21 days of exposure to the noise, the goldfish hearing sensitivity required 14 days to recover to normal levels. It should be noted that TTS is less likely to occur in the wild unless fish are prevented from leaving the immediate area of the sound source. Also, the above experiments that demonstrated TTS in fish used a continuous sound source. Seismic sound is impulsive sound.

Popper et al. (2005) exposed three caged freshwater fish species to seismic sound and then tested each species' hearing using the ABR method. Mean received peak SPLs ranged from 205 to 210 dB re 1 µPa 0-P. Each exposure consisted of either 5 or 20 discharges. Results indicated that adult northern pike and lake chub exposed to the seismic sound did exhibit temporary TTS with full recovery within 24 hours of exposure. Neither the broad whitefish nor the juvenile northern pike exhibited TTS. Popper et al. (2007) investigated the effects of exposure to high-intensity, low frequency sonar on rainbow trout (*Oncorhynchus mykiss*). They found that certain groups of trout showed auditory threshold shifts at particular frequencies but that results varied with different groups, suggesting developmental and/or genetic impacts on how the fish are affected.

Some studies have also provided some information on the effects of exposure to seismic sound on fish eggs and larvae (Kostyuchenko 1973; Dalen and Knudsen 1987; Holliday et al. 1987; Matishov 1992; Booman et al. 1996; Dalen et al. 1996). Effects on the ichthyoplankton appeared to be minimal and any mortality effect was generally not significantly different from the experimental controls. Typically, any observed larval mortality occurred as a result of exposures within 0.5 to 3 m of the airgun source. Matishov (1992) reported some retinal tissue damage in cod larvae exposed within 1 m of the airgun source. Saetre and Ona (1996) applied a 'worst-case scenario' mathematical model to investigate the effects of seismic sound on fish eggs and larvae and concluded that mortality rates caused by exposure to seismic sound are so low compared to the natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as very minimal. The ESRF funded a recent study of the effects of seismic on monkfish eggs but results were not available at time of writing this SEA.

Matishov (1992) reported cod and plaice mortality within 48 hours of their being exposed to sound within two metres from a seismic source. No other details of the exposure (e.g., received SPL, number of discharges) were provided by the author, making the usefulness of this information questionable. On the other hand, there are numerous examples of exposure of fish to seismic sound without any indication of acute mortality (Falk and Lawrence 1973; Holliday et al. 1987; La Bella et al. 1996; Santulli et al. 1999; McCauley et al. 2000a,b; Thomsen 2002; IMG 2002; McCauley et al. 2003; Hassel et al. 2003).

Summary of Pathological Effects

To date, there are not any properly documented cases of acute mortality of juvenile or adult marine invertebrates or fish exposed to seismic sound characteristic of typical field seismic surveys. Sub-lethal injury or damage has been observed but as a result of repeated exposure to very high received levels of sound, a higher cumulative level than would be expected in the field under normal seismic operating conditions. Acute mortality of eggs and larvae have been demonstrated in experimental exposures but only when the eggs and larvae were exposed very close to the seismic sound sources and the received pressure levels were presumably very high. To date, there have been no reports of chronic mortality as a direct result of exposure to seismic.

Physiological

Biochemical responses of marine invertebrates and fishes to acoustic stress have also been studied, albeit in a limited way. Studying the variations in the biochemical parameters influenced by acoustic stress may give some indication of the degree of stress and perhaps provide insight into associated effects on the animal. For example, stress could potentially affect animal populations by negatively impacting reproductive capacity. All primary and secondary stress responses of marine invertebrates and fishes after exposure to seismic sound appear to be temporary in any studies done to date. The times necessary for these biochemical changes to return to normal are variable depending on numerous aspects of the biology of the species and of the sound stimulus.

Sub-lethal physiological effects on American lobsters exposed to seismic energy were observed by Payne et al. (2007) during preliminary exploratory studies. The observed serum biochemical effects included reduced levels of serum protein, specific serum enzymes, and serum calcium. In some cases, the reduced levels persisted for a period of weeks. Stress indicators in the haemolymph of adult male snow crabs were monitored immediately following exposure (acute effects) to seismic sound and at two different times long after exposure (chronic effects) (Christian et al. 2004). No significant differences in the stress indicators (e.g., proteins, enzymes, cell type count) were detected between treatment and control animals. Potential physiological effects were also investigated during the DFO snow crab study off Cape Breton (DFO 2004b,c). Levels of enzymes in the haemolymph were comparable between the treatment and control animals.

McCauley et al. (2000a,b) employed various measures to study the physiological effects of exposure to seismic sound on fish and cephalopods. No statistically significant physiological stress increases attributable to seismic sound were detected. Caged European sea bass exposed to seismic sound exhibited numerous biochemical responses. All physiological parameters returned to normal levels within 72 hours of the exposure to seismic sound. Lagardère (1982) presented results from laboratory experimentation that suggested that physiological reactions of brown shrimp (*Crangon crangon*) were modified by exposure to increased background noise in tanks. Shrimp were kept in two environments for about three months, one noisier than the other. The mean difference in sound level in the 80 to 400 Hz range was 30 to 40 dB (unspecified measure type). There was a significant difference in growth rate and reproduction rate between the two groups. Those shrimp in the noisier environment had lower rates of each compared to those in the quieter environment. Increased noise levels also appeared to decrease food uptake. It is unclear how tank experiments with sound relate to conditions in the wild.

Summary of Physiological Effects

Primary and secondary stress responses of marine invertebrates and fishes after exposure to seismic energy all appear to be temporary in any studies done to date. The times necessary for these biochemical changes to return to normal are variable depending on numerous aspects of the biology of the species and of the sound stimulus.

Behavioural

Most concern now centers on the possible effects of exposure to seismic on the distribution, migration patterns and catchability of these animals because of the lack of indication of serious pathological and physiological effects of seismic energy on marine invertebrates and fishes, (i.e., behavioural effects). Studies investigating the possible effects of seismic sound on marine invertebrate behaviour have been conducted on both confined and unconfined animals. Studies looking at change in catch rate regard potential effects of exposure to seismic sound on larger spatial and temporal scales than are typical for close range studies often involved confined animals (Hirst and Rodhouse 2000). Christian et al. (2004) conducted an experimental commercial fishery for snow crab before and after the area was exposed to seismic pulses. No significant decrease in catch rate was observed after the air guns were activated. Anecdotal information from Newfoundland indicated that snow crab catch rates showed a noticeable reduction immediately following a pass by a seismic survey vessel. Other anecdotal information from Newfoundland indicated that a school of shrimp showing on a fishing vessel sounder shifted downwards and away from a nearby seismic source. Effects were temporary in both cases.

Experiments conducted off the coast of Brazil did not detect a significant effect of seismic surveying on shrimp fishing yields (Andriguetto-Filho et al. 2005). Bottom trawl yields were measured before and after the use of an array of four synchronized airguns, each with a source peak SPL of 196 dB re 1 μPa @ 1-m. The study was unable to detect immediate effects of exposure to seismic sound on the shrimp since fishing was not conducted until 12 to 36 hours after airgun firing. However, if shrimp were immediately driven from the area, the effect was both temporally and spatially limited. An Australian study examined longterm variation (1978 to 2004) in CPUE data of rock lobster to determine whether changes were correlated with seismic surveying activity in different regions (Parry and Gason 2006). The study concluded that there was no evidence that catch rates declined in areas near surveys in the weeks or years following any of the 33 seismic surveys conducted in the region between 1978 and 2004. One inference from these results is that rock lobster behaviour was not affected to the point of changing catchability of the crustacean.

Studies on the effects of sound on marine invertebrate behaviour have also been conducted using confined animals. Some were conducted in Australia using squid and cuttlefish as subjects (McCauley et al. (2000a,b). Squid exhibited strong startle responses to the onset of proximate airgun activation by releasing ink and/or jetting away from the source. The squid consistently made use of the 'sound shadow' at surface where the sound intensity was less than at 3-m depth. These Australian experiments provided more evidence that marine invertebrate behaviour will be modified at some received sound level, albeit temporarily. Another marine invertebrate behavioural investigation by Christian et al. (2004) involved caging snow crabs, positioning the cage 50 m below a seven-gun array, and observing the immediate responses of the crabs to the onset of seismic sound activity by remote underwater camera. No obvious startle behaviours were observed. Sub-lethal behavioural effects on lobsters exposed to seismic energy inside a tank were observed by Payne et al. (2007) during preliminary exploratory studies. Four of the five exposure trials resulted in observed increases in food consumption, and these feeding differences were often apparent several weeks post-exposure.

The full determination of behavioural effects of exposure to seismic sound on marine invertebrates is difficult. There have been well-documented observations of marine invertebrates exhibiting behaviours that appeared to be in response to exposure to seismic sound (i.e., startle response, change in swimming direction and speed, change in vertical distribution), but the ultimate importance of these behaviours is unclear. As is the case with pathological and physiological effects of exposure to seismic sound on marine invertebrates, available information is relatively scant and often contradictory. DFO has recently published two review papers relating to the potential effects of exposure to seismic sound on marine invertebrates (Moriyasu et al. 2004; Payne et al. 2008).

Studies investigating the possible effects of seismic on fishes have also been conducted on both confined and unconfined animals. Studies looking at change in catch rate regard potential effects of seismic on larger spatial and temporal scales than are typical for close range studies that often involving caged animals (Hirst and Rodhouse 2000). Hassel et al. (2003) investigated the behavioural effects of seismic on caged sand lance in Norwegian waters. The sand lance did exhibit responses to the seismic, including an increase in swimming rate, an upwards vertical shift in distribution, and startle responses. Normal behaviours were resumed shortly after cessation of the seismic. None of the observed sand lance reacted to the seismic by burying into the sand.

Engås et al. (1996) assessed the effects of seismic surveying on cod and haddock behaviour using acoustic mapping and commercial fishing techniques. Results indicated that fish abundance decreased at the seismic survey area and the decline in abundance and catch rate lessened as one moved away from the survey area. Engås et al. (1996) found that fish abundance and catch rates had not returned to pre-shooting levels five days after cessation of shooting. Other studies that used fishing catch rate as an indicator of behavioural shift also showed reduced catch rates, particularly in the immediate vicinity of the seismic survey (Løkkeborg 1991; Skalski et al. 1992). Marine fish inhabiting an inshore reef off the coast of Scotland were monitored by telemetry and remote camera before, during and after airgun activation (Wardle et al. 2001). Although some startle responses were observed, the seismic airgun pulses had little overall effect on the day-to-day behaviour of the resident fish. Experiments using fishes were also conducted in Australia (McCauley et al. (2000a,b). Common observations of fish behaviour included startle response, faster swimming, movement to the part of the cage furthest from the seismic source (i.e., avoidance), and eventual habituation. Fish behaviour appeared to return to pre-seismic state 15 to 30 minutes after cessation of seismic. These Australian experiments provided more evidence for modification of fish behaviour at some received sound level. Again, these behavioural changes seem to be temporary.

The influence of seismic sound on pelagic fish (i.e., herring, blue whiting and mesopelagic species) was investigated using acoustic mapping off western Norway in 1999 (Slotte et al. 2004). The distribution and abundance of pelagic fish within the survey area and in surrounding waters out to 50 km from the survey area were mapped three times and compared, and the abundance was recorded immediately prior to and after airgun activation along some of the survey transects. The inconclusive results indicated that the acoustic abundance of pelagic fish was higher outside than inside the survey area. At the same time, the abundance of pelagic fish prior to airgun activation was not significantly different than abundance immediately after shooting along some of the survey transects, indicating that no significant short-term horizontal movement occurred. However, there were indications that some of the pelagics might have moved downwards in response to the seismic pulses. Other species involved in studies that have indicated fish behavioural responses to underwater sound include rockfish (Pearson et al. 1992), Pacific herring (Schwarz and Greer 1984), and Atlantic herring (Blaxter et al. 1981). Again, the responses observed in these studies were relatively temporary. However, what is not known is the effect of exposure to seismic on fish and invertebrate behaviours that are associated with reproduction and migration.

Using telemetry techniques, Shin et al. (2003) investigated changes in the swimming behaviour of caged Israeli carp (*Cyprinus carpio*) in response to underwater explosions. The received sound levels ranged from 140 to 156 dB re 1 μPa (unspecified type of measurement). Immediately after an explosion, the fish swimming area was reduced. After one hour, the area had returned to pre-explosion size. Other behavioural reactions included downward movement and increased swimming speed, but these behavioural shifts also returned to normal shortly after cessation of explosions. Considering that underwater explosions are considered worst-case scenarios, compared to airgun discharges, and that these fish exhibited minor short-term behavioural changes in response to underwater explosions, reactions of these fish to airgun discharges should be minimal.

Bluefin tuna behaviour in response to exposure to boat noise was recently studied in the Mediterranean Sea (Sarà et al. 2007). The investigation concluded that boat noise produced behavioural deviations in tuna schools that resulted in changes in swimming direction, increased vertical movement both downwards and upwards, and general disruption of the school structure and swimming behaviour. The authors suggested that alteration in schooling behaviour might affect the accuracy of tuna migration to spawning and feeding grounds.

As discussed above, a number of clupeid species can detect and respond to ultrasonic sounds of frequencies up to 180 kHz. Behavioural studies of responses of American shad (*Alosa sapidissima*) to ultrasound demonstrated that these fish show a graded series of responses depending on the received SPL, and to a lesser degree, the frequency of the source sound (Plachta and Popper 2002 *in* Popper et al. 2004). The American shad exhibited negligible response to sounds below 160 dB re 1 μPa at any frequency. Received SPLs of 175 dB re 1 μPa at 30 to 120 kHz with stimuli of at least one second duration, the shad showed mild reactions to the onset of the sound. Between 175 and 184 dB re 1 μPa at stimulus frequencies ranging between 70 and 110 kHz, the fish showed rapid and directional responses directly away from the sound source. At received SPLs above 185 dB re 1 μPa, the shad exhibited very rapid and random patterns of behaviours that resulted in some animals attempting to jump from the experimental tank. A field study by Wilson and Dill (2002) showed that Pacific herring (*Clupea* *pallasi*) reacted in a manner similar to that of the shad in the tank experiment. There is speculation that these responses to ultrasound evolved to help these fish, particularly shallow-water species, detect and avoid echolating cetacean predators.

Summary of Behavioural Effects

It is difficult to fully determine the behavioural effects of exposure to seismic on marine invertebrates and fishes. There have been well-documented observations of fish and invertebrates exhibiting behaviours that appeared to be in response to exposure to seismic sound (i.e., startle response, change in swimming direction and speed, change in vertical distribution), but the ultimate importance of these behaviours is unclear. Some studies indicate that such behavioural changes are very short duration while others imply that marine animals might not resume pre-seismic behaviours/distributions for a number of days. As is the case with pathological and physiological effects of seismic on fish and invertebrates, available information is relatively scant, especially considering the large number of marine species, and often contradictory. There is also evidence that certain clupeids show a graded series of responses to exposure to ultrasound. The strongest responses involve rapid movement away from the sound source.

4.5.1.3 Fisheries

The chief sources for potential effects of underwater sound, particularly seismic sound, on the fisheries are related to changes in catch rates resulting from sound-induced behavioural changes (scaring) of fish and effects on stock assessments and DFO/industry research surveys, which are used, among other purposes, for setting fishing quotas or exploring new fisheries. The first issue has been raised during SEA consultations for other areas in Newfoundland (e.g., Western Newfoundland Offshore SEA (C-NLOPB 2005)). Impacts related to physical effects on fish and invertebrates have been discussed in the preceding section.

As discussed in Subsection 3.3 on the Fisheries VEC, commercial fisheries are conducted throughout the SEA Area. Fisheries industry representatives have registered concerns that seismic survey sound sources may scare finfish from their fishing locations, or discourage benthic species, such as snow crab, from entering fishing gear. The likelihood that finfish will move away as the air gun array approaches is considered a factor that helps prevent physical impacts on these species. The discussion of the behavioural effects on fish and invertebrates in the previous subsection presents the results of studies on the effects of seismic noise on catch rates. While some of these studies report some decrease in catch rates near seismic arrays, at least for finfish, reported effects have been variable.

Depending on the juxtaposition of the survey sound source, the species being harvested, and the gear type, the impact on fishing success could be either negative or positive. For example, the effect would be positive if fish were driven away from the sound source towards fishing gear (e.g., fixed gillnets). Macroinvertebrates such as snow crabs are less likely to disperse and, therefore, catch rates of these animals are not expected to be affected.

4.5.1.4 Marine-associated Birds

There are limited data on the effects of underwater sound on birds. A study on the effects of underwater seismic surveys on moulting Long-tailed Ducks in the Beaufort Sea showed little correlation with movement or diving behaviour (Lacroix et al. 2003). However, the study did not monitor the physical effects on the ducks. The authors suggested caution in interpretation of the data because the studies were limited to searching for correlations between behaviour and seismic emissions and they were limited in their ability to detect subtle disturbance effects. The authors recommended studies on other species to fully understand the potential effects of seismic testing.

Most species of seabirds that are expected to occur in the SEA Area feed at the surface or at less than one metre below the surface of the ocean. This includes Procellariidae (fulmars and shearwaters), Hydrobatidae (storm-petrels), Phalaropodinae (phalaropes), Laridae (gulls and terns), and Stercorariidae (skuas and jaegers). Northern

Gannet plunge dive to a depth of 10 metres. These species are under the surface for a few seconds during each dive so would have minimal opportunity to receive underwater sound.

There is only one group of seabirds occurring regularly in the SEA Area that require considerable time under water to secure food. They are the Alcidae (murres, auks, and puffins). From a resting position on the water they dive under the surface in search of small fish and invertebrates. Alcids use their wings to propel their bodies rapidly through the water. All are capable of reaching great depths and spending considerable time under water (Gaston and Jones 1998). An average duration of dive times for the five species of Alcidae is 25 to 40 seconds reaching an average depth of 20 to 60 m, but murres are capable of diving to 120 m and have been recorded underwater for up to 202 seconds (Gaston and Jones 1998).

The sound created by airguns is focused downward below the surface of the water. Above the water the sound is reduced to a muffled shot that should have little or no effect on birds that have their heads above water or are in flight. It is possible birds on the water at close range would be startled by the sound; however, the presence of the ship and associated gear dragging in the water should have already warned the bird of unnatural visual and auditory stimuli.

Only the Alcidae have some potential to be exposed to the sounds produced by the seismic and geohazard surveys. It is unknown what, if any, effects the high frequency sounds of the boomer, echo scanner and side scan sonar or the low frequency sound of the array would have on seabirds. The effects of underwater sound on Alcidae are not well known but sound is probably not important to Alcidae in securing food. On the other hand, all six species are quite vocal at breeding sites indicating auditory capabilities are important in that part of their life cycle. The 'laughing call' of the Thick-billed Murre is shown to cover a frequency range of 1.0 to 4.0 kHz (Gaston and Jones 1998).

The more important scenario regarding the potential effects of exposure to sound on marine-associated birds involves airborne sound produced close to shore and its potential effects on nesting shorebirds, for example. Behavioural effects, especially during breeding season, could be an issue.

4.5.1.5 Marine Mammals

Marine mammals rely heavily on the use of underwater sounds to communicate and gain information about their environment. Four types of potential effects of exposure to sound related to oil and gas exploration and production are considered here: hearing impairment (TTS) and permanent threshold shifts [PTS]); non-auditory physiological effects; masking; and behavioural. The reactions of marine mammals to noise can be variable and depend on the species involved, and the activity of the animal at the time of exposure to noise. The radius of audibility can be large for strong noise because underwater noise sometimes propagates for long distances. However, marine mammals usually do not respond overtly to audible, but weak, man-made sounds (Richardson et al. 1995). Thus, the zone of "responsiveness" is usually much smaller than the zone of audibility. There are several reviews of anthropogenic sound and marine mammals (i.e., Richardson et al. 1995; Gordon et al. 2004; Nowacek et al. 2007; Southall et al. 2007; Weilgart 2007), and a brief review will be provided here.

Offshore oil development and production activities produce sounds that can be classified into three broad categories. Sounds that are produced intermittently or at regular intervals, such as sounds from pile driving, underwater explosions, and seafloor pingers, are classed as "pulsed." Sounds produced for extended periods, such as sounds from power generation and drilling at exploration and production platforms, are classified as "continuous." Sounds from moving sources such as ships or aircraft can be continuous but, for a mammal at a given location, these sounds are "transient" (i.e., increasing in level as the ship or aircraft approaches, and then diminishing as it moves away). Studies indicate that marine mammals respond somewhat differently to the three categories of sound.

Hearing Impairment

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. The minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely detectable temporary hearing loss or TTS. The level associated with the onset of TTS is often considered to be a level below which there is no danger of permanent damage. Current U.S. NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 μPa (rms), respectively (NMFS 2000). Given a seismic source level of 234 dB re 1 μPa_{rms}, and presuming spherical spreading of sound, received sound pressure levels of 180 and 190 dB re 1 μPa_{rms}, would occur at approximate distances of 512 and 170 m, respectively, from the sound source. TTS is the mildest form of hearing impairment. It is the process whereby exposure to a strong sound results in a non-permanent elevation in hearing sensitivity (Kryter 1985). TTS can last from minutes or hours to days. The magnitude of the TTS depends on the level and duration of sound exposure, among other considerations (Richardson et al. 1995). For sound exposures at or somewhat above the TTS level, hearing sensitivity recovers rapidly after exposure to the sound ends. TTS commonly occurs in mammals, including humans. Only limited data on sound levels and durations necessary to elicit mild TTSs have been obtained for marine mammals, and all of these data are quite recent. TTS studies in humans and terrestrial mammals provide information helpful in understanding general principles of TTS, but it is unclear to what extent these data can be extrapolated to marine mammals.

There are no data on sound levels that might induce permanent hearing impairment in marine mammals. In theory, physical damage to a marine mammal's hearing apparatus could occur immediately if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times. Also, very prolonged exposure to a sound strong enough to elicit a TTS, or shorter-term exposure to sound levels well above the TTS level, could cause hearing injury. Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies. Richardson et al. (1995) hypothesized that permanent hearing impairment caused by prolonged exposure to continuous man-made sound is not likely to occur in marine mammals for sounds with source levels up to ~200 dB re 1 μPa-m. Single or occasional occurrences of mild TTS do not cause permanent auditory damage in humans or other terrestrial mammals, and presumably, do not do so in marine mammals. Sound impulse duration, peak amplitude, and rise time are the main factors thought to determine the onset and extent of PTS. Based on existing data, Ketten (1995) noted that the criteria for differentiating the sound pressure levels that result in a PTS (or TTS) are location and species specific. PTS effects may also be influenced strongly by the health of the receiver's ear.

For sound exposures at or somewhat above the TTS level, hearing sensitivity recovers rapidly after exposure to the sound ends. At least in terrestrial mammals, the received sound level from a single sound exposure must be far above the TTS level for there to be any risk of PTS (Kryter 1985, 1994; Richardson et al. 1995). Relationships between TTS and PTS levels have not been studied in marine mammals but are assumed to be similar to those in humans and other terrestrial mammals. There are no data on the levels or properties of sound that are required to induce TTS in any baleen whale, as it is not possible to study hearing directly in large, free-living marine animals. Temporary threshold shift has been demonstrated and studied in certain captive odontocetes and pinnipeds exposed to strong sounds (reviewed in Southall et al. 2007). However, there are no known studies of TTS (or PTS) in any free-ranging marine mammals exposed to sequences of airgun pulses during realistic field conditions.

Empirical data on sound exposures that elicit the onset of TTS involves captive bottlenose dolphins and beluga whales. In one study using single impulse watergun sound, the TTS threshold for odontocetes appeared to be somewhat lower than for exposure to non-impulse sound (Finneran et al. 2002). Recent work also emphasizes that noise level and its duration significantly affect the magnitude of TTS (Mooney et al. 2009). Preliminary evidence from a harbour porpoise exposed to airgun sounds suggests that its TTS threshold may be lower than those of dolphins or belugas (Lucke et al. 2007). However, additional information is needed to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sounds with variable received levels. A bottlenose dolphin developed TTS after exposure to a continuous tone (e.g., drilling) with maximum sound pressure levels at frequencies ranging from 4 to 11 kHz that was gradually increased in intensity to 179 dB and in duration to 55 min (Natchigall et al. 2003).

The frequencies to which mysticetes are most sensitive are assumed to be lower than those to which odontocetes are most sensitive, and natural background noise levels at those low frequencies tend to be higher. Thus, auditory thresholds of baleen whales within their frequency band of best hearing are believed to be less sensitive than those of odontocetes at their best frequencies (Clark and Ellison 2004).

For pinnipeds, TTS thresholds associated with exposure to brief pulses of underwater sound have not been measured. It is expected that the onset of TTS would occur at lower cumulative sound exposure levels given the assumed greater auditory effect of broadband impulses with rapid rise times. Captive bottlenose dolphins and a beluga whale exposed to single underwater pulses designed to imitate underwater explosions apparently experience no more than slight and temporary hearing loss (Finneran et al. 2000). It is unknown whether pinnipeds incur any hearing damage or other injuries when exposed to sound pulses from underwater explosions

Kastack et al. (1999) reported that they could induce mild TTS in California sea lions (*Zalophus californianus*), harbour seals, and northern elephant seals (*Mirounga angustirostris*) by exposing them to underwater octave-band sound (e.g., drilling) at frequencies in the 100 to 2000 Hz range for 20 to 22 min. However, Schusterman et al. (2000) showed that TTS of these seals were somewhat lower when the animals were exposed to the sound for 40 min than for 20 to 22 min.

Non-Auditory Physiological Effects

Non-auditory physiological effects may also occur in marine mammals exposed to strong underwater sound. Possible types of non-auditory physiological effects or injuries that, in theory, might occur, include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strongly pulsed sounds, particularly at higher frequencies (e.g., sonar).

Very little is known about the potential for seismic survey sounds to cause non-auditory physiological effects in marine mammals. Available data suggest that such effects, if they occur at all, would be limited to short distances from the sound source (Southall et al. 2007). However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of marine mammals that might be affected in these ways. Marine mammals that show behavioural avoidance of seismic vessels, including most baleen whales, some odontocetes, and some pinnipeds, are unlikely to incur auditory impairment or other physical effects.

Sound may be a potential source of stress in marine mammals, but almost no information is available on sound-induced stress or potential long-term effects (Wright et al. 2007a,b). Such long-term effects, if they occur at all, would be mainly associated with chronic noise exposure not characteristic of seismic surveys. One study found that there were minimal neural-immune changes following watergun impulse sound exposure of a beluga and bottlenose dolphin (Romano et al. 2004).

Masking Effects

Masking is the obscuring of sounds of interest by other sounds, often at similar frequencies. Marine mammals are highly dependent on sound and their ability to recognize sound signals amidst noise is important in communication, predator and prey detection, and in the case of toothed whales, echolocation. The ocean is usually "noisy", even in the absence of man-made sounds, and marine mammals are adapted to cope with momentary 'masking' by natural sounds such as surf noise (see Richardson et al. 1995). Although some degree of masking is inevitable when high levels of man-made broadband sounds are introduced into the ocean, marine mammals have evolved systems and behaviours that function to reduce the impacts of masking. It is primarily the components of background sound that are similar in frequency to the sound signal in question that determine the degree of masking. Low-frequency industrial sound has little or no masking effect on high-frequency echolocation sounds of toothed whales. Redundancy and context can also facilitate detection of weak signals. These phenomena may help marine mammals detect weak sounds in the presence of natural or man-made sound. Most masking studies in marine mammals present the test signal and the masking sound from the same direction. The sound localisation abilities of marine mammals suggest that, if signal and sound come from different directions, masking would not be as severe as the usual types of masking studies might suggest (Richardson et al. 1995). The dominant background sound may be highly directional if it comes from a particular anthropogenic source such as a ship or industrial site. Directional hearing may significantly reduce the masking effects of these sounds by improving the effective signal-to-sound ratio.

Toothed whales, and probably other marine mammals, have additional capabilities besides directional hearing that can facilitate detection of sounds in the presence of background sound. There is evidence that some toothed whales can shift the dominant frequencies of their echolocation signals from a frequency range with much ambient sound toward frequencies with less sound (e.g., Romanenko and Kitain 1992; Lesage et al. 1999). A few marine mammal species are known to increase the source levels of their calls in the presence of elevated sound levels (e.g., Lesage et al. 1999; Terhune 1999). These data demonstrate adaptations for reduced masking and pertain mainly to the very high-frequency echolocation signals of toothed whales. There is less information about the existence of corresponding mechanisms at moderate or low frequencies, or in other types of marine mammals. Directional hearing has been demonstrated at frequencies as low as 0.5 to 2 kHz in several marine mammals (see Richardson et al. 1995). This ability may be useful in reducing masking at these frequencies.

Masking effects of seismic noise on marine mammal calls and other natural sounds are believed to be limited. Some whales are known to continue calling in the presence of seismic pulses which are typically 20 ms in duration and occur every 11 sec. In some cases, baleen and large toothed whale calls can be heard between the seismic pulses (e.g., Richardson et al. 1986; Greene et al. 2000; Madsen et al. 2002; Jochens et al. 2006; 2008). However, animals have also ceased calling for an extended period starting soon after the beginning of a seismic survey in the area (e.g., Bowles et al. 1994; Clark and Gagnon 2006). However, it is unclear whether whales would cease calling due to masking effects, whether this was a behavioural response not directly involving masking, or an unrelated behavioural response. Dolphins and porpoises are also commonly heard calling during seismic operations (Potter et al. 2007). Airgun pulses may not be expected to mask sperm whale calls given the intermittent nature of seismic sounds (Madsen et al. 2006). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses and the fact that sounds important to them are predominantly at much higher frequencies than airgun sounds.

Most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz and considerably lower spectrum levels above 1000 Hz. These frequencies are mainly used by baleen whales, but not by toothed whales or true seals. Furthermore, the discontinuous nature of seismic pulses makes significant masking effects unlikely for all marine mammals.

In summary, high levels of sound generated by anthropogenic activities may act to mask the detection of weaker biologically important sounds by some marine mammals. This masking may be more prominent for lower frequencies. For higher frequencies, such as used in echolocation by toothed whales, several mechanisms are available that may allow them to reduce the effects of such masking.

Behavioural Effects

Disturbance includes a variety of effects, such as subtle changes in behaviour, more conspicuous dramatic changes in activities, and displacement. Disturbance is one of the main concerns of the potential impacts of man-made sound on marine mammals. For many species and situations, there is no detailed information about reactions to sound. Behavioural reactions of marine mammals to sound are difficult to predict. Marine mammal reactions to sound are dependent on numerous factors including species, state of maturity, experience, current activity, reproductive state, time of day, and weather state. If a marine mammal does react to an underwater sound by changing its behaviour or moving a small distance, the impacts of the change may not be important to the individual, the stock, or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be important.

Based on the literature reviewed in Richardson et al. (1995), it is apparent that most small and medium-sized toothed whales exposed to prolonged or repeated underwater sounds are unlikely to be displaced unless the overall received level is at least 140 dB re 1 µPa. Baleen whales probably have better hearing sensitivities at lower sound frequencies, and in several studies have been shown to react at received sound levels of approximately 120 dB. In general, baleen whales tend to react to lower received levels of continuous sound than of pulsed sound. Toothed whales (odonocetes) appear to exhibit a greater variety of reactions to man-made underwater sound than do baleen whales (mysticetes). Toothed whale reactions can vary from approaching vessels (e.g., to bow ride) to strong avoidance, while baleen whale reactions range from neutral (little or no change in behaviour) to strong avoidance. In general, pinnipeds seem more tolerant of, or at least habituate more quickly to, potentially disturbing underwater sound than whales.

There have been studies of the behavioural responses of several types of marine mammals to airgun discharges. Baleen whales generally tend to avoid operating airguns, but avoidance radii are quite variable. Whales have often been reported as showing no overt reactions to airgun pulses at distances beyond a few kilometres (e.g., Stone and Tasker 2006; Weir 2008). However, some studies of humpback and bowhead whales indicate that reactions, including avoidance, sometimes occur at greater distances from the seismic source than previously documented (e.g., Malme et al. 1984; Richardson et al. 1986; McCauley et al. 1998; 2000a,b). Avoidance distances often exceed the distances at which boat-based observers can see whales.

Studies of several species have determined that received levels of pulses in the 160 to 170 dB re 1 µPa rms range seem to cause obvious avoidance behaviour in a substantial fraction of the baleen whales exposed (Richardson et al. 1995). In some areas, seismic pulses will have diminished to these levels at distances of 4.5 to 14.5 km from the source. Thus, a substantial proportion of the baleen whales within this distance range may show avoidance or other strong disturbance reactions to the seismic array. On the other hand, some baleen whales show considerable tolerance of seismic pulses. However, when the pulses are strong enough, avoidance or other behavioural changes become evident. It has been difficult to determine the maximum distance (or minimum received sound level) at which marine mammal reactions to seismic occur because the responses become less obvious with diminishing received sound level.

Little systematic information is available on the reactions of toothed whales to seismic pulses. Toothed whales reactions to seismic surveying are variable and not well characterized. Dolphins and porpoises are often seen by observers on active seismic vessels, occasionally at close distances (e.g., bow riding). However, some studies have shown localized (~one kilometre) avoidance (e.g., Stone and Tasker 2006; Weir 2008). Recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications (Jochens et al. 2006, 2008; Miller et al. 2006). Small toothed whales have also been reported close to operating airguns (e.g., Stone 2003). There are no specific data on responses of beaked whales to seismic surveys. There is increasing evidence that some beaked whales may strand after exposure to strong sound from mid-frequency sonars. Whether they ever do so in response to low frequency seismic survey sound is unknown.

Few studies on the reactions of pinnipeds to sound from open-water seismic exploration have been published (reviewed in Richardson et al. 1995). Monitoring results indicate that some species may be quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, grey seals exposed to noise from airguns and linear explosive charges reportedly did not react strongly (J. Parsons *in* Greene et al. 1985). However, some seals also show localized and short-term avoidance of areas with operating airguns. Radio-telemetry results demonstrated short-term changes in the behaviour of harbour and grey seals exposed to airgun pulses (Thompson et al. 1998), and harbour seals have also been described as orienting and/or moving away upon exposure to sounds from a large airgun array (Bain and Williams 2006).

Reactions of baleen whales to pulsed sounds varies depending on the sound source level, species of whale, and activity state at the time of the sound (described above), but most baleen whales exhibit some displacement from strong pulsed sounds (reviewed in Malme 1993). In most cases, displacement is temporary and/or of limited extent. Under some circumstances, some species avoid such sounds when source levels are 115 dB (e.g., continuous sounds), whereas at other times, avoidance or disturbance occurs only when received levels exceed 140 dB (e.g., impulsive sounds).

Experimental results suggest that responses to impulsive sound sources are highly variable among toothed whales (e.g., Würsig et al. 2000; Akamatsu et al. 1993). Under some circumstances, some species will avoid such sounds when received levels exceed 180 dB (e.g., impulsive sounds). The variability is presumably related to the fact that the observations and experiments on toothed whales involved a variety of situations, and involved sources that emitted sounds at widely varying source levels and at differing frequencies, pulse lengths, and inter-pulse intervals.

Data on the reactions of seals to pulsed sounds are limited, but the few available reports suggest that they would exhibit either no, or short-term, behavioural responses (e.g., Richardson et al. 1995; Yurk and Trites 2000). Some seals exhibited limited displacement from strong-pulsed sounds and others showed high tolerance for strong underwater sound pulses. Seal reactions varied depending on sound source level, seal species, and activity state at the time of sound exposure. In most cases, displacement was temporary and/or of limited extent, with some species showing high tolerance for strong underwater sound pulses.

There is only one known study of the effect of underwater explosions on baleen whales. Humpback whales in Trinity Bay, Newfoundland apparently showed no changes in behaviour, distribution, or residency times in response to underwater explosions related to industrial activity; however, there was a coincidental increase in the rates of entrapment in fishing gear in Trinity Bay (Todd et al. 1996). Charges were generally 1000 to 2000 kg, with peak source levels typically 140 dB.

There have been a few observations of odontocetes to sound pulses from underwater explosions, but it appears that responses are generally minor. Some species have shown limited, if any, response to small explosive charges (Frost et al. 1984; Klima et al. 1988; Akamatsu et al. 1993). Odontocetes may even be attracted to fish killed by explosions. Sperm whales showed no change in click rates in response to detonations used to calibrate a hydrophone array (Madsen and Mohl 2000).

The available evidence suggests that pinnipeds are quite tolerant of sound pulses from underwater explosions, with little reaction to blasting sounds and only temporary reactions to firecracker-like explosives designed to deter them from feeding around fishing gear (Richardson et al. 1995).

Broadband source levels produced by a working semi-submersible drilling rig may be about 154 dB re 1 μPa-m (Greene 1986)—quite a low source level. Assuming spherical spreading close to the source, received levels would diminish to about 114 dB within 100 m. A semi-submersible drilling rig has large underwater hulls, which act to radiate sound efficiently into the water. In contrast, a drilling rig that is standing on steel legs would likely radiate much less sound into the water during operations (Gales 1982). Based on the documented reactions by cetaceans to floating drillships with large areas of hull in contact with the water, and the lower sound output from a bottom-founded platform, behavioural reactions to a bottom-founded platform could be limited to a very small area.

Baleen whales have sometimes shown behavioural changes in response to received broadband drillship sounds of 120 dB or greater (e.g., Malme et al. 1984, 1985; Richardson et al. 1995; Schick and Urban 2000). Dolphins and other toothed whales may show considerable tolerance of floating and bottom-founded drillrigs and their support vessels. In different studies, individuals of the same species have shown localized disturbance to playbacks of drilling sounds (e.g., Stewart et al. 1982), while others seem quite tolerant (Thomas et al. 1990). Responses of pinnipeds to drilling sounds have not been well studied. Ringed and bearded seals (*Phoca groenlandica* and *Erignathus barbatus*, respectively) in the Arctic appear to be rather tolerant of drilling sound (Richardson et al. 1995).

Sound from an elevated source in the air is refracted upon transmission into water because of the difference in sound speeds in the two media (a ratio of about 0.23). The direct sound path is totally reflected if the sound reaches the surface at an angle more than 13 degrees from vertical. The pressure field is doubled at the surface of the water, resulting in a 6-dB increase in pressure level at the surface because of the large difference in the acoustic properties of water and air. In the case of passing airborne sources, the peak received level at and below the water surface diminishes with increasing source altitude. With increasing horizontal distance from the airborne source, underwater sound diminishes more rapidly than does the airborne sound.

There are published observations of marine mammal reactions to aircraft (for a review, see Richardson et al. 1995). In most cases, airborne or waterborne sound from the aircraft was the apparent stimulus, although vision was probably involved in some cases. Responses to aircraft were variable, partly because of differences in aircraft type, altitude, and flight pattern (e.g., straight-line overflight, circling, or hovering). Such factors can affect the spectral properties, temporal properties, and level of sound received by animals.

In general, baleen whales are more likely to react to an aircraft at low than at high altitude that passes directly overhead rather than well to the side, and that circles or hovers rather than simply flying over (Richardson et al. 1985a,b). Most species of toothed whales do not appear to react overtly to aircraft overflights, except when the aircraft fly at low altitudes. Whales that do react appear to dive hastily, turn, or swim away from the flight path. Seals hauled out for pupping or moulting have variable sensitivities to aircraft disturbance, but react strongly at times, generally by moving abruptly into the water (Richardson et al. 1995). There are few observations of the reactions of seals in the water to aircraft, but overflights at low altitudes cause some animals to dive (Richardson et al. 1995).

4.5.1.6 Sea Turtles

Although there have been a limited number of studies on sea turtle hearing, the available data demonstrate that sea turtles appear to be low-frequency specialists. Information on the potential effects of industrial noise is most directly relevant to seismic exploration. Most studies have focused on short-term behavioural responses of sea turtles in enclosures to single airguns, and little information is available describing exposures of free-ranging turtles. Comparisons of results among studies are difficult, because experimental designs and reporting procedures have varied greatly. However, there is a consistent trend suggesting that sea turtles show avoidance of an operating airgun (e.g., McCauley et al. 2000a,b; Moein et al. 1994; Weir 2007). Only in one case were sea turtles observed during a seismic survey showing no evidence of adverse impacts (Parente et al. 2006).

<u>Physical Effects</u>

There have been few studies that have directly investigated hearing or sound-induced hearing loss in sea turtles. Moein et al. (1994) concluded that five loggerhead turtles (of ~11 tested) exhibited some change in their hearing sensitivity when tested within 24 h after exposure to airgun sound relative to pre-exposure sensitivity, and that hearing had reverted to normal when tested two weeks after exposure. These results are consistent with the occurrence of TTS upon exposure of the turtles to airgun pulses. The report did not state the size of the airgun used, or the received sound levels at various distances. The distances of the turtles from the airgun were also variable during the tests. Thus, the levels of airgun sounds that apparently elicited TTS are not known. Nonetheless, it is noteworthy that there was evidence of TTS from exposure to pulses from a single airgun. However, it may be relevant that these turtles were confined and unable to move more than about 65 m away. Turtles in the open sea might move away, and even if they did not move away, turtles near the seismic line would receive only a few pulses at near-maximum level as the seismic vessel went by.

In theory, a reduction in hearing sensitivity, either temporary or permanent, may be harmful for sea turtles. However, very little is known about the role of sound perception in the sea turtle's normal activities. Hence, it is not possible to estimate how much of a problem it would be for a turtle to have either temporary or permanent hearing impairment. However, hearing impairment, either temporary or permanent, might inhibit a turtle's ability to avoid injury from vessels, because they may not hear them in time to move out of their way. In any event, sea turtles are unlikely to be at great risk of hearing impairment.

Possible types of non-auditory physiological effects or injuries that might occur in sea turtles exposed to strong underwater sound might, in theory, include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. There is no proof that any of these effects occur in sea turtles exposed to sound from airgun arrays. If any non-auditory physiological effects do occur, they would probably be limited to unusual situations when animals might be exposed at close range for unusually long periods.

Behavioural Effects

The paucity of data precludes specific predictions as to how free-ranging sea turtles respond to seismic sounds. The possible responses could include one or more of the following: avoid the entire seismic survey area to the extent that the turtles move to less preferred habitat; avoid only the immediate area around the active seismic vessel, i.e., local avoidance of the source vessel but remain in the general area; and/or exhibit no appreciable avoidance, although short-term behavioural reactions are likely. The potential alteration of a migration route might have negative impacts. However, it is not known whether the alteration would ever be on a sufficient geographic scale, or be sufficiently prolonged, to prevent turtles from reaching an important destination.

Avoidance of a preferred foraging area because of seismic survey sound may prevent sea turtles from obtaining preferred prey species and hence could impact their nutritional status. However, it is highly unlikely that sea turtles would completely avoid a large area along a migration route. Available evidence suggests that the zone of avoidance around seismic sources is not likely to exceed a few kilometres (McCauley et al. 2000b). Avoidance reactions on that scale could prevent sea turtles from using an important coastal area or bay if there was a prolonged seismic operation in the area. Sea turtles might be excluded from the area for the duration of the seismic operation, or they might remain but exhibit abnormal behavioural patterns (e.g., lingering at the surface where received sound levels are lower). Whether those that were displaced would return quickly after the seismic operation ended is generally unknown.

The results of experiments and monitoring studies on responses of marine mammals and fish to seismic surveys show that behavioural responses are possible, depending on species, time of year, activity of the animal, and other unknown factors. The same species may show different kinds of responses at different times of year or even on different days (Richardson et al. 1995). It is reasonable to expect similar variability in the case of sea turtles exposed to airgun sounds. For example, sea turtles of different ages have very different sizes, behaviour, feeding habits, and preferred water depths. Nothing specific is known about the ways in which these factors may be related to airgun sound effects on sea turtles. However, it is reasonable to expect lesser effects in young turtles concentrated near the surface (where levels of airgun sounds are attenuated) as compared with older turtles that spend more time at depth where airgun sounds are generally stronger.

To the best of our knowledge, there are no systematic data on sea turtle reactions to helicopter overflights. Given the hearing sensitivities of sea turtles, they can likely hear helicopters, at least when the helicopters are at lower altitudes and the turtles are in relatively shallow waters. It is unknown how sea turtles would respond, but single or occasional overflights by helicopters would likely only elicit a brief behavioural response. As with respect to helicopter overflights, there are no systematic data on sea turtle reactions to ships and boats but it is thought that response would be minimal relative to responses to seismic sound.

4.5.1.7 Species at Risk and Potentially Sensitive Areas

The potential effects of sound produced by oil and gas exploration and production activities, particularly seismic air gun sound, on those animal species identified as SAR in Subsection 3.7, have been addressed in the preceding subsections on fish habitat, fish, marine-associated birds, marine mammals and sea turtles. Mitigations presented in Subsection 4.5.1.8 would minimize impacts on these animals.

The potential effects of sound produced by oil and gas exploration and production activities, particularly seismic air gun sound, on potentially sensitive areas identified in Subsection 3.8 have been addressed in the preceding subsections on fish habitat, fish, marine-associated birds, marine mammals and sea turtles. Mitigations presented in Subsection 4.5.1.8 would minimize impacts on these sensitive areas.

4.5.1.8 Planning Implications

There are numerous mitigations that can be applied to minimize the potential effects of exposure to sound, especially seismic air gun sound, on the various VECs. They are as follows:

1. **Spatial and temporal avoidance** – Avoidance of specific areas at specific times in order to not expose biota to the seismic sound. This mitigation applies to such things as sensitive fish spawning locations/times, commercial fishery and research survey areas, important cetacean feeding areas, shorebird breeding areas, etc. For example, DFO recommends a 7 to 10 day temporal buffer and a 30 to 40 km spatial buffer between the seismic surveys and DFO surveys in order to reduce the potential for disruption of fish distribution patterns. It will be necessary for operators to develop mitigative protocols in collaboration with fishers and DFO prior to the commencement of seismic operations.
2. **Ramping-up or 'soft starting' the air gun array** – The gradual start-up of a seismic air gun array over a period of 20 to 30 minutes provides time for nearby fish, mobile invertebrates, marine mammals, sea turtles and sea birds to leave the immediate area before the seismic sounds become sufficiently strong to have any potential of causing physical effects. This is a standard mitigation used in the East Coast offshore.
3. **FLOs** – Personnel on marine vessels communicate and mitigate potential conflicts with fishing vessels.
4. **Communications** – Operators should implement operational arrangements to ensure that the operator/survey contractor and the local fishing interests are informed of each other's planned activities (i.e., FLOs and guard vessels). Where more than one survey operation is active in a region, the operator(s) should arrange for a 'Single Point of Contact' for marine users to facilitate communication. The operator should publish a Canadian Coast Guard 'Notice to Mariners' and a 'Notice to Fishers' via the CBC Radio program *Fisheries Broadcast*.
5. **Power-down** – Operators are required to power-down or completely shut-down the air gun array during line changes. If at least a single airgun remains activated, no ramp-up procedures are required to return to full volume.
6. **Shut-down** – Operators are required to shut-down the airgun array if a *SARA*-listed species or other species of concern is detected within the safety zone.
7. **Observers** – Placement of trained observers aboard the seismic vessel to monitor the immediate area from presence of marine mammals and sea turtles is a typical practice during seismic operations. Shutdown "triggers" may vary by location and species.
8. **Minimization of air gun source level** – Minimization of the airgun source level to one practical for the survey will also help limit potential impacts to marine animals. For example, seismic surveying in shallow water areas would have greater potential to impact benthic animals if air gun source levels are as high as those used in deeper water areas.
9. ***Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NLOPB 2008) and the *Statement of Canadian Practice with Respect to the Mitigation of Seismic Sound in the Marine Environment* (DFO 2009l; also in Appendix 2 of C-NLOPB 2008)** – Recommended minimum mitigation measures for seismic sound.

4.5.1.9 Data Gaps

Although the amount of study of the potential effects of exposure to sound, particularly seismic sound, on marine animals has increased substantially during recent years, knowledge on this subject is severely lacking. Marine mammals have received most of the attention in these types of studies, followed by fishes and invertebrates.

Much of the attention is now focused on potential behavioural effects of exposure to sound, the thought being that most marine animals have the capability of moving away from strong sound sources so as to minimize any potential physical effects. However, certain marine invertebrate species are not able to move away from a strong sound source so investigations of potential physical effects are still required. Other data gaps relating to the potential effects of exposure to sound produced by oil and gas exploration and production activities pertain to how underwater sound level attenuation varies by location, chronic effects of prolonged exposure to relatively low level sound, and difference in potential effects of exposure to various sound types (e.g., pulsed versus continuous). Probably the biggest data gap related to the effects of exposure to sound on marine biota is life history and biological knowledge of the animals.

It is premature at this time to adopt sound pressure guidelines for fish and shellfish without some knowledge of dose-response relationships for exposure. The issue of chronic seismic exposure under conditions of a two to three week survey is a knowledge gap for which no information is available for any species. Injury zones may not exist to any extent for fish and shellfish but representative studies are needed if only for assurance. This is supported by recent sublethal effect observations including disturbances on blood parameters, feeding and alteration in gene expression (Payne et al 2007; Andrews et al 2007).

4.5.2 Effects of Drilling Muds and Cuttings

The primary effects of routine offshore drilling on the marine environment, especially the benthic environment, are related to discharge of drilling mud and cuttings. Effects on benthos are described in the following subsection.

4.5.2.1 Fish, Fish Habitat and Fisheries

As discussed previously, drill muds and cuttings have the most potential to affect the sediment and benthos components of the fish habitat VEC but could also affect water quality and plankton for brief periods when the fine components are in suspension. However, the primary potential effects of drill muds and cuttings on fish habitat relate to smothering and contamination of benthic communities near the drill rig, especially sedentary species (Buchanan et al. 2003; Hurley and Ellis 2004). However, the deposition of drilling muds and cuttings is limited both spatially and temporally and would likely have little effect on the Fish Habitat VEC beyond a few hundred metres of the exploratory well.

Drill muds and cuttings have the potential to affect those fish VEC components occurring in the lowest part of the water column (i.e., eggs of some species, juveniles, adult groundfish) but this potential is much lower than for benthos. Again, the deposition of drilling muds and cuttings is limited both spatially and temporally and would likely have minimal effect on the Fish VEC.

The potential effects of drilling muds and cuttings on fisheries are indirect in that the target species could potentially be affected by effects on benthic species, some of which are either commercial species or provide forage for fisheries species. In general, drilling muds and cuttings have minimal potential to affect populations of marine invertebrates and fishes because effects, for the most part, are confined to a limited area of the seabed. In addition, disturbed areas will eventually re-colonize, therefore, the regulated discharge of muds and cuttings has little potential to affect fish at the population level and hence little potential to affect fisheries.

4.5.2.2 Marine-associated Birds

Concerns have been expressed by regulators and interest groups during the White Rose Hearings and some subsequent site-specific EAs that SBMs could create sheens on the water surface that could affect seabirds in much the same way as an oil spill. There have been several SBM spills in the Newfoundland offshore but the authors are not aware of any reported sheens or associated bird mortalities. The potential effects of hydrocarbons on marine-associated birds are discussed in detail in Subsection 4.6.4.4 on accidental hydrocarbon releases.

4.5.2.3 Marine Mammals and Sea Turtles

No interaction of these VECs with drilling muds and cuttings has been identified and thus potential effects on these VECs are not discussed further.

4.5.2.4 Species at Risk and Potentially Sensitive Areas

The only SAR species that have any potential of being directly affected by drilling muds and cuttings are the fishes. However, the deposition of drilling muds and cuttings is limited both spatially and temporally and would likely have minimal effect on fishes, including SAR. However, smothering of any identified critical habitat (as defined under *SARA*) is a potential issue.

The potential effects of drilling muds and cuttings produced by oil and gas drilling activities on potentially sensitive areas identified in Subsection 3.8 have been addressed in the preceding subsections on fish habitat, fish, and fisheries. Mitigations described in Subsection 4.5.2.5 would minimize impacts on these sensitive areas.

4.5.2.5 Planning Implications

There are mitigations that can be applied to minimize the potential effects of drilling muds and cuttings on particular VECs. They are as follows:

1. **Bottom substrate survey** – Operators may be required to survey areas targeted for drilling through the use of ROVs. The surveys would provide information on epibenthic communities and determine the occurrence of any sensitive species, such as deep-sea corals. Smothering of sensitive communities can be avoided using this mitigation.
2. **Minimization of drilling mud toxicity** – Both WBMs and SBMs may be used during the drilling of an offshore well. More specifics on mud formulations per specific hole sections and their respective toxicities would be provided in the applications for approval to drill a well (ADW) that must be approved by the C-NLOPB for each well. In addition, each generic mud formulation must be toxicity tested and the results presented to the C-NLOPB as per the *Offshore Waste Treatment Guidelines* (NEB et al. 2002).
3. **Modeling** – Modeling of cuttings is often conducted during the EA process to determine the extent of cuttings deposition on the sea bottom, both in terms of distance and direction from the well and thickness of the deposited layer. The extent of cuttings deposition is primarily dependant on ocean currents and mud particle sizes. Quality of modeling results is in turn dependant on the quality of data being used in the modeling exercise.
4. **Sheen prevention** – During SBM use, subject to C-NLOPB conditions and approval, mitigation (discharge below surface) is employed to minimize the potential for visible sheens on the water. If conditions are flat calm and sheen appears, it can be dispersed using prop wash from support vessels.

4.5.2.6 Data Gaps

Studies specific to the Newfoundland offshore environment concerning the impacts of smothering on both benthic infauna and epifauna are needed to establish resettlement times and changes in community structure. There are few available data which can be used to estimate benthic recovery rates in the Newfoundland offshore.

4.5.3 Effects of Bottom Disturbance

In addition to the deposition of drill mud and cuttings, bottom disturbance can occur from a variety of exploration and production activities including sediment excavation during glory hole construction, anchor placement, rock berms to protect flowlines, GBS presence, and deployment of various anchors

4.5.3.1 Fish Habitat, Fish and Fisheries

The potential effects of the various activities that could cause bottom disturbance apply to all components of the fish habitat VEC. Sediment and benthos would be most affected by these activities although water and plankton would also be potentially affected by the re-suspension of sediment in the water column. Potential negative effects of bottom disturbance include disruption of substrate, smothering of benthos and suspension of sediments in the water column, resulting in changes to habitat. On the other hand, construction of rock berms could potentially create an increase in habitat diversity and complexity, resulting in a positive effect on the Fish Habitat VEC. In fact, strategic placement of rock of varying sizes yielding various dimensions of interstitial spaces is an accepted marine habitat compensation approach in NL waters.

Bottom disturbance could potentially affect both macroinvertebrate and fish components of the Fish VEC but only minimally. While some mortality could occur, the primary effect would be dislocation of individual animals from a relatively small area. Construction of rock berms could potentially create an increase in habitat diversity and complexity, resulting in a positive effect on the Fish VEC by increasing available food and shelter.

As with drilling muds and cuttings, the potential effects of bottom disturbance on fisheries are indirect in that the target species could potentially be affected. Generally, bottom disturbance has minimal potential to affect populations of marine invertebrates and fishes, and therefore have minimal potential to affect fisheries.

4.5.3.2 Marine-associated Birds, Sea Turtles and Marine Mammals

No interaction of these VECs with bottom disturbance has been identified.

4.5.3.3 Species at Risk and Potentially Sensitive Areas

The only SAR species that have any reasonable potential of being directly affected by bottom disturbance are the fishes. *SARA*-defined critical habitat could become an issue is some locations. Effects are briefly discussed in Subsection 4.5.2.1. The potential effects of bottom disturbance caused by oil and gas exploration and production activities on potentially sensitive areas identified in Subsection 3.8 have been addressed in the preceding subsections on fish habitat, fish, and fisheries. Mitigations described in Subsection 4.5.3.4 would minimize impacts on these sensitive areas.

4.5.3.4 Planning Implications

There are a number of mitigations that can be applied to minimize the potential effects of bottom disturbance on particular VECs. They are as follows:

1. **Bottom substrate survey** – Operators can survey areas that would be disturbed through the use of ROVs. The surveys would provide information on epibenthic communities and determine the occurrence of any sensitive species, such as deep-sea corals. Damage to sensitive communities can be avoided using this mitigation.
2. **Harmful Alteration, Disruption or Destruction (HADD)** – Fish Habitat Compensation is required to satisfy the No Net Loss guiding principle of DFO's Policy for the Management of Fish Habitat and is often included as a condition of a Subsection 35(2) *Fisheries Act* Authorization which is required for the harmful alteration, disruption or destruction of fish and fish habitat. Operators may be required to provide some form of compensation for fish habitat lost during 'bottom disturbance' activities.
3. **Minimize Placement Time** – Minimize the time that temporarily-placed objects, such as anchors and CSEM receivers, are in contact with the substrate.

4.5.3.5 Data Gaps

Determining whether a HADD of fish habitat is likely to occur, quantifying this HADD and negotiating appropriate fish habitat compensation, is required by DFO prior to issuing a Subsection 35(2) *Fisheries Act* authorization. The Habitat Protection Division (HPD) of DFO in the NL Region has developed a draft Habitat Classification/Quantification System which is currently being used to classify and quantify marine habitat in Newfoundland and Labrador. The Department also uses a national practitioner's guide to apply fair and consistent decisions on compensation matters across Canada; however, habitat compensation is considered an adaptive process which may change on a project-by-project basis as new information becomes available through project monitoring and additional research.

4.5.4 Effects of Produced Water

Produced water is normally associated with production activities and not drilling activities. However, in the case of produced water during exploratory or delineation wells, the produced water is shipped ashore or mixed with hydrocarbons burned in the flare. Produced water is discussed in more detail in the subsection on production activities. Most interactions would occur with organisms in the water column unless the water is very shallow. Components of produced water such as hydrocarbons, nutrients, metals, and radioisotopes could potentially affect the water and plankton in the SEA Area. However, the risks from regulated discharges of produced water to ecologically or commercially important marine populations do not appear to be great based on modelling and field sampling studies. The risk from produced water to ecologically or commercially important marine populations in the Newfoundland offshore has not been reported to be high. Nonetheless, potential effects on individuals of *SARA*-listed species should be considered. As with previous sources of effects, the potential effects of produced water on fisheries are indirect in that the target species could potentially be affected.

Environmental observers on project platforms or vessels could be tasked with monitoring for visible sheens and visibly oiled birds.

4.5.4.1 Marine-associated Birds

Fraser et al. (2006) modelled the potential effect of produced water on the Grand Banks on alcids. They used published estimates of alcid density and assumed a daily occurrence of sheens (210 days) and assumed that every contact between birds and sheens causes mortality. Their modelling suggests a potential negative impact ranging in magnitude from low to high within an area of 1 km^2. However, the geographic area from which birds are attracted to a drilling platform may be much greater (Wiese et al. 2001), so the geographic extent of such a negative impact could be greater than 1 km^2 (Faser et al. 2006).

As discussed in greater detail in Subsection 4.6.4.4, exposure to oil can be fatal to seabirds. Although free oil is usually removed from produced water before discharge, oil sheens are sometimes associated with produced water discharges (e.g., ERIN Consulting Ltd. and OCL Services Ltd. 2003). These sheens are thought to be derived from the dispersed oil or soluble medium- to high-molecular weight hydrocarbons components of produced water (Veil et al. 2004). Data on the relationship between sheen thickness and lethality to seabirds are lacking (Hartung 1995). The geographic extent of produced water is usually thought to be 1 km^2 or less (Fraser et al. 2006).

4.5.4.2 Sea Turtles and Marine Mammals

Produced water likely has little direct interaction with sea turtles and marine mammals although these VECs may be indirectly affected through their food organisms if they became contaminated.

4.5.4.3 Species-at-Risk and Potentially Sensitive Areas

The ichthyoplankton of SAR fish species in the SEA Area potentially could be affected by produced water, but the number affected would likely be small compared to the number of ichthyoplankton succumbing to natural mortality. There is some potential for produced water to affect water quality and plankton but it is unlikely that these effects would be large enough to affect the populations of marine animals that characterize the potentially sensitive areas in the SEA Area. However, any potential effects on individuals of *SARA*-listed species should be considered.

4.5.4.4 Planning Implications

There are mitigations that can be applied to minimize the potential effects of produced water on particular VECs. They are as follow:

1. ***Offshore Waste Treatment Guidelines*** (NEB et al. 2002) identify minimum standards for the discharge of effluents from oil and gas drilling and production facilities.
2. **Routine toxicity testing.**

4.5.4.5 Data Gaps

Previous modeling and field studies in the Gulf of Mexico and the North Sea have found few far-field effects (lethal or sublethal) on biota from produced water. Nonetheless, produced water is normally discharged in relatively large volume during production and contains petroleum hydrocarbons including some of the more toxic ones (e.g., PAHs). More *in situ* study of the potential effects of produced water on plankton, zooplankton and ichthyoplankton in the NW Atlantic should be conducted to verify results of laboratory studies and field studies in other regions.

4.5.5 Effects of Lights and Flaring

Seismic vessels, drill rigs, production facilities, and supply and standby vessels will all be equipped with navigation and warning lights. Working areas will be illuminated with floodlights. Drill rigs and production platforms conduct flaring from time to time for safety reasons; flaring produces large amounts of light and heat. Production facilities on the Grand Banks have a continuous safety flare.

4.5.5.1 Fish Habitat, Fish and Fisheries

Some plankton may be attracted to illuminated surface waters near the vessels but the potential effects of this attraction are likely benign. No interactions of the fish and fisheries VECs with lights have been identified.

4.5.5.2 Marine-associated Birds

Seabirds, particularly storm-petrels (Hydrobatidae), are known to be attracted to offshore rigs on the East Coast, presumably due to attraction by light (Montevecchi 2006; Williams and Chardine nd;.; D. Taylor, Husky, pers. comm.). Concern has been expressed during both Terra Nova and White Rose public hearings that this attraction could lead to mortalities if the birds collided with the rig or the flare. Dovekies have also been mentioned as a potential concern.

4.5.5.3 Marine Mammals and Sea Turtles

Although these species may be aware of surface light, no direct effects of lights and flaring has been identified.

4.5.5.4 Species at Risk and Potentially Sensitive Areas

Only the marine-associated birds considered to be SAR are considered to potentially interact with lights and flaring. The information provided in Subsection 4.5.5.2 is relevant to these birds. Only the potentially sensitive areas that are characterized in some way by marine-associated birds are considered to potentially interact with lights and flaring.

4.5.5.5 Planning Implications

There are mitigations that can be applied to minimize the potential effects of lights on marine-associated birds. They are as follows:

1. **Seabird monitoring program** – Production and drilling installations in the Newfoundland and Labrador offshore area are involved in seabird monitoring programs.
2. **Seabird monitoring protocols** – ESRF study on seabird monitoring protocols (Moulton et al. 2004).
3. **Bird release programs** – Programs undertaken by operators to gently capture, hold and release petrels that become stranded on offshore vessels or rigs (Williams and Chardine nd).
4. **Minimization of deck lighting** – Use the minimal amount of lighting required for safe deck operations.

4.5.5.6 Data Gaps

There is no evidence to suggest, with the possible exception of birds, that there are important effects from lights on marine biota. Nonetheless, there has been little systematic study of this potential issue.

4.5.6 Effects of Presence of Structures

Surface structures could include drill rigs, FPSOs, dredges, and seismic streamers and air gun arrays. Subsurface structures would include all of the above as well as flowlines, rock berms to protect flowlines, anchors, and wellhead and riser.

4.5.6.1 Fish Habitat, Fish and Fisheries

The presence of structures results in various effects on fish and fish habitat including those related to the establishment of safety zones and the artificial reef effect. The safety zone would have a potential positive effect on all fish components by excluding other users from the area, including commercial fishers. The safety zone would provide some protection against damage to the seabed by trawlers and shellfish dredges. Hibernia, Terra Nova and White Rose currently have safety zones associated with their production areas.

The artificial reef effect would also have a potential positive effect on some fish habitat components by increasing habitat complexity and, thereby providing increased food and shelter for a more diverse assemblage of marine organisms. The attraction of fish to an oil and gas platform is a well known phenomenon in the Gulf of Mexico and has created an active sportfishery there.

In the North Sea, most of the epifaunal biomass in the upper 50 m is composed of seaweeds, hydroids, mussels, soft corals and anemones. Below that depth, hydroids, soft corals, anemones and tubeworms are the most common animals (Welaptega 1993). Colonization of subsea structures by fouling epifaunal animals and plants might be considered a nuisance and eventually a hazard (i.e., an effect of the environment on the project). If necessary, fouling organisms may be periodically removed using diver- or ROV-deployed brushes or high-pressure water jets (Welaptega 1993). The accumulation of removed fouling organisms on the bottom may further attract invertebrate and fish predators (Dicks 1982).

Safety zones around offshore drilling structures effectively restrict fishers from fishing grounds. However, the areal extent of these safety zones is relatively small compared to all fishing ground available to fishers. The artificial reef effect may actually have long-term benefit to the fisheries in that invertebrates and fishes within the safety zone are not being subjected to commercial fishery pressure but may eventually provide recruitment to the fished animals occurring outside of the safety zone. However, there are also potential negative effects associated with the presence of structures such as exclusion or conflicts with fishing space or gear. In addition, the attraction of animals can have a negative side if they become chronically exposed to contaminants. Placement of structures could become an issue if critical habitat is identified for an area to be developed.

4.5.6.2 Marine-associated Birds

Seabirds are attracted to offshore structures such as drilling rigs and production platforms and vessels (Tasker et al. 1986; Baird 1990; Wiese et al. 2001), including those in Jeanne d'Arc Basin (Wiese and Montevecchi 2000). The reasons for this attraction may be structural stimuli, concentrations of prey attracted to the structures, human waste as food, oceanographic processes and lights and flares (see the summary of Wiese et al. 2001). Seabirds attracted to such structures may be at risk of contact with intermittent presence of oil on the water, collisions with structures, or injuries from flares (Wiese et al. 2001). The potential effects of oil on marine-associated birds are discussed under Accidental Hydrocarbon Releases (Section 4.6.4.4). The potential effects of lights and flaring marine-associated birds are discussed under Routine Activities (Section 4.5.5.2).

4.5.6.3 Marine Mammals and Sea Turtles

Direct physical effects to marine mammals during seismic operations include entanglement with seismic gear. There are no documented cases of marine mammal entanglement, and it is assumed to be a very remote possibility. Towing of hydrophone streamers or other equipment is not expected to significantly interfere with marine mammal movements, including migration, unless they were to become entrapped as indicated above. It is possible that permanent structures will attract marine mammals due to an artificial reef effect, effectively concentrating fish prey resources. For example, harbour porpoise echolocation clicks, indicating foraging activity, were detected around offshore gas installations in the North Sea (Todd et al. 2009). Increased clicks (and presumed foraging) during darkness hours likely reflected the diel vertical movements of their prey species. The authors suggest that these installations may be important foraging areas, particularly at night.

Direct physical effects to sea turtles during seismic operations include entanglement with seismic gear. Entanglement of sea turtles with marine debris is a documented occurrence, and of elevated concern for sea turtles. Seismic personnel reported that sea turtles (number unspecified) have became fatally entrapped between gaps in tail-buoys associated with seismic vessel gear deployed off West Africa (Weir 2007). Towing of hydrophone streamers or other equipment is not expected to significantly interfere with sea turtle movements, including migration, unless they were to become entrapped as indicated above. It is possible that permanent structures will attract sea turtles due to an artificial reef effect, effectively concentrating prey resources.

4.5.6.4 Species at Risk and Potentially Sensitive Areas

All fish, seabird, marine mammal and sea turtle SAR could potentially be affected by the presence of structures associated with oil and gas exploration and production, as indicated in Subsections 4.5.6.1, 4.5.6.2, and 4.5.6.3. Sensitive areas could potentially be affected by the presence of structures associated with oil and gas exploration and production if they occur in the same area.

4.5.6.5 Planning Implications

There are mitigations that can be applied to minimize the potential effects of the presence of structures on a number of VECs. They are as follows:

1. **FLOs** – Personnel on marine vessels used to communicate and mitigate potential conflicts with fixed fishing gear and fishing vessels.
2. **Communications** – Operators should implement operational arrangements to ensure that the operator/survey contractor and the local fishing interests are informed of each other's planned activities (i.e., FLOs and guard vessels). Where more than one survey operation is active in a region, the operator(s) should arrange for a 'Single Point of Contact' for marine users to facilitate

communication. The operator should publish a Canadian Coast Guard 'Notice to Mariners' and a 'Notice to Fishers' via the CBC Radio program *Fisheries Broadcast*. As discussed, fishing (and other) vessels will not be able to enter a safety zone around the drill rig, and this information and the rig's location will be publicized and communicated to the fishing industry. The typical safety zone for a semi-submersible is the anchor pattern plus 50 m. The typical safety zone for a jack-up rig is 500 m from the at-surface structure. Thus there should be no opportunity for conflict with fishing gear. Operators are required to check regulations regarding wellhead removal.

3. **Gear compensation program** – In case of accidental damage to fishing gear or vessels, the operator will implement damage compensation plans to provide appropriate and timely compensation to any affected fisheries participants. The operator will follow the procedures employed successfully in the past for documenting any incidents. Procedures must be in place on the survey vessels to ensure that any incidents of contact with fishing gear are clearly detected and documented.
4. **Environmental Observers** – Can be used to provide information on potential issues arising with attraction of animals and to institute stranded bird rescue protocols. Attraction of animals to structures can be minimized by proper waste handling procedures. Attraction of birds can be minimized by adjusting lighting on structures.

4.5.6.6 Data Gaps

Further study is required of the 'artificial reef effect' where animals are attracted to artificial structures (e.g., rock berms), which is a normal part of oil and gas activities as well as a method (e.g., boulder reefs) for compensating for lost habitat. Results would facilitate science-based discussion in both EA and for HADD compensation programs.

4.5.7 Effects of Liquid and Solid Wastes

Other liquid and solid wastes typically produced during oil and gas industry exploration and production activities include sanitary/domestic waste water, BOP fluid, cooling water, bilge water, ballast water, garbage, and cement. Drill muds and cuttings and produced water are considered in Subsections 4.5.2 and 4.5.4, respectively. Accidental hydrocarbon releases are considered in Subsection 4.6.

4.5.7.1 Fish Habitat, Fish and Fisheries

Liquid and solid wastes released to the marine environment have potential to interact with the Fish Habitat VEC, particularly the water quality and plankton components. However, the mitigations indicated in Subsection 4.5.7.5 should minimize effects on the Fish Habitat VEC. Liquid and solid wastes released to the marine environment water could potentially affect the ichthyoplankton component of the Fish VEC. However, the mitigations indicated in Subsection 4.5.7.5 should minimize effects on the Fish VEC.

The potential effects of liquid and solid wastes on fisheries are indirect in that the target species could potentially be affected. Generally, liquid and solid wastes have minimal potential to affect populations of marine invertebrates and fishes, and therefore have minimal potential to affect fisheries in the SEA Area.

4.5.7.2 Marine-associated Birds

Waste fluids containing treated oily water, like machinery deck drainage and bilge water, may have the potential to affect the health of seabirds. However, because these substances are treated, recycled, or discharged below the water surface, effects on seabirds are likely minimal in the absence of upsets. Effects of hydrocarbons on marine-associated birds are discussed in Subsection 4.6 on accidental hydrocarbon releases.

4.5.7.3 Marine Mammals and Sea Turtles

No direct interactions of these VECs with liquid and solid wastes have been identified although indirect interactions through food organisms are possible.

4.5.7.4 Species at Risk and Potentially Sensitive Areas

The ichthyoplankton of SAR fish species in the SEA Area could potentially be affected by liquid and solid wastes, but the number impacted would likely be small compared to the number of ichthyoplankton succumbing to natural mortality. As indicated in Subsection 4.5.7.1 on fish habitat, there is some potential for liquid and solid wastes to affect water quality and plankton but it is unlikely that these effects would be large enough to measureably affect the populations of marine animals that characterize the potentially sensitive areas in the SEA Area.

4.5.7.5 Planning Implications

There are mitigations that can be applied to minimize the potential effects of liquid and solid wastes on particular VECs. The primary mitigations are contained in the *Offshore Waste Treatment Guidelines* (NEB et al. 2002). The *OWTG* dentify minimum standards for the discharge of effluents from oil and gas drilling and production facilities. [Note that these guidelines are presently being revised.]

4.5.7.6 Data Gaps

The potential effects of exposure to various liquid and solid wastes on plankton, zooplankton and ichthyoplankton should be studied further.

4.5.8 Effects of Atmospheric Emissions

Atmospheric emissions from aircraft, vessels, flaring, fugitive emissions, and generators will occur during all types of oil and gas industry exploration and production activities.

4.5.8.1 Fish, Fish Habitat and Fisheries

No interaction of these VECs with atmospheric emissions has been identified.

4.5.8.2 Marine-associated Birds, Sea Turtles and Marine Mammals

Although atmospheric emissions could, in theory, affect the health of some air-breathing animals, the effects would likely be minimal because emissions of potentially harmful materials will rapidly disperse to undetectable levels in the often windy offshore environment. In addition, exposure times of these highly mobile animals would be very brief.

4.5.8.3 Species at Risk and Potentially Sensitive Areas

Considering the rapid dispersion of atmospheric emissions offshore direct effects of atmospheric emissions on SAR would be minimal. Considering the rapid dispersion of atmospheric emissions (see Subsection 4.5.8.2), direct effects of atmospheric emissions on potentially sensitive areas would be minimal.

4.5.8.4 Planning Implications

There are mitigations that can be applied to minimize the potential effects of atmospheric emissions on particular VECs. They include careful selection of fuels and new equipment, and regular maintenance to maintain engine efficiency. Operators are required to use best available technology to minimize emissions.

4.5.8.5 Data Gaps

Further research and development could be done to lessen atmospheric emissions from more efficient fuel burning equipment and cleaner burning fuels. Although no effects are expected, there are few, if any, data of the effects of air emissions on marine animals.

4.5.9 Effects of Marine Vessel Presence (non-acoustic effects)

4.5.9.1 Fish Habitat, Fish and Fisheries

There is some potential for interaction between the physical presence of marine vessels and the Fish Habitat, Fish and Fisheries VECs. One of the primary concerns of the physical presence of marine vessels relates to potential conflicts with commercial fixed gear, and to a lesser degree, fisheries vessel traffic. Contact between marine vessels associated with oil and gas exploration and production activities and fixed fishing gear would likely result in gear damage and/or loss. There is also potential for interaction between marine vessel presence and the three VECs through the introduction of invasive species, primarily in the coastal areas.

4.5.9.2 Marine-associated Birds

Marine vessel presence could potentially affect marine-associated birds by attracting them. This is discussed above in Subsection 4.5.5 on potential effects of lights on birds.

4.5.9.3 Marine Mammals and Sea Turtles

Marine mammals may respond to the physical presence of vessels and/or to the production of underwater sound by the engine and propellers. Baleen whales may also be at risk of serious injury or mortality due to ship strikes. Sea turtle injury or mortality may also occur due to collisions with vessels, particularly with vessels traveling at speeds >4 km/h (Hazel et al. 2007). Large species such as leatherback sea turtles that spend extended periods near the surface would be more susceptible to ship strikes.

Reactions of baleen whales to vessels are variable, ranging from approach to avoidance (Richardson et al. 1995). Several species show localized avoidance of areas with high vessel traffic or move away when vessels are within several kilometres (e.g., Baker and Herman 1989). In other cases, baleen whales exhibit little or no reaction to boats (e.g., Watkins 1986). Abrupt changes in vessel speed or course appear to elicit the strongest responses. Many odontocetes also show considerable tolerance of vessel traffic, although they sometimes react at long distances if confined by ice or shallow water, or if previously harassed by vessels (Richardson et al. 1995). Dolphins of many species approach vessels to ride bow or stern waves (Shane et al. 1986). In contrast, other studies have shown that dolphin behaviour becomes more erratic, avoid areas and times characterised by high vessel traffic, decrease foraging, or increase swimming speed as a response to vessels (e.g., Williams et al. 2002; Lusseau 2005; Bejder et al. 2006). Pinnipeds also display a range of behavioural responses to vessels. Seals often approach and follow nearshore fishing vessels, but hauled out seals may flee approaching boats (Suryan and Harvey 1999).

For fast-moving and large ships, there is also the possibility of cetacean mortality or injury due to ship strikes. As the speed and numbers of ships transiting marine waters has increased through time, so have the instances of collision between ships and cetaceans; 11 species are known to be struck by ships, with fin whales being most frequently struck, but right, humpback, sperm, and gray whales are also regularly hit (Laist et al. 2001). There are less frequent records of collisions with blue, sei, and minke whales (Laist et al. 2001). Collisions with ships travelling at speeds above 14 kts are expected to result in critical injury for large baleen whales (Laist et al. 2001). Any large whale, particularly the baleen whales, would be susceptible to ship strikes, but vessel collisions are of particular concern for slow-moving, surface-oriented right whales. Mortality induced by ship strikes is recognized as a primary factor limiting the recovery of North Atlantic right whales (Glass et al. 2008; Brown et al. 2009).

4.5.9.4 Species at Risk and Potentially Sensitive Areas

The primary concern of the physical presence of marine vessels with respect to the SAR VEC is ship strikes. Marine mammals and sea turtles are vulnerable to being struck and injured by moving marine vessels (Subsection 4.5.9.3).

4.5.9.5 Planning Implications

There are a number of mitigations that can be applied to minimize the potential effects of marine vessel presence on fisheries, marine mammals and sea turtles:

1. **FLOs** – Personnel on marine vessels used to communicate and mitigate potential conflicts with fixed gear and vessels.
2. **Communications** – Operators should implement operational arrangements to ensure that the operator/survey contractor and the local fishing interests are informed of each other's planned activities (i.e., FLOs and guard vessels). Where more than one survey operation is active in a region, the operator(s) should arrange for a 'Single Point of Contact' for marine users to facilitate communication. The operator should publish a Canadian Coast Guard 'Notice to Mariners' and a 'Notice to Fishers' via the CBC Radio program *Fisheries Broadcast*.
3. **Gear compensation program** – In case of accidental damage to fishing gear or vessels, the operator will implement damage compensation plans to provide appropriate and timely compensation to any affected fisheries participants. The operator will follow the procedures employed successfully in the past for documenting any incidents. Procedures must be in place on the marine vessels to ensure that any incidents of contact with fishing gear are clearly detected and documented.
4. **Constant speed and course** – Vessels should maintain a constant speed and course when in the presence of marine mammals, as much as possible. If feasible, vessel operators should take evasive action (including reducing speed) if large whales or sea turtles are detected within the vessel's path and the vessel is traveling at high speeds.
5. **Marine mammal/sea turtle observers** – Placement of trained observers aboard geophysical survey vessels to monitor the immediate area from the presence of marine mammals and sea turtles is a typical practice during seismic operations.

4.5.9.6 Data Gaps

Additional and more precise data are needed on the distribution in time and space of marine mammals, sea turtles and fishing activities.

4.6 Accidental Hydrocarbon Releases

This section discusses the various types of accidental hydrocarbon releases that could occur during oil and gas exploration and production activities, specifically blowouts and batch spills. Blowouts and batch spills are briefly described, followed by discussions of probability of occurrence of each type of accidental release, the fate and behaviour of different types of released hydrocarbons, the potential effects of released hydrocarbons on the various VECs, and the mitigations that would be used to minimize the effects of released hydrocarbons. Mitigations will be discussed in the subsection on planning implications. Data gaps related to accidental hydrocarbon releases and their effects will also be identified.

More details on accidental hydrocarbon releases would be provided in a project-specific environmental assessment that will be done for any proposed oil and gas exploration and production program within the SEA Area.

4.6.1 Blowouts and Spills

Blowouts are continuous releases lasting hours, days or weeks that could involve the discharge of hydrocarbon gas into the air and crude oil into surrounding waters. Batch spills are short-duration releases of oil that could occur from accidents on the drilling platforms or support vessels where fuel oil and other hydrocarbon products are stored and handled. The international oil and gas industry primarily works with the oil volume unit of petroleum barrel (which is different than a U.S. barrel and a British barrel). There are 6.29 petroleum barrels in one m^3 (1000 litres/ m^3; 159 litres/bbl).

A study by the U.S. National Academy of Sciences (NAS 2003) indicated that the oil extraction industry worldwide contributes <3% of the total petroleum input to the environment. In the U.S. Outer Continental Shelf (OCS) where 28,000 wells were drilled and over 10 billion (10^9) barrels (bbl) of oil and condensate were produced from 1972 to 2000, only ten blowouts occurred that involved release of oil or condensate. The total oil released in the ten events was 751 bbl.

The practices and technologies that will be used during any drilling in the SEA Area will be in accordance with the accepted practices of the international petroleum industry, as a minimum.

4.6.2 Accidental Hydrocarbon Release Sizes

Five hydrocarbon release size categories are typically used for detailed analyses (Table 4.5). Note that the top three categories are cumulative (i.e., the large-spill category (>1000 bbl) includes the very large and extremely large spills, and the very large category includes extremely large spills).

Table 4.5. Accidental Hydrocarbon Release Size Categories.

Release Size Category	Volume of Release Size		
	Barrels (bbl)	Litres (l)	Cubic Metres (m^3)
Extremely large	>150,000	>23.85 million	>23,850
Very large	>10,000	>1.59 million	>1590
Large	>1000	>159,000	>159
Medium	50 – 1000	7950 – 159,000	7.95 - 159
Small	1 - 49.9	159 – 7949	0.159 - 7.949

The main concern from a safety, environmental, and economic perspective is a well blowout that releases large quantities of oil into the marine environment. In the U.S., only two oil-well blowouts involving oil releases >50,000 bbl have occurred since offshore drilling began in the 1950s. Worldwide, there have been five 'extremely large' accidental hydrocarbon releases in the history of offshore drilling, two of which occurred during development drilling, two during production or work-over activities, and the fifth, the largest, during exploration drilling. This largest oil release in history was caused by drilling procedures (used by Petróleos Mexicanos (PEMEX, Mexico's national oil company) that are not practiced in U.S. or Canadian waters. These drilling procedures are contrary to U.S. and Canadian regulations and to the accepted practices within the international oil and gas industry.

Almost no historical information is available on 'large' accidental hydrocarbon releases (>1000 to 10,000 bbl). These likely have occurred with greater regularity than 'very large' releases (>10,000 bbl). While no 'large' releases from blowouts have occurred in U.S. Gulf of Mexico (GOM) OCS operations since 1972, it seems likely that several have occurred elsewhere.

The lone recorded 'large' accidental hydrocarbon release in the Newfoundland and Labrador Offshore Area (NLOA) occurred in November 2004 at Petro-Canada's Terra Nova production site. The spill involved ~1038 bbl (~165,000 l) of crude oil (Table 4.6). The spill occurred when an emulsion formed in the test separator due to inadequate metering of demulsifier to the test separator. Oil water separator was impeded in the test separator resulting in an oil water emulsion being sent through the produced water system and not water with a high oil concentration.

Table 4.6 presents information on oil and gas industry-related hydrocarbon spills >1 litre on the NLOA from 1997 to present. Other than the one large crude release in 2004, the summary data represent five medium category releases of SBM, 39 small category releases of various hydrocarbon types, and 145 accidental hydrocarbon releases with volumes <159 l (i.e., 1 bbl). Almost 64% of the total volume of hydrocarbons accidentally released on the NLOA since 1997 occurred in 2004. Releases in 2003 and 2007 accounted for almost 25% of the 1997 to 2009 total volume. Since 1997, 200 exploration and production wells have been drilled in the NLOA. No blowouts have occurred during that time.

Probabilities of occurrence of various sized accidental hydrocarbon releases can be calculated for the NLOA although the data time series is relatively short compared to the database for the U.S. GOM OCS. Comparison between the two offshore areas in terms of accidental release probability must consider the caveat that statistics for the NLOA include more spill types and sizes than do those for the U.S. GOM OCS.

4.6.3 Fate and Behaviour

Oil spill fate/behaviour and trajectory modeling has been conducted in association with numerous drilling programs proposed for the Newfoundland and Labrador offshore area in recent years.

Typical input data required for fate/behavior and trajectory modeling include the following:

- Crude oil and diesel properties;
- Volumes of crude and diesel released to the marine environment;
- Surface water current data;
- Air and water temperature data; and
- Wind and wave data.

The modeling provides some idea of the persistence and direction of movement of crude and diesel oil in specific geographic/environmental scenarios. The higher the quality of data entered into the model, the more realistic the modeling results.

4.6.4 Interactions and Potential Effects of Accidental Hydrocarbon Releases

Any accidental release of hydrocarbons has the potential to interact with all VECs. The potential effects of exposure of each VEC to accidentally released hydrocarbons are briefly discussed in this subsection. More detailed discussion of potential interactions, effects, and significance of post-mitigation residual effects would be provided in project-specific environmental assessments of proposed oil and gas projects. Possible mitigations intended to reduce residual effects of accidental hydrocarbon releases are discussed in Subsection 4.6.7.11 Planning Implications.

Table 4.6. Oil Spill (>1 Litre) Data Pertaining to the Newfoundland and Labrador Offshore Area, 1997-2009.

Year	Number of Spills by Oil Type						Volume of Spills by Oil Type (l)					
	Crude	Diesel	Hydraulic	Synthetic Based Mud/Fluid[1]	Others[2]	TOTAL	Crude	Diesel	Hydraulic	Synthetic Based Mud/Fluid[1]	Others[2]	TOTAL
2009	3	0	1	0	4	**8**	181	0	2	0	11	**194**
2008	6	0	0	1	7	**14**	4629	0	0	100	178	**4907**
2007	0	0	0	2/0	3	**5**	0	0	0	75,089/0	93	**75,182**
2006	3	0	4	4/0	0	**11**	605	0	18	3630/0	0	**4253**
2005	4	0	6	1/0	1	**12**	17	0	24	4030/0	140	**4211**
2004	8	1	9	4/1	3	**26**	165,813	3	68	108,101/2	12	**273,999**
2003	2	1	8	3/1	1	**16**	11	100	275	30,100/2	925	**31,413**
2002	2	1	0	1/1	2	**7**	5	10	0	12,000/250	11	**12,276**
2001	0	2	4	1/1	1	**9**	0	5	118	5000/600	3	**5726**
2000	2	0	0	5/0	1	**8**	220	0	0	4700/0	2	**4922**
1999	12	7	4	3/5	7	**38**	985	924	690	7,340/32	263	**10,234**
1998	7	8	0	0/2	8	**25**	375	3312	0	0/2008	95	**5790**
1997	2	6	2	0/0	1	**11**	1004	476	211	0/0	40	**1731**
TOTAL	**48**	**26**	**38**	**35**	**34**	**190**	**169,362**	**4830**	**1406**	**252,884**	**1649**	**430,131**

Notes: [1] Includes both synthetic based mud and synthetic based fluid. Numbers and volumes of each separated by /.
[2] Includes mixed oil, condensate, well bore fluids, unidentified oil/hydrocarbons, jet, and lubricating oil.

Source: C-NLOPB website, 18 May 2009.

4.6.4.1 Fish Habitat

There has been extensive study of the effects of oil spills on fish habitat (Armstrong et al. 1995; Rice et al. 1996; and others). The fish habitat VEC includes plankton because it is a source of food for larvae and some adult fish thus, effects of an oil spill or blowout on plankton could affect fish. Dispersion and dissolution cause the soluble, lower molecular weight hydrocarbons to move from the slick into the water column. Effects of spills on pelagic organisms need to be assessed through examination of effects of water-soluble fractions of oil or light hydrocarbon products.

Effects of crude oil spills on plankton are short-lived, with zooplankton being more sensitive than phytoplankton. Zooplankton accumulate hydrocarbons in their bodies. The hydrocarbons may be metabolized and depurated (Trudel 1985). Hydrocarbons accumulated in zooplankton during a spill would be depurated within a few days after a return to clean water and thus, there is limited potential for transfer of hydrocarbons up the food chain

(Trudel 1985). There is a potential for transfer of hydrocarbons up the food chain in an environment subject to chronic inputs of hydrocarbons, but there is no potential for biomagnification. Celewycz and Wertheimer (1996) concluded that the *Exxon Valdez* spill did not reduce the available prey resources, including zooplankton, of juvenile salmon in Prince William Sound.

Mortality of zooplankton can occur at diesel concentrations of 100 to 10,000 ppm (24 to 48 h LC_{50}, where LC_{50} is the concentration of toxicant that kills 50 percent of the test animals; Trudel 1985). Diesel oil is much more toxic, but shorter-lived in the open ocean, than crude oil. There is great variability among species and some species are relatively insensitive. For example, the 96-h LC_{50} of crude oil for *Calanus hyperboreus*, a common cold water copepod, was 73,000 ppm (Foy 1982). Complete narcotization of copepods can occur after a 15-min exposure to 1800 ppm of aromatic heating oil and mortality can occur after a 6-h exposure (Berdugo et al. 1979). Exposure to concentrations of 1000 ppm of aromatic heating oil for three days had no apparent effect on mobility, but exposure for as little as 10 minutes shortened life span and total egg production (Berdugo et al. 1979). No. 2 fuel oil at concentrations of 250 to 1000 ppm completely inhibited or modified copepod feeding behaviour, while concentrations of 70 ppm or lower may not affect feeding behaviour (Berman and Heinle 1980). Exposure to naphthalene at concentrations of 10 to 50 ppm for 10 days did not affect feeding behaviour or reproductive potential of copepods although egg development was not examined (Berdugo et al. 1979). Individual zooplankton could be affected by a blowout or spill through mortality, sublethal effects, or hydrocarbon accumulation if oil concentrations are high enough. However, the predicted maximum concentrations for batch and blowouts are well below those known to cause effects.

Under some circumstances, oil spilled in nearshore waters can become incorporated into nearshore and intertidal sediments, where it can remain toxic and affect benthic animals for years after the spill (Sanders et al. 1990). Oil from an offshore spill will not likely become incorporated in the sediments. Oil released from an offshore blowout should quickly rise to the surface.

4.6.4.2 Fish

The fish VEC includes fish and invertebrate eggs and larvae, juvenile fish and invertebrates, adult pelagic fish and invertebrates, and adult groundfish/demersal invertebrates. Planktonic fish eggs and larvae (ichthyoplankton) are less resistant to effects of contaminants than are adults because they are not physiologically equipped to either detoxify them or actively avoid them. In addition, many eggs and larvae develop at or near the surface where oil exposure may be the greatest (Rice 1985; see also Section 3.0 for a description of ichthyoplankton on the Grand Banks). It is estimated that sensitivities of fish larvae range from 0.1 to 1.0 ppm of soluble aromatic hydrocarbons, approximately 10 times the sensitivities of adults (Moore and Dwyer 1974). However, an organism's sensitivity to oiling is not simply a function of age.

Generally, fish eggs appear to be highly sensitive at certain stages and then become less sensitive just prior to larval hatching (Kühnhold 1978; Rice 1985). Larval sensitivity varies with yolk sac stage and feeding conditions (Rice et al.

1986). Eggs and larvae exposed to high concentrations of oil generally exhibit morphological malformations, genetic damage, and reduced growth. Damage to embryos may not be apparent until the larvae hatch. For example, although Atlantic cod eggs were observed to survive oiling, the hatched larvae were deformed and unable to swim (Kühnhold 1974). Atlantic herring larvae exposed to oil have exhibited behavioural abnormalities such as initial increased swimming activity followed by low activity, narcosis, and death (Kühnhold 1972). Similarly, Pacific herring eggs and larvae (possibly exposed as embryos) collected from beaches contaminated with *Exxon Valdez* oil in 1989 exhibited morphological and genetic damage (Hose et al. 1996; Norcross et al. 1996; Marty et al. 1997). Marty et al. (1997) indicated that herring larvae collected from oiled sites had ingested less food, displayed slower growth, and had a higher prevalence of cytogenetic damage than those sampled from ‘clean’ sites. However, these effects were not observed in eggs and larvae collected in later years (Hose et al. 1996; Norcross et al. 1996) and there is no conclusive evidence to suggest that these oiled sites posed a long-term hazard to fish embryo or larval survival (Kocan et al. 1996).

The natural mortality rate in fish eggs and larvae is so high that large numbers could be destroyed by anthropogenic sources before effects would be detected in an adult population (Rice 1985). Oil-related mortalities would probably not affect year-class strength unless >50% of the larvae in a large proportion of the spawning area died (Rice 1985). Herring are one of the most sensitive fish species to oiling. Hose et al. (1996) claim that even though 58% fewer than normally expected herring larvae were produced at a site oiled during the *Exxon Valdez* spill, no effect would be detected at the population level. Ten-day exposures of large numbers of pink salmon smolt (*Oncorhynchus gorbuscha*) to the water-soluble fraction of crude oil (0.025 to 0.349 ppm) did not result in any detectable effects on their survival to maturity (Birtwell et al. 1999). However, it should be noted that pink salmon may be more resistant to environmental disturbance than other species because they spend so much time in the variable estuarine environment.

The occurrence, abundance and distribution of ichthyoplankton in the SEA Area are highly variable by season and dependent on a variety of biological (e.g., stock size, spawning success, etc.) and environmental (temperature, currents, etc.) factors. In the event of a blowout or spill in the SEA Area, there is potential for individual ichthyoplankters in the upper water column to sustain lethal and sublethal effects following contact with high concentrations of oil. The LC_{50} value at 25°C used by Hurlbut et al. (1991) to predict effects on ichthyoplankton was 0.0143 ppm.

As in the case of fish larvae, the sensitivity of invertebrate larvae to petroleum hydrocarbons varies with species, life history stage, and type of oil. Generally, invertebrate larvae are more sensitive to effects of oil than are adult invertebrates. Sublethal and lethal effects on individual larvae are possible during a spill or blowout in the SEA Area. American lobster larvae (Stages 1 to 4) showed a 24-h LC_{50} of 0.1 ppm to Venezuelan crude oil (Wells 1972). Larvae exposed to 0.1 ppm of South Louisiana crude oil swam and fed actively while those exposed to 1 ppm were lethargic (Forns 1977). Stage 1 crab larvae (king crab, *Paralithodes camtschatica* and Tanner crab (*Chionectes bairdi*)) succumbed to similar concentrations of crude oil (0.96 to 2 ppm; Brodersen et al. 1977) while larval shrimp generally had higher LC_{50} limits (0.95 to 7.9 ppm; Brodersen et al. 1977; Mecklenburg et al. 1977). Anderson et al. (1974) tested a variety of crude and refined oils and found that post-larval brown shrimp (*Penaeus aztecus*) were less sensitive than adult invertebrate species. Also, moulting larvae appear to be more sensitive to oil than intermoult larvae (Mecklenburg et al. 1977). Kerosene affected development of sea urchin embryos at concentrations of 15 ppb or greater, as did gasoline at concentrations of 28 ppb or greater (Falk-Petersen 1979). Invertebrate larvae exposed to oil may exhibit reductions in food consumption and growth rate, and increases in oxygen consumption (Johns and Pechenik 1980). Despite these physiological changes, deleterious effects on invertebrate populations have not been detected, even after major oil spills (Armstrong et al. 1995). Larval distribution and settlement, fecundity, recruitment and growth of juveniles and subadult crab, pandalid shrimp, clams and scallops were not significantly affected by the *Exxon Valdez* oil spill (Armstrong et al. 1995).

The geographical and seasonal distribution of fish eggs and larvae in the region is highly variable. For example, in general, there are two peaks in abundance of ichthyoplankton on the Grand Banks. The first typically occurs in April-May and the second in August-September. As already indicated, the eggs and larvae of most of the above species are distributed in the upper 50 m of the water column. When all of the above ichthyoplankton are considered as a whole, the period of their occurrence in the plankton is quite broad (i.e., March to October).

There is an extensive body of literature regarding the effects of exposure to oil on juvenile and adult fish. Although some of the literature describes field observations, most refers to laboratory studies. Reviews of the effects of oil on fish have been prepared by Armstrong et al. (1995), Rice et al. (1996), and numerous other authors. If exposed to oil in high enough concentrations, fish may suffer effects ranging from direct physical effects (e.g., coating of gills and suffocation) to more subtle physiological and behavioural effects. Actual effects depend on a variety of factors such as the amount and type of oil, environmental conditions, species and life stage, lifestyle, fish condition, degree of confinement of experimental subjects, and others. Based on laboratory toxicity studies, pelagic fish tend to be more sensitive (LC_{50}s of 1 to 3 ppm) than either benthic (LC_{50}s of 3 to 8 ppm) or intertidal fish species (LC_{50}s of >8 ppm) (Rice et al. 1979). An LC_{50} is based upon controlled laboratory experiments using confined fish, usually in a container of standing water. The result is expressed as the concentration of a contaminant that achieves a mortality rate of 50%. There are recognized problems in applying LC_{50} data to the ”real world” but they are useful for “ball park” comparative information, especially in situations where it is very difficult to obtain good controlled field data.]

Reported physiological effects on fish have included abnormal gill function (Sanders et al. 1981 and Englehardt et al. 1981 *in* Brzorad and Burger 1994), increased liver enzyme activity (Koning 1987; Payne et al. 1987), decreased growth (Swatrz 1985 *in* Brzorad and Burger 1994; Moles and Norcross 1998), organ damage (Rice 1985), and increased disease or parasites loads (Brown et al. 1973; Steedman 1991 *in* Brzorad and Burger 1994; Carls et al. (1998); Marty et al. 1999).

Reported behavioural effects include avoidance of contamination by migrating salmon (Weber et al. 1981), and cod in laboratory studies at refined petroleum levels in excess of 100 µg/L (Bohle 1986 *in* Crucil 1989), and altered natural behaviours related to predator avoidance (Gardner 1975; Pearson et al. 1984) or feeding (Christiansen and George 1995). Juvenile (i.e., those past the egg and larval stages) and adult fish can and probably will avoid any crude oil by swimming from the blowout/spill region (Irwin 1997).

4.6.4.3 Fisheries

The primary effects of accidental hydrocarbon releases on the Fisheries VEC pertain to physical effects on target species (see Subsection 4.6.4.2 on Fish VEC), tainting of target species, fouling of gear, and perceived tainting of target species. Physical effects on fish from a spill may not be extensive because of their avoidance abilities. However, economic impacts might occur if the spill prevented or impeded a harvester’s ability to access fishing grounds (because of areas temporarily excluded during the spill or spill clean-up), caused damage to fishing gear (through oiling) or resulted in a negative effect on the marketability of fish products (because of market perception resulting in lower prices, even without organic or organoleptic evidence of tainting).

If a spill slick were to reach an area when fisheries were active, it is likely that fishing would be halted, owing to the possibility of fouling the buoy lines, or the nets or pots if these were raised through the slick. Exclusion from a spill area would be expected to be short-term, as typical sea and wind conditions would promote fairly rapid evaporation and weathering of the slick, and fishing vessels would likely be able to return within several days. Nevertheless, if fishers were required to cease fishing, harvesting might be disrupted. An interruption could result in an economic impact because of reduced catches, or extra costs associated with having to relocate crab harvesting effort.

Effects due to market perceptions of poor product quality (no buyers or reduced prices, etc.) are more difficult to predict, since the actual (physical) impacts of the spill might have little to do with these perceptions. It would only be possible to quantify these effects by monitoring the situation if a spill were to occur.

4.6.4.4 Marine-associated Birds

Marine-associated birds are the marine animals most at risk from oil spills and blowouts. Exposure to oil causes thermal and buoyancy deficiencies that typically lead to the deaths of affected seabirds. Although some may survive these immediate effects, long-term physiological changes may eventually result in death (Ainley et al. 1981; Williams 1985; Frink and White 1990; Fry 1990). Reported effects vary with bird species, type of oil (Gorsline et al. 1981), weather conditions, time of year, and duration of the spill or blowout. Although oil spills at sea have the potential to kill tens of thousands of seabirds (Clark 1984; Piatt et al. 1990), some studies suggest that even very large spills may not have long-term effects on seabird populations (Clark 1984; Wiens 1995).

Preening leads to the ingestion of significant quantities of oil which, although apparently only partially absorbed (McEwan and Whitehead 1980) can cause lethal effects (Holmes et al. 1979; Peakall et al. 1980, 1982; Khan and Ryan 1991). Birds exposed to oil are also at risk of starvation (Hartung 1967, 1995; Gorman and Milne 1970; McEwan and Koelink 1973). It appears that direct, long-term sublethal toxic effects on seabirds are unlikely (Neff 1985 *in* Hartung 1995; Hartung 1995; McEwan and Whitehead 1980). However, nesting seabirds that are contaminated with oil, but still survive generally exhibit decreased reproductive success (Eppley and Rubega 1990; Harfenist et al. 1990).

Considering the proximity of the SEA Area to the south coast of Newfoundland, there are potential effects of accidental events on coastal bird habitats and sensitive areas, particularly the identified IBAs and Piping Plover critical habitat sites. There is no conclusive evidence that oil spills have either caused marked reductions in bird populations or have changed community structure at a large scale (Leighton 1995). Some studies have suggested that oil pollution is unlikely to have major long-term effects on bird productivity or population dynamics (Clark 1984; Butler et al. 1988; Boersma et al. 1995; Wiens 1995) while others suggest the opposite (Piatt et al. 1990; Walton et al. 1997). Natural interannual variation in other factors that affect populations (e.g., prey availability and weather) reduces the ability of scientists to assess the full effect of oil spills on bird populations.

It is clear that truly aquatic and marine species of birds are most vulnerable and most often affected by exposure to marine oil spills. Diving species such as the Alcidae, sea ducks, loons, and grebes are considered to be the most susceptible to the immediate effects of surface slicks (Leighton et al. 1985; Chardine 1995; Wiese and Ryan 1999, 2003). Alcids often have the highest oiling rate of seabirds recovered from beaches along the south and east coasts of the Avalon Peninsula, Newfoundland (Wiese and Ryan 1999, 2003). Other species such as fulmars, shearwaters, storm-petrels, gulls and terns are vulnerable to contact with oil because they feed over wide areas and make frequent contact with the water's surface. They are also vulnerable to the disturbance and habitat damage associated with oil spill cleanup (Lock et al. 1994). In the SEA Area, this would include species like terns and storm-petrels. Oil residues in bedrock habitat, like that used by most seabirds in Newfoundland, do not persist as long as residues in sedimentary habitat (e.g., sand beaches) (Gilfillan et al. 1995).

Birds are particularly vulnerable to oil spills during nesting, moulting, and prior to young seabirds gaining the ability to fly. Newly fledged murres and Northern Gannets are unable to fly for the first two to three weeks at sea, and are, therefore, less likely to avoid contact with oil during this time (Lock et al. 1994). Before and during moult, the risks of hypothermia and drowning (Erasmus and Wessels 1985) are increased because feather wear and loss reduce the ability to repel water by about 50% (Stephenson 1997). As discussed in Section 3.0, a small number of pairs of the *endangered* Piping Plover nest on coastal beaches in the SEA Area. Sandy beaches are rare on the coast of Newfoundland and Cape Breton and Piping Plovers are vulnerable to oil washed ashore and to human disturbance (Lock et al. 1994). Consequently, most of such beaches are officially protected to preserve breeding habitat. Terns are less vulnerable to oil, but spill clean-up activities may disturb nesting terns and cause nesting failure (Lock et al. 1994).

Several oil spills have occurred on the Grand Banks, and "small" oil releases (most likely from bilge pumping and de-ballasting by vessel traffic) occur frequently, killing thousands of seabirds (Brown et al. 1973, Anon. 1990, Chardine and Pelly 1994). Primarily diving birds are affected, most notably Northern Fulmar, Long-tailed Duck, Red-breasted Merganser, murres, Dovekie, and grebes (Brown et al. 1973). On a broader geographical scale, estimates of the number of birds that die annually from operational spills range from 21,000 on the Atlantic coast of Canada, and 72,000 in all of Canada (Thomson et al. 1991), to 315,000±65,000 Common Murres, Thick-billed Murres and Dovekies annually in southeastern Newfoundland alone due to illegal oil discharges from ships (Wiese and Robertson 2004). There is no clear correlation between the size of an oil spill and numbers of seabirds killed (Burger 1993). The density of birds in a spill area, wind velocity and direction, wave action, and distance to shore may have a greater bearing on mortality than the size of the spill (Burger 1993). However, even small spills can cause cumulative mass mortality of seabirds (Joensen 1972; Clark 1984; Cairns and Elliot 1987).

In November 2004, a spill of crude oil occurred from the production platform of the Terra Nova oil field. Based on the total area of the spill and on seabird densities derived from seabird surveys conducted in the spill area after the release, Canadian Wildlife Service (CWS) has estimated that mortality to seabirds in the area may have been in the order of 10,000 (Wilhelm et al. 2007). This estimate rests on a number of assumptions including: the seabird surveys conducted seven and eight days following the incident were representative; that the proportion of those birds flying during those surveys that made contact with the oil is known; and that the oil covered the entire surface area within the slick's perimeter. In fact, the high sea state during and after the spill resulted in windrows of slick-free water within the slick (Wilhelm et al. 2007). Memorial University of Newfoundland researcher David Schneider independently arrived an estimate of mortality similar to the CWS estimate, but based on spill volume and independent of seabird density (Wilhelm et al. 2007).

4.6.4.5 Marine Mammals

Most marine mammals, with the exception of fur seals, polar bears, and sea otters, are considered to be not directly susceptible to deleterious effects of oil. There is not clear evidence implicating oil spills with the mortality of cetaceans (Geraci 1990), although there was a significant decrease and lack of recovery in the population size of a killer whale pod that uses the area of the *Exxon Valdez* oil spill (Dahlheim and Matkin 1994). Several species of cetaceans and seals have been documented behaving normally in the presence of oil (St. Aubin 1990; Harvey and Dahlheim 1994; Matkin et al. 1994). There may have been a long-term decline by 36% in the number of moulting harbour seals at oiled haul-out sites in Prince William Sound following the *Exxon Valdez* oil spill (Frost et al. 1994). Pup mortality at these beaches was 23 to 26%, which may have been higher than natural mortality. Further analyses do not support high mortality, but indicated that seals moved away from some oiled haul-out sites (Hoover-Miller et al. 2001).

There are several physical and internal functions that may be affected by oil fouling of marine mammals. Whales and seals rely on a layer of blubber for insulation, so oil has little effect on thermoregulation. It can be assumed that if oil contacted the eyes, effects would be similar to that observed in ringed seals (conjunctivitis, corneal abrasion, and swollen nictitating membranes), and that continued exposure to eyes could cause permanent damage (St. Aubin 1990). Damage to the visual system would likely limit foraging abilities, as vision is an important sensory modality used to locate and capture prey, particularly for marine mammals. Animals could ingest oil with water, contaminated food, or oil could be absorbed through the respiratory tract; absorbed oil could cause toxic effects (Geraci 1990). Inhalation of vapours from volatile fractions of oil from a spill or blowout could potentially irritate respiratory membranes and hydrocarbons could be absorbed into the bloodstream. Absorbed oil can cause toxic effects such as minor kidney, liver, and brain lesions (Geraci and Smith 1976; Spraker et al. 1994), but contaminated animals could depurate this oil when returned to clean water (Engelhardt 1982). In baleen whales, crude oil could coat the baleen and reduce filtration efficiency, but these effects are considered to be reversible (Geraci 1990). Seals fouled externally with heavy oil may also encounter problems with locomotion, with flippers becoming stuck to their sides (Seargent 1991). Stressed individuals or those that could not escape a contaminated area would be most at risk to potentially deleterious effects. Animals exposed to heavy doses of oil for prolonged periods could experience mortality.

4.6.4.6 Sea Turtles

It is unknown whether sea turtles can detect and avoid oil slicks. Gramentz (1988) reported that sea turtles did not avoid oil at sea, and sea turtles experimentally exposed to oil showed a limited ability to avoid oil (Vargo et al.

1986). Gross histologic lesions developed in loggerhead sea turtles experimentally exposed to oil, but most effects were apparently reversed by the tenth day after exposure (Bossart et al. 1995). Oil may also reduce lung diffusion capacity, decrease oxygen consumption or digestion efficiency, or damage nasal and eyelid tissue (Lutz et al. 1989). Hall et al. (1983) observed seven live and three dead sea turtles following an oil well blowout in 1979; two of the carcasses had oil in the gut but no lesions, and there was no evidence of aspirated oil in the lungs. However, hydrocarbon residues were found in kidney, liver, and muscle tissue of all three dead turtles, and prolonged exposure to oil may have disrupted feeding behaviour and weakened the turtles.

4.6.4.7 Species at Risk and Potentially Sensitive Areas

The potential effects of accidental hydrocarbon releases on all marine species considered as SAR (Subsection 3.7) are discussed in the relevant subsections on fish habitat, fishes, marine-associated birds, marine mammals and sea turtles (Subsections 4.6.4.1 to 4.6.4.6).

The potential effects of accidental hydrocarbon releases on potentially sensitive areas identified in Subsection 3.8 are discussed in the relevant subsections on fish habitat, fishes, marine-associated birds, marine mammals and sea turtles (Subsections 4.6.4.1 to 4.6.4.6). The potentially sensitive areas occurring in coastal areas would be at highest risk.

4.6.4.8 Planning Implications

The mitigations that can be applied to minimize the potential effects of accidental hydrocarbon releases on all VECs are discussed below.

Containment and Recovery

The typical approach for blowouts involves the deployment of a collection boom at a point downstream of and as close to the source as safe and practicable. Typically the boom might be deployed in a J-configuration to provide a sweep width of one-third the total boom length. A suitable oil recovery skimming system would be positioned near the apex of the 'J' and would discharge recovered oil to a storage barge or the tanks of a suitable support vessel. Clearly either of the scenarios will be strongly influenced by weather conditions at the time as well as safety and practical tactical decisions made by the response organization. For any major offshore oil spill there are environmental and technological constraints to response and cleanup. High sea states and visibility are examples of typical environmental constraints while examples of technological constraints include pumping capacity of oil recovery devices and effectiveness of chemical dispersants on viscous oils. These kinds of limitations apply even if the response organizations are perfectly prepared and trained and outfitted with the world's best available equipment.

Dispersants and *in situ* burning are possible alternative countermeasures that offer some advantages in certain spill situations although approval from regulators would be required and little of the required material or expertise is presently in the province. Dispersants are specially-formulated chemicals that, when applied to an oil slick reduce the interfacial tension of the oil and enhance its dispersion into the water under the influence of wave action. Notwithstanding the fact that dispersants function by causing the oil to be dispersed from the sea surface into the water column for spills in an offshore environment, this can be a good trade-off in that the lower concentrations of subsurface oil are generally less harmful to the environment, and more readily degraded naturally, than the relatively high concentrations of oil in a surface slick. In addition, the potential for seabirds to encounter oil on the sea surface can be reduced. The main advantages of dispersant use over containment and recovery are that with appropriate equipment slicks that cover large areas can be treated, the logistics involved in storing and disposing of recovered oil are avoided, and the rough sea conditions that prevail in the Newfoundland offshore complement and enhance the effectiveness of the dispersant.

For *in situ* burning the approach is to collect and thicken the oil slick with fire-resistant boom, ignite it, and burn the oil in place on the water surface. While its main advantage is that the logistics of storing and disposing of recovered oil are avoided, and that much higher treatment rates (i.e., versus skimming) are possible, it offers no advantage when it comes to encounter rates. The oil must still be collected with a containment boom, the effectiveness of which is constrained by sea state conditions. Apart from the potential limited availability of fire resistant booms, more limiting is that burning is generally only effective on oils that are not emulsified or have suffered little emulsification.

It should be noted that the extremely high energy environment encountered off the coast of Newfoundland, particularly in the winter months likely has more impact on the final fate of the spilled hydrocarbon than any human effort.

Fisheries

Economic compensation can be provided to affected fishers for gear damage, loss of access to fishing grounds, and decrease in marketability due to either actual or perceived tainting of the invertebrates and fishes typically harvested.

Bird Rehabilitation

The rescue, cleaning, and rehabilitation of oiled birds have been practised in several parts of the world for a number of years (Clark 1984). Considerable effort has been made to improve rehabilitation techniques (Berkner et al. 1977; Williams 1985; Frink and White 1990), and release rates of birds have generally increased (Randall et al. 1980; Williams 1985; Frink 1987). However, cleaned seabirds often die shortly after release (Sharp 1996), which is reflected in much lower survival rate than non-oiled birds, regardless of cleaning techniques (Sharp 1996). Recently, some oil companies operating on the Grand Banks have committed to conduct bird cleaning and rehabilitation programs on the basis of the following principles:

- Bird cleaning and rehabilitation operations will be carried out under the terms of permits issued by the CWS;
- Procedures and protocols to ensure safe effective and humane cleaning and rehabilitation of birds under the guidance of a qualified veterinarian will be put in place pursuant to the aforementioned permits;
- Procedures and protocols will make appropriate provision for triage and euthanasia under the direction of a qualified veterinarian and ensure appropriate focus for any *SARA* species that might be affected by an incident; and
- Collection of birds offshore for cleaning and rehabilitation during a spill incident will be conducted with strict regard for safety of personnel involved.

Bird Population Enhancement Techniques

In the unlikely event that seabird populations are significantly affected by oil spills (Clark 1984; Wiens 1995), it may be possible to restock certain species' populations. Although no efforts to restock birds in areas that have suffered from major oil spills have been conducted, there have been several programs to reintroduce birds into abandoned parts of their ranges (e.g., Common Eiders in Hare Bay, Newfoundland, and Atlantic Puffins off the Maine coast and along the Brittany coast) (Gilliland, CWS, in prep.; Duncombe and Reille 1980; Clark 1984). These efforts have met with variable success. They all involved much planning, considerable labour and the programs were multi-year efforts that required a long-term commitment of personnel and resources.

The nesting success of some species can be improved by manipulation of nesting habitat. Nest shelter programs have been ongoing in Newfoundland and Labrador for Common Eiders since the late 1980s (Goudie 1989, 1991d).

4.6.4.9 Data Gaps

While the effects of different types of hydrocarbons are fairly well known, the physical characteristics of hydrocarbons potentially occurring in the SEA Area are not well known. The distribution of the fisheries in the SEA Area is well known in time and space. The key data gaps in assessing the potential effects of a large oil spill or blowout are listed below:

- Distribution of key VECs such as fish eggs and larvae, seabirds, marine mammals and sea turtles in the SEA Area are not completely understood;
- Specific characteristics, fate and behaviour of hydrocarbon spills in most of the SEA Area are relatively unknown;
- Development of better containment and recovery methods; and
- Development of more effective bird rehabilitation techniques.