4.0 Environmental Effects of Exploration and Production Activities

Offshore oil and gas activity has been ongoing at least since the 1940s and therefore most environmental effects are reasonably well known. The SEA has focused on such sources as sound, drilling fluids and cuttings, attraction of animals, discharges, and accidental events.

Important potential interactions have been identified in the following sections. The potential effects of underwater sound (particularly seismic surveying) and non-sound aspects of exploration/production drilling are discussed in detail. Mitigations for the potential effects are also considered.

4.1 Sound

4.1.1 Underwater Acoustics

The audibility or apparent loudness of a sound source is determined by (1) the radiated acoustic power (source level), (2) the propagation efficiency, (3) the ambient sound, and (4) 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.

4.1.1.1 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):

Sound Pressure Level = 20 log (P/P_o),

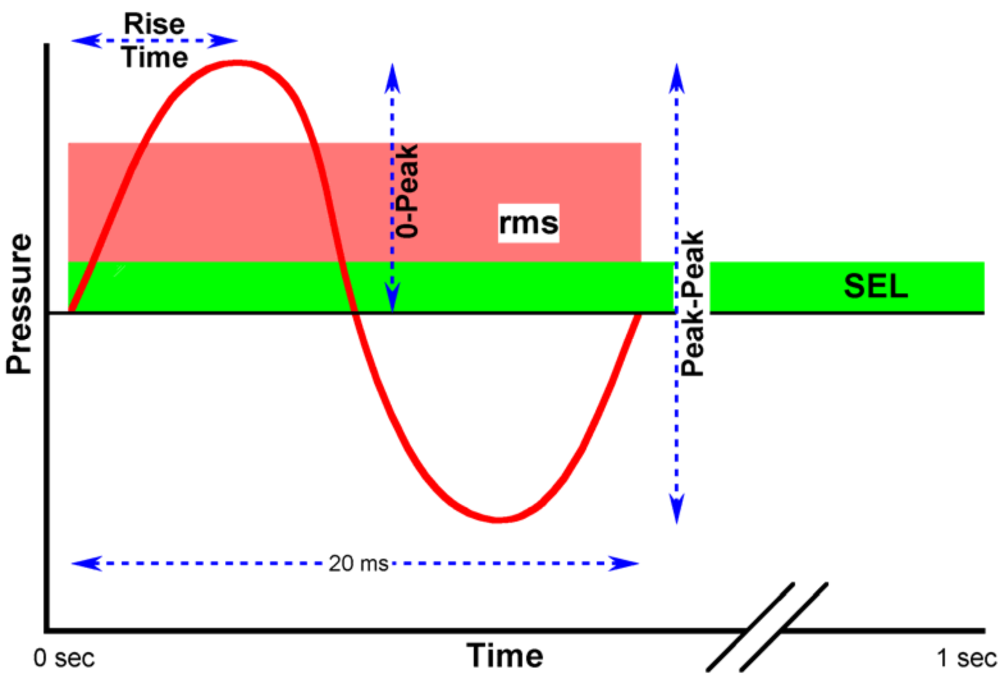
where P_o is a reference level, usually 1 μPa (micro-pascal). The reference level should always be shown as part of the SPL unit. A sound pressure (P) of 1,000 Pascals (Pa) has an SPL of 180 dB re 1 μPa and a pressure of 500 Pa has an SPL of 174 dB. On this scale, a doubling of the sound pressure means 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 meter (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 4.1). 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).

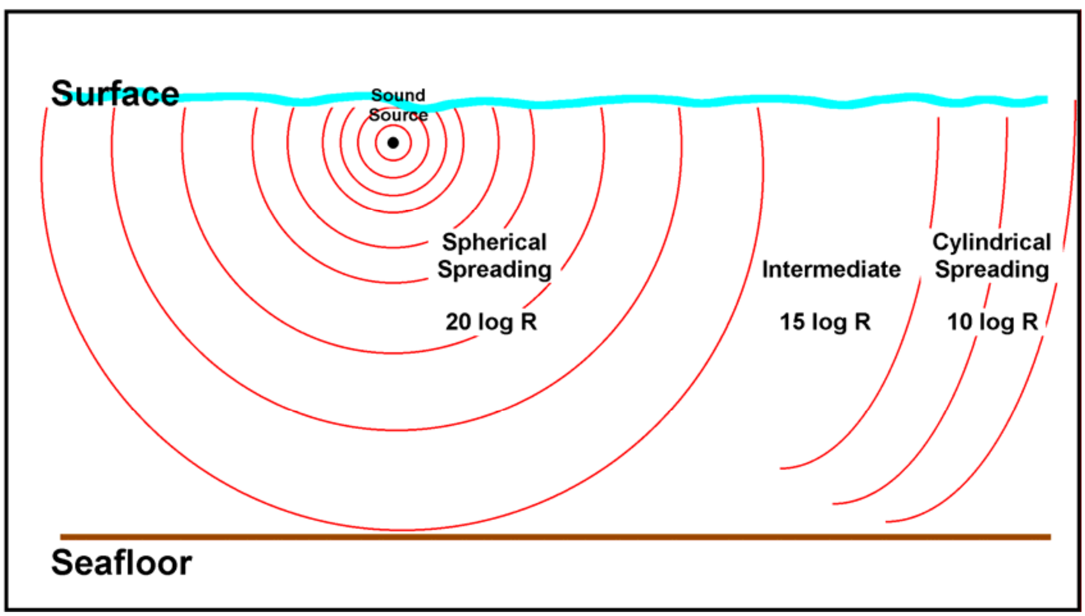
4.1.1.2 Path

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 4.2). 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.



Source: Lawson et al. (2000).

Figure 4.1. Terminology Used to Describe Sound Pressure Levels in an Acoustic Impulse (horizontal axis not drawn to scale).



Source: Lawson et al. (2000).

Figure 4.2. Schematic Representation of Acoustic Spreading Loss from a Sound Source as a Function of Distance and Interaction with the Seafloor.

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.

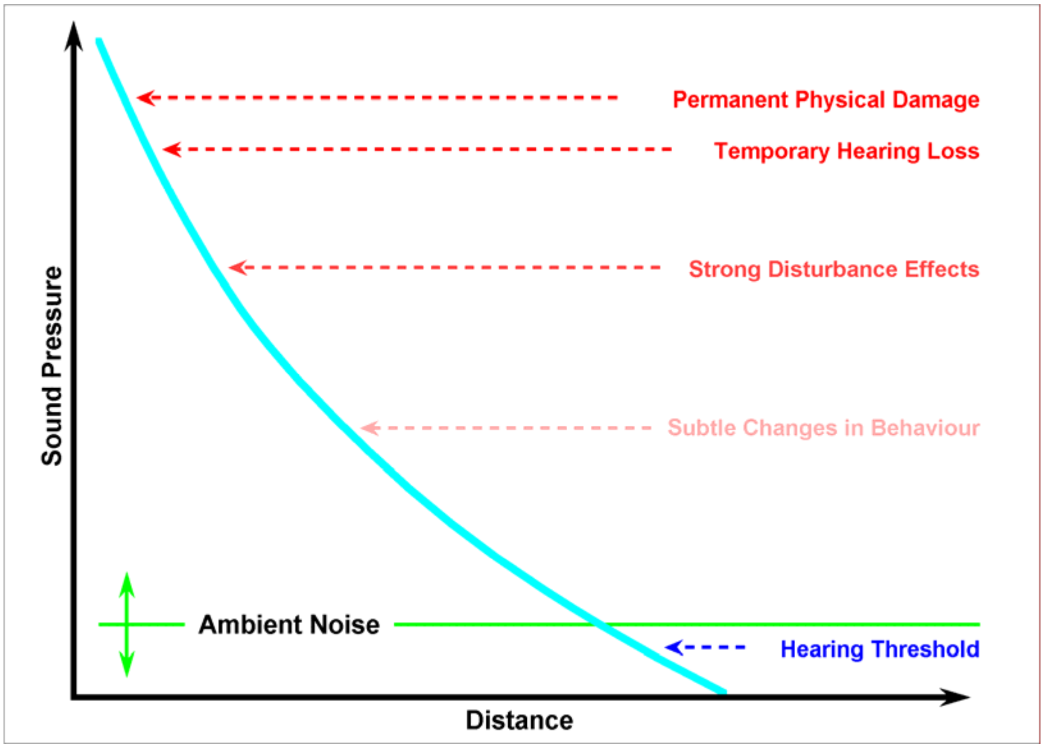
4.1.1.3 Receiver

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 4.3).

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.



Source: Lawson et al. (2000).

Figure 4.3. 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).

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.

4.1.2 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: (1) via a direct refracted path; (2) via direct refracted paths that are reflected by the bottom; (3) via a "lateral" (surface-traveling) wave; and (4) 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).

4.1.3 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 185-188 dB re 1 µPa at 1 m have been recorded for snapping shrimp (Au and Banks 1998).

4.1.4 Offshore Oil and Gas Industrial Sounds

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

4.1.4.1 Exploration Activities

Geophysical Surveys

Typical seismic surveys on the East Cost consist of 2-D or 3-D seismic where a sound source array composed of a tuned series of compressed air cylinders and strings of hydrophones (streamers) are towed behind a vessel. The streamers may cover an area of 900 m by 8,000 m behind the vessel. The sound is produced by the rapid release of air and is focused down into the seabed; the characteristics of the returned sound signals allow a map of geological structure below the seabed. Resolution for 3-D surveys is greater than for 2-D. The vertical seismic profile (VSP) is used to assist the drilling process and is similar to 3-D except that is usually conducted with a smaller sound source, and over a much smaller geographic area and much shorter time span (typically one or two days). Shallow geohazard or well site surveys may consist of multi-beam sonar, side scan sonar, bottom sampling and/or video and a small seismic array.

Airguns

Most marine seismic surveys use airguns, singly or strung in array. Airguns create a sound wave through the rapid release of compressed high pressure air (typically 2,000 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).

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. Adaptations are now being developed to allow their 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 200-230 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 50-500 kHz with source levels around 220-230 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 global positioning systems (GPS). Navigation transponders generally have frequencies about 7 to 60 kHz, source levels of 180-200 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 few 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).

Offshore Drilling

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.

4.1.4.2 Offshore Construction Activities

Construction activities 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).

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).

Construction on Ice. Construction activity in Alaskan waters may occur on or through the ice. Underwater and ice vibration sound levels have been recorded for truck traffic, ice road construction, ice cutting, trenching, driving of sheet piles and drilling (Moulton et al. 2003). On-ice activities would not be likely to occur in the SEA Study Area.

Note that these offshore construction activities are not exploration activities, although seismic surveys can be conducted from the ice under certain conditions..

4.1.4.3 Offshore Production Activities

In general, the amount of underwater sound a production 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 floating, production, storage and offloading platform (FPSO) constructed from a ship's hull is expected to be noisier than a semi-submersible or jack-up. Artificial islands are probably the quietest.

4.1.4.4 Offshore Decommissioning Activities

Decommissioning of offshore infrastructure such as pipelines, caissons, wellheads, conductors and platforms, etc. entails a number of activities that generate sound. The removal of structures in the Gulf of Mexico has become an environmental issue because of the use of explosives and the large number that will have to be decommissioned in the near future. It has been estimated by API that 5,500 structures will have to be removed over the next 35 years (DOC 2002).

Of the various types of sound energy produced by offshore oil and gas activities, explosions are the only source for which damage to marine animals has been conclusively demonstrated. This is of concern for fish which are know to congregate around structures in the Gulf of Mexico, turtles (particularly loggerheads) which may at times use the structures for feeding and resting, and for marine mammals which are potentially sensitive to sound and whose ranks include *endangered* and *threatened* species (e.g., blue whale).

4.1.5 Effects of Industrial Sounds on Marine Animals

Once source levels and propagation loss have been evaluated, the next step is to assess the effects of this sound on the marine animals of interest. This is clearly the most complicated and least understood component of the *Source → Path → Receiver* concept. For example, for a marine mammal to hear an underwater sound, the received level of the sound within a particular bandwidth relevant to the animal's hearing processes must, to a first approximation, be greater than the absolute hearing threshold of that animal at that frequency (Richardson et al. 1995; Davis et al. 1998). A sound whose received level is below this threshold is not detectable by the marine mammal. The hearing threshold varies with frequency and the frequencies of greatest hearing sensitivity vary among the different groups and species of marine mammals.

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 is swimming. 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 (e.g., Chapman et al. 1998; Desharnais et al. 1999; Swift and Thompson 2000) and this probably results in significant variability in the range at which marine animals can detect anthropogenic sounds.

There are many gaps in the information on hearing capabilities and on the responses of marine animals to sounds that they hear. For example, marine mammals, like other highly intelligent vertebrates, exhibit individual variation in their behavioural patterns and responses to stimuli (e.g., Bonner 1968; Slater 1981; Suryan and Harvey 1999). They do not always respond behaviourally to sounds that are audible, and they do not always respond in the same way to a given received sound level. The received sound levels necessary to elicit different responses (e.g., subtle behavioural change vs. strong avoidance) often differ, and received levels necessary to cause hearing damage or injury to other organs will be higher than those that often elicit behavioural reactions. For these reasons, it is not yet possible to establish specific or unequivocal criteria for determining the zone of influence or zone of effects around a sound source.

A hierarchy of criteria for establishing zones of influence can be derived based on six factors:

1. ambient sound levels,
2. absolute hearing thresholds of the species of interest,
3. slight changes in behaviour of the species of interest (including habituation),
4. stronger disturbance effects (e.g., avoidance),
5. temporary hearing impairment, and
6. permanent hearing or other physical damage.

Based on these criteria, we can define a series of zones of potential sound influence of generally decreasing size. The zone within which the received level from a particular source of anthropogenic sound in at least one part of the frequency spectrum exceeds both the ambient level and the absolute detection threshold for a particular marine animal species (at that frequency) is often large. This is the zone of detection. However, the zones within which there is disturbance or displacement, and especially impairment to the animal, will be much smaller. The maximum possible zone of influence of anthropogenic sound is the distance beyond which its received level falls substantially below the ambient sound level or the hearing threshold in all frequency bands. Once the sound falls substantially below ambient or below the hearing threshold, marine animals will not be able to detect sound from the anthropogenic sound source. Ambient sound levels vary dramatically over time and season and among geographic areas. Thus, the radius of the zone of detection is also highly variable.

It is not realistic to use an ambient sound criterion alone to determine a zone of influence. In some cases, the sound level from an anthropogenic source may diminish below the marine animal's hearing threshold before the sound level reaches ambient levels. Even when this is not the case, detectable but weak anthropogenic sounds usually do not elicit overt behavioural reactions, and probably do not affect marine animals significantly (Richardson et al. 1995). It is necessary to distinguish between a zone of potential influence and a zone of actual effects. The former is a zone within which the marine animal might be aware or react mildly to an anthropogenic sound. The latter is the zone, generally much smaller, within which the received sound level is higher and the animal might be detrimentally affected.

4.1.5.1 Fish and Invertebrates

The various types of potential effects of exposure to seismic on fish and invertebrates can be considered in three categories: (1) pathological, (2) physiological, and (3) behavioural. Pathological effects include lethal and sub-lethal damage to the animals, physiological effects include temporary primary and secondary stress responses, and behavioural effects refer to changes in exhibited behaviours of the fish and invertebrate animals. The three categories should not be considered as independent of each other. They are certainly interrelated in complex ways. For example, it is possible that certain physiological and behavioural changes could potentially lead to the ultimate pathological effect on individual animals (i.e., mortality).

The following sections provide an overview of the information that exists on the effects of seismic on fish and invertebrates. The information is comprised of results from scientific studies of varying degrees of soundness as well as anecdotal information.

Pathological Effects

In water, acute injury or death of organisms exposed to seismic energy depends primarily on two features of the sound source: (1) the received peak pressure, and (2) the 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. Payne (2004), in his review of available data on the potential effect of seismic surveys on fish eggs, larvae and zooplankton, states that limited data indicate that some fish eggs and larvae may be damaged at a distance of approximately five metres from a typical seismic discharge. However, he adds that it is premature to suggest that five metres is the approximate injury zone for effects on the eggs and larvae of finfish and shellfish, zooplankton, or planktonic life stages in general.

Fish

Matishov (1992) reported that some cod and plaice died within 48 hours of exposure to seismic at two metres from the source. No other details were provided by the author, making this information source questionable. On the other hand, there are numerous examples of no fish mortality effect as a result of exposure to seismic sources (Falk and Lawrence 1973; Holliday et al. 1987; La Bella et al. 1996; Santulli et al. 1999; McCauley et al. 2000a, 2000b; Thomsen 2002; IMG 2002; McCauley et al. 2003; Hassel et al. 2003).

There are examples of damage to fish ear structures from exposure to seismic airguns (McCauley et al. 2000a,b, 2003; Enger 1981) but it should be noted the experimental fish were caged and exposed to high cumulative levels of seismic energy. 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. Temporary threshold shift (TTS) can occur in fish under certain conditions, 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 sound (158 dB re 1 µPa; unspecified measure type) for periods of 12 and 24 hours and then tested their post-exposure hearing sensitivities using auditory brainstem response (ABR) immediately following exposure as well as at three, seven and 14 days after exposure. Hearing sensitivities were also measured prior to exposure to the intense sound. Both species exhibited loss of hearing sensitivity (maximum of 26 to 32 dB) immediately after 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 sound (160-170 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 sound. Threshold shifts did not increase beyond the 24-hour exposure time. After 21 days of exposure to the sound, the goldfish hearing sensitivity required 14 days to recover to normal levels. It should be noted that TTS may seldom (or never) occur in the wild unless fish are prevented from fleeing the irritant.

Some studies have also provided some information on the effects of seismic exposure 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). Overall, effects appeared to be minimal and any mortality effect was generally not significantly different from the experimental controls. Generally, any observed larval mortality occurred after exposures within 0.5 to three metres of the airgun source. Matishov (1992) reported some retinal tissue damage in cod larvae exposed at one metre from the airgun source. Saetre and Ona (1996) applied a ‘worst-case scenario’ mathematical model to investigate the effects of seismic energy on fish eggs and larvae and concluded that mortality rates caused by exposure to seismic are so low compared to the natural mortality that the impact of seismic surveying on recruitment to a fish stock must be regarded as insignificant.

Invertebrates

The pathological impacts of seismic energy on marine invertebrate species have also been investigated. Christian et al. (2004) exposed adult male snow crabs, egg-carrying female snow crabs and fertilized snow crab eggs to the energy from seismic airguns. Neither acute nor chronic (12 weeks after exposure) mortality was observed for the adult male and female crabs. There was a significant difference in development rate noted between the exposed and unexposed fertilized eggs. The egg mass exposed to seismic energy had a higher proportion of less-developed eggs than the unexposed mass. It should be noted that both egg masses came from a single female and any measure of natural variability was unattainable.

In 2001 and 2003, there were two incidents of multiple strandings of the giant squid (*Architeuthis dux*) on the north coast of Spain. The strandings occurred at about the same time as geophysical seismic surveys 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 was affected by the impact of acoustic waves. However, little is known about the physical 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 so no valid conclusions can be drawn from this study.

McCauley et al. (2000a) reported behavioural effects of exposure of caged cephalopods (50 squid and two cuttlefish) to sound from a single 20 in^3 airgun but no physical effects, other than the fact that no acute or chronic mortality was observed in the squid after exposure to the airgun sound. The cephalopods were exposed to both stationary and mobile sound sources. The two-run total exposure times of the three trials ranged from 69 to 119 minutes at a firing rate of once every 10 to 15 seconds. Maximum zero-to-peak exposure levels were greater than 200 dB re 1 µPa. Statocysts were removed and preserved but at the time of the study report publication, results of the statocyst analyses were not available. Some of the squid fired their ink sacs apparently in response to the first shot of one of the trials and then moved quickly away from the airgun. However, the ink sac firing was not observed for similar or greater received levels if the signal was ramped up. In addition to the above-described startle responses, some squid also moved towards the water surface as the airgun approached. Sound shadows, areas of lower sound pressure levels, are known to occur there (Richardson et al. 1995). An increase in swimming speed was also exhibited by some of the squid. No squid or cuttlefish mortalities were reported as a result of these exposures.

Pearson et al. (1994) exposed Stage II larvae of the Dungeness crab to single discharges from a seven-airgun seismic array and compared their mortality and development rates with those of unexposed larvae. For immediate and long-term survival and time to molt, this field experiment did not reveal any statistically significant differences between the exposed and unexposed larvae, even those exposed within one metre of the seismic source.

Bivalves of the Adriatic Sea were also exposed to seismic energy and subsequently assessed (LaBella et al. 1996). No effects of the exposure were noted.

Summary of Pathological Effects

To date, there have not been any well-documented cases of acute post-larval fish or invertebrate mortality as a result of exposure to seismic sound under normal seismic operating conditions. Sub-lethal injury or damage has been observed but generally as a result of exposure to very high received levels of sound, higher 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 sources and the received pressure levels were presumably very high. Limited information has not indicated any chronic mortality as a direct result of exposure to seismic.

Physiological Effects

Biochemical responses by marine fish and invertebrates to acoustic stress have also been studied, albeit in a limited way. Studying the variations in the biochemical parameters influenced by acoustic stress might give some indication of the extent of the stress and perhaps forecast eventual detrimental effects. Such stress could potentially affect animal populations by reducing reproductive capacity and adult abundance.

McCauley et al. (2000a,b) used various physiological measures to study the physiological effects of exposure to seismic energy on various fish species, squid and cuttlefish. No significant physiological stress increases attributable to seismic were detected. Sverdrup et al. (1994) found that Atlantic salmon subjected to acoustic stress released primary stress hormones, adrenaline and cortisol as a biochemical response although there were different patterns of delayed increases for the different indicators. Caged European sea bass were exposed to seismic energy and numerous biochemical responses were indicated. All returned to their normal physiological levels within 72 hours of exposure.

Stress indicators in the haemolymph of adult male snow crabs were monitored after exposure of the animals to seismic energy (Christian et al. 2004). No significant differences between exposed and unexposed animals in terms of the stress indicators (e.g., proteins, enzymes, cell type count) were indicated.

In December 2003, egg-bearing female snow crabs (*Chionoecetes opilio*) off Cape Breton, Nova Scotia were caught, caged and subsequently exposed to seismic energy released during a commercial seismic survey. Both acute and chronic effects on the adult female crabs, embryos and larvae hatched from the eggs were studied in this DFO study. According to DFO (DFO 2004i), there were three definitive observations from the study.

1. The seismic survey did not cause any acute or chronic (five months) mortality of the crab, or any changes to the feeding activity of the treated crabs being held in the laboratory.
2. Neither the survival of embryos being carried by the female crabs during exposure nor the locomotion of the larvae after hatch appeared to be affected.
3. There was acute soiling of gills, antennules and statocysts of the crabs at the exposure site but after five months, all structures had returned to their clean state.

The third observation regarding the soiling of crab structures cannot be attributed to exposure to seismic energy.

Lagardère (1982) presented results from laboratory experimentation that suggested that behavioural and physiological reactions of brown shrimp (*Crangon crangon*) were modified by exposure to increased background sound 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 sound levels also appeared to increase aggression (cannibalism) and mortality rate, and 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 fish 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 Effects

Because of the relative lack of indication of serious pathological and physiological effects of seismic energy on marine fish and invertebrates, most concern now centers on the possible effects of exposure to seismic on the distribution, migration patterns and catchability of fish (i.e., behavioural effects).

Fish and Invertebrate Acoustic Detection and Production

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. 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. Only some species of fish with a swim bladder appear to be sound pressure-sensitive via this indirect pathway to the ears and 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 2,000 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).

Because they lack air filled cavities and are often the same density as water, invertebrates detect underwater acoustics differently than fish. Rather than being pressure sensitive, invertebrates appear to be most sensitive to particle displacement. However, their sensitivity to particle displacement and hydrodynamic stimulation seem poor compared 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., <1,000 Hz) (Budelmann 1992; Popper et al. 2001).

Many fish and invertebrates are also capable of sound production. It is believed that 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).

Behavioural Effects of Seismic

Studies investigating the possible effects of seismic on fish and invertebrate behaviour have been conducted on both uncaged and caged 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). Anecdotal information from Newfoundland, Canada indicated that snow crab catch rates showed a significant reduction immediately following a pass by a seismic survey vessel. Other anecdotal information from Newfoundland, Canada 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 the snow crab and shrimp anecdotes.

Christian et al. (2004) conducted an experimental commercial fishery for snow crab before and after the area was exposed to seismic shooting. No drastic decrease in catch rate was observed after seismic shooting commenced. It should be noted that there were study limitations associated with the experimental fishery conducted by Christian et al. (2004). In addition to the high variability inherent in catchability studies, poor weather conditions resulted in considerable variability in set durations and a relatively low number of sets. Another 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 shooting by remote underwater camera. No obvious startle behaviours were observed.

Marine fish inhabiting an inshore reef off the coast of Scotland were monitored by telemetry and remote camera before, during and after airgun firing (Wardle et al. 2001). Although some startle responses were observed, the seismic gun firing had little overall effect on the day-to-day behaviour of the resident fish.

Studies on the effects of sound on fish behaviour have also been conducted using caged or confined fish. Such experiments were conducted in Australia using fish, squid and cuttlefish as subjects (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 pre-seismic state 15 to 30 minutes after cessation of seismic. Squid exhibited strong startle responses to the onset of proximate airgun firing 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 fish and invertebrate behaviour will be modified at some received sound level. Again, these behavioural changes seem to be temporary.

The influence of seismic activity 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 shooting along some of the survey transects. Results suggested that the acoustic abundance of pelagic fish was higher outside the survey area than inside. At the same time, the abundance of pelagic fish prior to shooting 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 shooting.

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.

Behavioural Effects of Ultrasound

As mentioned in a previous section, 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

The full determination of behavioural effects of exposure to seismic is difficult. There have been well-documented observations of fish and invertebrates exhibiting behaviours that appeared to be in response to exposure to seismic (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 temporary 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 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.

4.1.5.2 Commercial Fisheries

The chief sources for potential impacts of underwater sound, particularly seismic sound, on the commercial fisheries are related to (1) changes in catch rates resulting from sound-induced behavioural changes (scaring) of fish, (2) as a result of effects on stock assessments and DFO research, which is used, among other purposes, for setting fishing quotas or exploring new fisheries. The first issues were raised during SEA consultations in July 2005. Impacts related to physical effects on fish and invertebrates were discussed in the preceding section.

As discussed in Section 3.4.4, commercial fisheries are prosecuted throughout the Study 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. Indeed, the likelihood that finfish will move away to a comfortable distance as the 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 Section 4.1.5.1 presents the results of studies on the effects of seismic noise on catch rates. While most - though not all - of these studies report some decrease in catch rates near seismic arrays, there is less agreement on the duration and geographical extent of the effect, ranging from a quick return to several days, and from very localized effects to decreased catch rates as far as 15-km to 20-km away.

Depending on the juxtaposition of the survey sound source, the fish being harvested, and the fishing gear, the impact on fishing success could be either negative or positive. The effect would be positive if, for instance, the fish were driven away from the sound source and towards fishing gear (e.g., fixed gillnets). Snow crab, being sedentary benthic species, are not likely to disperse and catch rates are not expected to be affected.

Potential impacts on fishing catch rate will be mitigated by avoiding heavily fished areas when these fisheries are active to the greatest extent possible.

There is also the potential for interaction between sound and DFO research surveys in the area. The standard mitigative measure for this is coordination between the seismic survey operators and DFO. DFO recommends a seven 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 gear conflict and disruption of fish distribution patterns. It will be necessary for operators to develop mitigative protocols in collaboration with DFO prior to the commencement of seismic operations.

4.1.5.3 Marine-associated Birds

There are few 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 effect on the 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 they were limited in their ability to detect subtle disturbance effects and 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 Study Area feed at the surface or at less than one metre below the surface of the ocean. This includes *Procellariidae* (Northern Fulmar, Greater Shearwater, Sooty Shearwater and Manx Shearwater), *Hydrobatidae* (Wilson's Storm-Petrel and Leach's Storm-Petrel), *Phalaropodinae* (Red Phalarope and Red-necked Phalarope), *Laridae* (Great Skua, Pomarine Jaeger, Parasitic Jaeger, Long-tailed Jaeger, Herring Gull, Iceland Gull, Glaucous Gull, Great Black-backed Gull, Ivory Gull, Black-legged Kittiwake and Arctic Tern). 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 Study Area that require considerable time under water to secure food. They are the *Alcidae* (Dovekie, Common Murre, Thick-billed Murre, Razorbill and Atlantic Puffin). 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 25-40 seconds reaching an average depth of 20-60 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 1.0-4.0 khz (Gaston and Jones 1998).

4.1.5.4 Marine Mammals

Marine mammals rely heavily on the use of underwater sounds to communicate and gain information about their environment. The reactions of marine mammals to sound can be variable and depend on the species involved and the activity of the animal at the time of exposure to sound. Because underwater sound sometimes propagates for long distances, the radius of audibility can be large for a strong sound. 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. Potential effects of sound on marine mammals include masking, disturbance (behavioural), hearing impairment (temporary threshold shift [TTS] and permanent threshold shift [PTS]), and non-auditory physiological effects.

Background

Masking

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 amid sound is important in communication, predator and prey detection, and, in the case of toothed whales, echolocation.

Even in the absence of man-made sounds, the sea is usually noisy. Background ambient sound often interferes with or masks the ability of an animal to detect a sound signal even when that signal is above its absolute hearing threshold. Natural ambient sound includes contributions from wind, waves, precipitation, other animals, and (at frequencies above 30 kHz) thermal sound resulting from molecular agitation (see Chapter 5 of Richardson et al. 1995). Background sound can also include sounds from distant human activities such as shipping and oil exploration and production. Masking of natural sounds can result when human activities produce high levels of background sound. Conversely, if the background level of underwater sound is high (e.g., on a day with strong wind and high waves), an anthropogenic sound source will not be detectable as far away as would be possible under quieter conditions, and will itself be masked. Ambient sound is highly variable on continental shelves (e.g., Thompson 1965; Myrberg 1978; Chapman et al. 1998; Desharnais et al. 1999). This inevitably results in a high degree of variability in the range at which marine mammals can detect anthropogenic sounds.

Although masking is a natural phenomenon to which marine mammals must be adapted, introduction of strong sounds into the sea at frequencies important to marine mammals will inevitably increase the severity and the frequency of occurrence of masking. For example, if a baleen whale is exposed to continuous low-frequency sound from an industrial source, this will reduce the size of the area around that whale within which it will be able to hear the calls of another whale. In general, little is known about the importance to marine mammals of detecting sounds from conspecifics, predators, prey, or other natural sources. In the absence of much information about the importance of detecting these natural sounds, it is not possible to predict the impacts if mammals are unable to hear these sounds as often, or from as far away, because of masking by industrial sound (Richardson et al. 1995). In general, masking effects are expected to be less severe when sounds are transient than when they are continuous.

Although some degree of masking is inevitable when high levels of man-made broadband sounds are introduced into the sea, marine mammals have evolved systems and behaviour that function to reduce the impacts of masking. Structured signals such as echolocation click sequences of small toothed whales may be readily detected even in the presence of strong background sound because their frequency content and temporal features usually differ strongly from those of the background sound (Au and

Moore 1988; 1990). 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 of that signal. Low-frequency industrial sound has little or no masking effect on high-frequency echolocation sounds. 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. In the cases of high-frequency hearing by the bottlenose dolphin, beluga whale, and killer whale, empirical evidence confirms that masking depends strongly on the relative directions of arrival of sound signals and the masking sound (Penner et al. 1986; Dubrovskiy 1990; Bain et al. 1993; Bain and Dahlheim 1994).

Toothed whales, and probably other marine mammals as well, 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 (Au et al. 1974, 1985; Moore and Pawloski 1990; Thomas and Turl 1990; 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 (Dahlheim 1987; Au 1993; Lesage et al. 1999; Terhune 1999).

These data demonstrating adaptations for reduced masking 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. For example, Zaitseva et al. (1980) found that, for the bottlenose dolphin, the angular separation between a sound source and a masking sound source had little effect on the degree of masking when the sound frequency was 18 kHz, in contrast to the pronounced effect at higher frequencies. Directional hearing has been demonstrated at frequencies as low as 0.5-2 kHz in several marine mammals (including killer whales) (see Section 8.4 in Richardson et al. 1995). This ability may be useful in reducing masking at these frequencies.

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.

Disturbance

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.

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.

Temporary Threshold Shift

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 a few 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.

Permanent Threshold Shift

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 a 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.

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.

Seismic Surveying

Masking

Masking effects of seismic survey sound 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 s. Their calls can be heard between seismic pulses (e.g., Richardson et al. 1986; McDonald et al. 1995; Greene and McLennan 2000). Although there was one report that sperm whales ceased calling when exposed to pulses from a very distant seismic ship (Bowles et al. 1994), more recent studies have reported that sperm whales continued calling in the presence of seismic pulses (Madsen et al. 2002a; Jochens and Biggs 2003). 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 the strongest spectrum levels below 200 Hz, and considerably lower spectrum levels above 1,000 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 even for baleen whales.

Disturbance

There have been studies of the behavioural responses of several types of marine mammals to airgun discharges. Detailed studies have been done on humpback whales, grey whales (*Eschrichtius robustus*), bowhead whales (*Balaena mysticetus*), sperm whales, and ringed seals (*Pusa hispida*). Data from less intensive studies are available for some other species of baleen and small toothed whales.

Baleen Whales

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. However, recent studies of humpback and bowhead whales indicate that reactions, including avoidance, sometimes occur at greater distances from the seismic source than previously documented. Avoidance distances often exceed the distances at which boat-based observers can see whales.

Studies of humpback whales have determined that received levels of pulses in the 160-170 dB re 1 µPa rms range seem to cause obvious avoidance behaviour in a substantial fraction of the animals exposed. 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. Because the responses become less obvious with diminishing received sound level, it has been difficult to determine the maximum distance (or minimum received sound level) at which marine mammal reactions to seismic occur.

Migrating humpback, grey, and bowhead whales have reacted to sound pulses from marine seismic exploration by deviating from their normal migration route and/or interrupting their feeding and moving away (e.g., Malme et al. 1984, 1985, 1988; Richardson et al. 1986, 1995; Ljungblad et al. 1988; Richardson and Malme 1993; McCauley et al. 1998, 2000a,b; Miller et al. 1999). Finback and blue whales have also displayed some behavioural reactions to airgun sound (McDonald et al. 1995; Stone 1997, 1998, 2000). Prior to the late 1990s, it was thought that migrating bowhead whales, grey whales, and humpback whales all begin to show strong avoidance reactions to seismic pulses at received levels of about 160 to 170 dB re 1 µPa rms. Subtle behavioural changes sometimes became evident at somewhat lower received levels. Recent studies have shown that some species of baleen whale may show strong avoidance at received levels somewhat lower than 160-170 dB re 1 µPa rms. The observed avoidance reactions included movement away from feeding locations or statistically significant deviations in the whales' direction of swimming and/or migration corridor as they approached or passed the sound sources. In the case of the migrating whales, the observed changes in behaviour appeared to be of little biological consequence to the animals. They simply avoided the sound source by slightly displacing their migration route yet remained within the natural boundaries of the migration corridors.

McCauley et al. (1998, 2000a,b) studied the responses of humpback whales off western Australia to a full-scale seismic survey with a 16-gun 2678-in^3 array, and to a single 20-in^3 airgun with a source level of 227 dB re 1 µPa-m (peak-peak). They found that the overall distribution of migrating humpbacks through their study area was not affected by the full-scale seismic program. McCauley et al. (1998) did, however, document localized avoidance of the array and of the single gun. Avoidance reactions began at five to eight kilometres from the array, and those reactions kept most pods about three to four kilometres from the operating seismic boat. Observations were made from the seismic vessel, from which the maximum viewing distance was listed as 14 km. Avoidance distances with respect to the single airgun were smaller but consistent with the results from the full array in terms of the received sound levels. The mean avoidance distance from the airgun corresponded to a received sound level of 140 dB re 1 µPa rms; this was the level at which humpbacks started to show avoidance reactions to an approaching airgun. The startle response occurred at a mean received level of 122 dB rms. The standoff range, that is, the closest point of approach of the airgun to the whales, corresponded to a received level of 143 dB rms. The initial avoidance response generally occurred at distances of five to eight kilometres from the airgun array and two kilometres from the single gun. However, some individual humpback whales, especially males, approached within distances of 100 to 400 m, where the maximum received level was 179 dB re 1 µPa rms.

Humpback whales summering in southeast Alaska did not exhibit persistent avoidance when exposed to seismic pulses from a 1.64-L airgun (Malme et al. 1985). Some humpbacks seemed "startled" at received levels of 150-169 dB re 1 µPa. Malme et al. (1985) concluded that there was no clear evidence of avoidance, despite the possibility of subtle effects, at received levels up to 172 re 1 µPa effective pulse pressure level.

Data on short-term reactions (or lack of reactions) of cetaceans to impulsive sounds do not necessarily provide information about long-term effects. It is not known whether impulsive sounds affect reproductive rate or distribution and habitat use in subsequent days or years. Grey whales continue to migrate annually along the west coast of North America despite intermittent seismic exploration (and much ship traffic and an existing developed oil field) in that area for decades (Malme et al. 1984). Bowhead whales continue to travel to the eastern Beaufort Sea each summer despite long-term seismic exploration in their summer and autumn range. Bowheads are often seen in summering areas where seismic exploration occurred in preceding summers (Richardson et al. 1987). They also have been observed over periods of days or weeks in areas repeatedly ensonified by seismic pulses. However, it is not known whether the same individual bowheads were involved in these repeated observations (within and between years) in strongly ensonified areas. It is also not known whether whales that tolerate exposure to seismic pulses are stressed.

Toothed Whales

Little systematic information is available on the reactions of toothed whales to seismic pulses. Few studies similar to the more extensive baleen whale/seismic pulse work summarized above have been reported for toothed whales, and none similar in size and scope to the studies of bowhead and grey whales mentioned above. 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, especially near the UK, showed localized (~one kilometre) avoidance. Recent studies show little evidence of reactions by sperm whales to airgun pulses, contrary to earlier indications. 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.

Dolphins

Seismic operators sometimes see species of toothed whales near operating airgun arrays (e.g., Duncan 1985; Arnold 1996; Stone 2003). When a 3,959-in^3, 18-gun array was firing off California, toothed whales behaved in a manner similar to that observed when the airguns were silent (Arnold 1996). Most, but not all, dolphins often seemed to be attracted to the seismic vessel and floats, and some rode the bow wave of the seismic vessel, seemingly unperturbed by firing guns. However, in Puget Sound, Dall's porpoises (*Phocoenoides dalli*) observed when a 6,000-in^3, 12-16 gun array was firing, tended to be heading away from the boat (Calambokidis and Osmek 1998). White-beaked (*Lagenorhynchus albirostris*) and white-sided dolphins (*L. acutus*) in the U.K. showed fewer positive interactions (approaching, bow riding, swimming alongside) with a seismic vessel while its airgun array was operating. These species, along with killer whales, harbour porpoises (*Phocoena phocoena*), and bottlenose dolphins all were seen further away from the seismic vessel when its airguns were firing than when they were not (Stone 2003).

Goold (1996a,b,c) studied the effects of 2-D seismic surveys in the Irish Sea on common dolphins (*Delphinus delphis*). Passive acoustic surveys were conducted from the "guard ship" that towed a hydrophone 180 m aft. The results indicated that there was a local displacement of dolphins around the seismic operation. However, observations indicated that the animals were tolerant of the sounds at distances outside a 1-km radius from the guns (Goold 1996a). Initial reports of larger-scale displacement were later shown to represent a normal autumn migration of dolphins through the area, and were not attributable to seismic surveys (Goold 1996a,b,c).

Beaked whales

There are no data on the behavioural reactions of beaked whales to seismic surveys. Most beaked whales tend to avoid approaching vessels of other types (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986). It is likely that these beaked whales would normally show strong avoidance of an approaching seismic vessel, but this has not been documented explicitly.

Much attention has been given to a recent (September 2002) stranding of Cuvier's beaked whales (*Ziphius cavirostris*) in the Gulf of California (Mexico) while a seismic survey was under way in the general area (Malakoff 2002). The evidence linking the Gulf of California strandings to the seismic surveys is inconclusive, and to this date is not based on any physical evidence. However, it may be noteworthy that the ship implicated in the stranding was operating its multi-beam bathymetric sonar, which emits high-frequency sound thought to be in the best hearing range of toothed whales like the Cuvier's beaked whale.

Sperm whales

Sperm whales have been reported to show avoidance reactions to standard vessels not emitting airgun sounds (e.g., Richardson et al. 1995; Würsig et al. 1998). Thus, it is to be expected that they would tend to avoid an operating seismic survey vessel. There are some limited observations suggesting that sperm whales in the Southern Ocean ceased calling during some (but not all) times when exposed to weak sound pulses from extremely distant (>300 km) seismic exploration (Bowles et al. 1994). This "quieting" was suspected to represent a disturbance effect, but there are other more plausible explanations. However, sperm whales exposed to pulsed man-made sounds at higher frequencies often cease calling (Watkins and Schevill 1975; Watkins et al. 1985).

On the other hand, recent (and more extensive) data from vessel-based monitoring programs in UK waters suggest that sperm whales in that area show little evidence of avoidance or behavioural disruption in the presence of operating seismic vessels (Stone 2003). These types of observations are difficult to interpret because the observers are stationed on or near the seismic vessel, and may underestimate reactions by some of the more responsive species or individuals, which may be beyond visual range. A recent study off northern Norway indicated that sperm whales continued to call when exposed to pulses from a distant seismic vessel, with received levels of up to 146 dB re 1 µPa peak-

peak, and remained in the area throughout the survey (Madsen et al. 2002a). Similarly, sperm whales in the Gulf of Mexico did not alter their calling behaviour in the presence of seismic pulses, and there was no indication that they moved away from the sound source at received levels of up to 148 dB (Jochens and Biggs 2003). A study conducted off Nova Scotia detected no difference in the acoustic abundance of male sperm whales between years without any seismic survey activity and years with an active seismic program, with received levels of 130 to 150 dB re 1 µPa (McCall Howard 1999). In addition, in the Gulf of Mexico, Davis et al. (2000) found no differences in sighting frequencies of sperm whales among areas with and without seismic surveys, with received levels of up to >12 dB above ambient sound levels.

Pinnipeds

Few studies on the reactions of pinnipeds to sound from open-water seismic exploration have been published (for review, see Richardson et al. 1995). However, pinnipeds have been observed during a number of seismic monitoring studies in recent years. Monitoring studies in the Beaufort Sea during 1996-2001 provide a substantial amount of information on avoidance responses (or lack thereof) and associated behaviour. Pinnipeds exposed to seismic sound have also been observed during recent seismic surveys along the U.S. west coast. Also, there are data on the reactions of pinnipeds to various other related types of impulsive sounds.

Early observations provided considerable evidence that pinnipeds are often quite tolerant of strong pulsed sounds. During seismic exploration off Nova Scotia, grey seals (*Halichoerus grypus*) exposed to sound from airguns and linear explosive charges reportedly did not react strongly (J. Parsons *in* G.D. Greene et al. 1985). An airgun caused an initial startle reaction among South African fur seals but was ineffective in scaring them away from fishing gear (Anonymous 1975). Pinnipeds in both water and air sometimes tolerate strong sound pulses from non-explosive and explosive scaring devices, especially if attracted to the area for feeding or reproduction (Mate and Harvey 1987; Reeves et al. 1996). Thus, pinnipeds are expected to be rather tolerant of, or habituate to, repeated underwater sounds from distant seismic sources, at least when the animals are strongly attracted to the area.

In the UK, a radio-telemetry study has demonstrated short-term changes in the behaviour of harbour seals (*Phoca vitulina*) and grey seals exposed to airgun pulses (Thompson et al. 1998). In that study, harbour seals were exposed to seismic pulses from a 90-in^3 array (3 × 30-in^3 airguns), and behavioural responses differed among individuals. One harbour seal avoided the array at distances up to 2.5 km from the source and only resumed foraging dives after the seismic survey stopped. Another harbour seal exposed to the same small airgun array showed no detectable behavioural response, even when the array was within 500 m. All grey seals exposed to a single 10-in^3 airgun showed an avoidance reaction. Seals moved away from the source, increased swimming speed and/or dive duration, and switched from foraging dives to predominantly transit dives. These effects appeared to be short-term as all grey seals either remained in, or returned at least once to, the foraging area where they had been exposed to seismic pulses. These results suggest that there are interspecific as well as interindividual differences in seal responses to seismic sounds.

Monitoring work in the Alaskan Beaufort Sea during 1996-2001 provided considerable information regarding the behaviour of seals exposed to seismic pulses (Harris et al. 2001; Moulton and Lawson 2002). These seismic projects usually involved arrays of 6 to 16 airguns with total volumes 560 to 1,500 in^3. The combined results suggest that some seals avoided the immediate area around seismic vessels. In most survey years, ringed seal sightings tended to be farther away from the seismic vessel when the airguns were operating than when they were not (Moulton and Lawson 2002). However, these movements were relatively small and were on the order of 100 m to (at most) a few hundreds of metres, and many seals remained within 100-200 m of the trackline as the operating airgun array passed.

The operation of the airgun array had minor and variable effects on the behaviour of seals visible at the surface within a few hundred meters of the array. The behavioural data indicate that some seals were more likely to swim away from the source vessel during periods of airgun operations and more likely to swim toward or parallel to the vessel during non-seismic periods. No consistent relationship was observed between exposure to airgun sound and the proportions of seals engaged in other recognizable behaviours, e.g., "looked" and "dove." Such a relationship might have occurred if seals seek to reduce exposure to strong seismic pulses, given the reduced airgun sound levels close to the surface where "looking" occurs (Moulton and Lawson 2002).

In summary, visual monitoring from seismic vessels has shown only slight (if any) avoidance of airguns by pinnipeds, and only slight (if any) changes in behaviour. These studies show that pinnipeds frequently do not avoid the area within a few hundred metres of an operating airgun array. However, initial telemetry work suggests that avoidance and other behavioural reactions may be stronger for some individuals than evident to date from visual studies.

Hearing Impairment

There are no data on the levels or properties of sound that are required to induce a TTS in any baleen whale, as it is not possible to study hearing directly in such a large, free-living marine animal. TTSs for pinnipeds exposed to brief pulses (either single or multiple) have not been measured.

Toothed Whales

Finneran et al. (2002) exposed a beluga whale and a bottlenose dolphin to single pulses using an 80-in^3 water gun. Water gun pulses contain proportionally more energy at higher frequencies than do airgun pulses (Hutchinson and Detrick 1984). Masked TTS (MTTS), defined as a TTS that occurred with considerable background sound, was observed in a beluga after exposure to a single impulse with a peak-to-peak pressure of 226 dB re 1 µPa, peak pressure of 160 kPa, and total energy flux of 186 dB re 1 µPa2·s. Thresholds returned to within 2 dB of the pre-exposure value approximately four minutes after exposure. No MTTS was observed in a bottlenose dolphin exposed to one pulse with a peak-to-peak pressure of 228 dB re 1 µPa, equivalent to a peak pressure of 207 kPa and total energy flux of 188 dB re

1 µPa2·s (Finneran et al. 2000, 2002). In that study, TTS was defined as occurring when the post-exposure threshold was ≥6 dB higher than the pre-exposure threshold. Pulse duration at the highest exposure levels, where MTTS became evident in the beluga, was typically 10-13 ms.

The data quoted above concern the exposure of small odontocetes to single pulses, generally at frequencies higher than the predominant frequencies in airgun pulses. Additional data are needed in order to determine the received sound levels at which small odontocetes would start to incur TTS upon exposure to repeated, low-frequency pulses of airgun sound. Given the results of the aforementioned study and a seismic pulse duration (as received at close range) of approximately 20 ms, the received level of a single seismic pulse might need to be on the order of 210 dB re 1 µPa rms (approximately 221-226 dB peak-peak) in order to produce a brief, mild TTS. Exposure to several seismic pulses at received levels near 200-205 dB (rms) might result in a slight TTS in a small odontocete. Seismic pulses with received levels of 200-205 dB or more are usually restricted to a radius of no more than 100 m around a seismic vessel.

Non-Auditory Physiological Effects

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. 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.

Toothed Whales

Romano et al. (2004) exposed a beluga whale and a bottlenose dolphin to single underwater impulsive sounds (up to 200 kPa) from a seismic water gun and measured nervous system and immune system indicators before and after these exposures. In the beluga whale, levels of norepinephrine, epinephrine, and dopamine increased significantly with increasing sound levels and were significantly greater after sound exposures >100 kPa than after sound exposures <100 kPa and after control exposures. In the bottlenose dolphin, there was a significant increase in aldosterone level and a significant decrease in monocyte count after exposure to impulsive sounds. How short-term stress responses might affect the long-term health of cetaceans is unknown.

Sound Other than Seismic

Sound produced during exploration and production drilling emanates from the drill rig, supply vessels, and associated aircraft. Seismic guns may also be discharged periodically from the rig or supply ship (vertical seismic profiling [VSP]) in order to get more detailed information on the hole or reservoir (this aspect is covered in the previous section). The effects of underwater sound produced by offshore oil and gas development and production activities have been studied for only a few marine mammal species, and under only a limited number of circumstances. Thus, the broader literature on general effects of underwater sound must be used to estimate possible reactions of marine mammals to the kinds of sounds being considered in this assessment.

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 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.

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. The limited available data indicate that the sperm whale is sometimes, though not always, more responsive than other toothed whales. 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.

Pulsed Sounds

Baleen Whales

There are no data on hearing thresholds versus pulse duration in baleen whales. However, there is some evidence that disturbance response thresholds in gray and bowhead whales may be related to pulse duration in a manner similar to the relationship between hearing threshold and pulse duration in toothed whales and seals. Malme (1993) summarised the received levels of seismic (airgun) sounds at which an estimated 50% of bowhead and gray whales avoided the source. He then examined the received levels in relation to effective pulse pressure and in relation to response thresholds of the same two species to continuous sound. With pulsed (airgun) sounds, the sound pressure necessary to elicit avoidance in 50% of the whales was about 50 dB higher than that for continuous sounds.

In summary, whereas reactions of baleen whales to pulsed sounds varied depending on the sound source level, type of whale exposed to the sounds, and the whales' activity when the sounds were heard, most baleen whales exhibited some displacement from strong pulsed sounds. In most cases, the displacement was 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).

Toothed Whales

Experimental results (e.g., Würsig et al. 2000; Akamatsu et al. 1993) show that responses to impulsive sound sources are highly variable among toothed whales. 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 species in 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.

Ridgway et al. (1997) and Schlundt et al. (2000) exposed bottlenose dolphins and beluga whales to single 1-s pulses of underwater sound. TTSs generally became evident at received levels of 192-201 dB re 1 µPa rms at 3, 10, 20, and 75 kHz. At 75 kHz, one dolphin exhibited a TTS at 182 dB, and at 0.4 kHz, no dolphin or beluga exhibited a TTS after exposure to levels up to 193 dB (Schlundt et al. 2000). There was no evidence of permanent hearing loss, as all hearing thresholds returned to baseline values at the end of the study.

Pinnipeds

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

Pulsed Sounds: Sonar

The effects of most types of sonar on marine mammals are relatively poorly studied given their widespread use. Observed effects vary depending on the species group involved and the frequency of the sonar, and range from no apparent affect at all to mortality.

Baleen Whales

Humpback, finback, and right whales reportedly do not react to pingers and sonars at frequencies of 36, 40, 50, and 60 kHz and higher as long as the signals contain little energy in the lower frequencies (Watkins 1986). Most of those whales react to sounds with frequencies from 15 Hz to 28 kHz.

Humpback whales in Hawaii displayed apparent avoidance behaviour of a 3.3-kHz sonar pulse and a sonar frequency sweep from 3.1 to 3.6 kHz (Maybaum 1993). The whales reacted by increasing their swimming speed and the linearity of their course, while diving and calling were not affected.

Male humpback whales were reported to increase the length of their songs during the transmission of military low-frequency active (LFA) sonar at less than full strength (Miller et al. 2000). The transmission consisted of ten 42-s LFA signals at 6-min intervals. The response was of limited duration, as song length returned to normal after exposure. In five cases, singing humpbacks ceased singing, apparently in response to the sound. Singing is thought to be a sexual display used to attract mates, and the effect of a change in this behaviour on reproductive success is unknown.

Toothed Whales

Responses of toothed whales to sonar vary according to species and the type of sonar used and include avoidance, changes in calling rates, and recently, death. Dall's porpoises and some Delphinids show apparent avoidance (Richardson et al. 1995). Sperm whales react strongly to many types of sonar usually by ceasing vocalizing. Conversely, pilot whales in the Ligurian Sea apparently responded to a military sonar signal by calling in response (Rendell and Gordon 1999). While beaked whale strandings have been linked to the use of military mid-frequency sonar (see below), strandings of 14 harbour porpoises in Washington State in May–June of 2003 that coincided in space and time with the use this type sonar could not be definitively linked to its use (NOAA Fisheries 2004).

Beaked Whales

Military sonar has been implicated in strandings of beaked whales and, occasionally, other cetacean species. Frantzis (1998) reported on a mass live stranding in 1996 of 12 Cuvier's beaked whales in the Mediterranean Sea that corresponded closely in time and space to NATO testing of an LFA sonar system, which produces a broadband signal with a maximum intensity of ≥230 dB re 1 μPa at frequencies ranging from 250–3000 Hz. In March of 2000, a mass stranding of Cuvier's beaked whales and Blainville's beaked whales (*Mesoplodon densirostris*) that occurred in The Bahamas was most likely caused by tactical mid-range frequency military sonar (U.S. Department of Commerce and U.S. Navy 2001; Schrope 2002). Finally, eight Cuvier's beaked whales, one Blainville's beaked whale, and one Gervais' beaked whale (*Mesoplodon europaeus*), which were part of a group of 14 beaked whales that stranded in the Canary Islands close to the site of an international naval exercise in September 2002, were found to have gas-bubble lesions consistent with acute trauma due to in vivo bubble formation as a result of rapid decompression (Jepson et al. 2003).

Sperm Whales

Watkins and Schevill (1975) reported that sperm whales ceased calling in response to the calibration sequences of their pingers, which had frequencies that varied from 6–13 kHz and sound levels that varied from 110–130 dB re 1 µPa at 1 m. Sperm whales did not react to 36-, 40-, 50-, and 60-kHz calibration pingers or sonars (Watkins et al. 1985). Sperm whales in the Caribbean exhibited a dramatic reaction to military sonar, heard as short sequences of four to twenty 0.145- to 0.45-second pulses at rates of 1–5 signals per minute with frequencies ranging from 3250–8400 Hz, by falling silent and dispersing (Watkins et al. 1985, 1993).

Pinnipeds

The possible effects of sonar on pinnipeds are not well studied. Richardson et al. (1995) reviewed the available data and found harp seals to alter their swimming patterns in relation to a 200-kHz echosounder, while other species showed no apparent responses to 60-69 kHz acoustic pingers.

Pulsed Sounds: Underwater Explosions

Baleen Whales

Humpback whales in Trinity Bay Newfoundland (Todd et al. 1996) apparently did not react to underwater explosions related to industrial activity in the Bay, with behaviour, distribution, and residency time apparently unaffected by the blasts. Charges were generally 1,000-2,000 kg and peak source levels were typically 140-140 dB re 1 µPa near 400 Hz.

Toothed Whales

Observations of toothed whale responses to sound pulses from underwater explosions have also been made over the years. During the 1950s, small explosive charges were dropped into an Alaskan river in attempts to scare belugas away from salmon. Success was limited (Fish and Vania 1971; Frost et al. 1984). Small explosive charges were "not always effective" in moving bottlenose dolphins away from sites in the Gulf of Mexico where larger demolition blasts were about to occur (Klima et al. 1988). Odontocetes may be attracted to fish killed by explosions, and thus attracted rather than repelled by "scare" charges.

Captive false killer whales (*Pseudorca crassidens*) showed no obvious reaction to single sound pulses from small (10-g) charges; the received level was approximately 185 dB re 1 µPa (Akamatsu et al. 1993). Jefferson and Curry (1994) reviewed several additional studies that found limited or no effects of sound pulses from small explosive charges on killer whales and other odontocetes. Excluding the potential for hearing loss, the tolerance to these charges may indicate a lack of effect or the failure to move away may simply indicate a stronger desire to eat, regardless of circumstances.

Finneran et al. (2000) exposed bottlenose dolphins and a beluga whale to single underwater pulses designed to generate sounds with pressure waveforms similar to those produced by distant underwater explosions. Pulses were of 5.1-13 ms in duration and the measured frequency spectra showed a lack of energy below 1 kHz. Exposure to those impulses at a peak received sound pressure level of 221 dB re 1 µPa produced no more than a slight and temporary reduction in hearing.

Sperm Whales

Male sperm whales off Andenes in northern Norway did not change their click rates in response to detonations used to calibrate a hydrophone array, with estimated received sound levels of 173–179 dB re 1 µPa (Madsen and Møhl 2000).

Pinnipeds

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). However, it is unknown whether these animals incur any hearing damage or other injuries.

Continuous Sounds: Drilling

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

Baleen whales sometimes show behavioural changes in response to received broadband drillship sounds of 120 dB or greater. On their summer range in the Beaufort Sea, bowhead whales reacted to drillship sounds within four to eight kilometres of a drillship at received levels 20 dB above ambient or about 118 dB (Richardson et al. 1990). Reactions were stronger at the onset of the sound (Richardson et al. 1995). Migrating bowhead whales avoided an area with a radius of 10-20 km around drillships and their associated support vessels, corresponding to a received sound level around 115 dB (Greene 1987; Koski and Johnson 1987; Hall et al. 1994; Davies 1997; Schick and Urban 2000). For gray whales off California, the predicted reaction zone around a semi-submersible drill rig was less than one kilometre, at received levels of ~120 dB (Malme et al. 1983, 1984). Humpback whales showed no obvious avoidance response to broadband drillship sounds at a received level of 116 dB (Malme et al. 1985).

Toothed Whales

Dolphins and other toothed whales may show considerable tolerance of floating and bottom-founded drillrigs and their support vessels. Kapel (1979) reported many pilot whales within visual range of drillships and their support vessels off West Greenland. Belugas have been observed swimming within 100-150 m of an artificial island while drilling was underway (Fraker and Fraker 1979; 1981), and within 1,600 m of the drillship *Explorer I* while the vessel was drilling (Fraker and Fraker 1981). Of the seven occasions when the whales were observed near an artificial island while drilling was being conducted, calves were present. Some belugas in Bristol Bay and the Beaufort Sea, Alaska, when exposed to playbacks of drilling sounds, altered course to swim around the source, increased swimming speed, or reversed direction of travel (Stewart et al. 1982; Richardson et al. 1995). Reactions of beluga whales to semi-submersible drillship sound were less pronounced than were reactions to motorboats with outboard engines. Captive belugas exposed to playbacks of recorded semi-submersible sound seemed quite tolerant of that sound (Thomas et al. 1990).

Pinnipeds

Responses of pinnipeds to drilling sound have not been well studied. Richardson et al. (1995) summarized the few available studies, which showed ringed seals and bearded seals (*Erignathus barbatus*) in the Arctic to be rather tolerant of drilling sound. Seals were often seen near active drillships and approached, to within 50 m, a sound projector broadcasting low-frequency drilling sound.

Other Continuous Sounds

Toothed Whales

Harbour porpoises off Vancouver Island, British Columbia, were found to be sensitive to the simulated sound of a 2 MW offshore wind turbine (Koschinski et al. 2003). Harbour porpoises remained significantly further away from the sound source when it was active and this effect was seen out to a distance of 60 m. The device used in that study produced sounds in the frequency range of 30–800 Hz, with peak source levels of 128 dB re 1 µPa at 1 m at the 80 and 160 Hz frequencies.

TTSs were measured in a single bottlenose dolphin after exposure to a continuous tone with maximum sound pressure levels at frequencies ranging from 4–11 kHz that was gradually increased in intensity to 179 dB re 1 µPa and in duration to 55 minutes (Nachtigall et al. 2003). No threshold shifts were measured at sound pressure levels of 165 or 171 dB re 1 µPa. However, at 179 dB re 1 µPa TTSs >10 dB were measured during different trials with exposures ranging from 47–54 minutes. Hearing sensitivity apparently recovered by 45 minutes after sound exposure.

Pinnipeds

Reactions of harbour seals to the simulated sound of a 2-MW windpower generator were measured by Koschinski et al. (2003). Harbor seals surfaced significantly further away from the sound source when it was active and did not approach the sound source as closely. The device used in that study produced sounds in the frequency range of 30–800 Hz, with peak source levels of 128 dB re 1 µPa at 1 m at the 80 and 160 Hz frequencies.

Kastak et al. (1999) reported that they could induce mild TTSs in California sea lions (*Zalophus californianus*), harbour seals, and northern elephant seals (*Mirounga angustirostris*) by exposing them to underwater octave-band sound at frequencies in the 100-2000 Hz range for 20-22 minutes. Mild TTSs became evident when the received levels were 60-75 dB above the respective hearing thresholds, that is, at received levels of about 135-150 dB. Three of the five animals tested showed shifts of approximately 4.6-4.9 dB, and all recovered to baseline hearing sensitivity within 24 hours of exposure. Schusterman et al. (2000) showed that TTSs of these seals were somewhat lower when the animals were exposed to the sound for 40 minutes than for 20-22 minutes, confirming that there is a duration effect in pinnipeds. There are some indications that, for corresponding durations of sound, pinnipeds may incur a TTS at a somewhat lower received level than do small odontocetes (Kastak et al. 1999; cf. Au 2000).

Transient Sounds: Vessels

Broadband source levels (at 1 m) for most small ships are in the 170-180 dB re 1 µPa range, excluding infrasonic components (Richardson et al. 1995). Broadband underwater sounds from the supply ship *Robert Lemeur* in the Beaufort Sea were 130 dB at a distance of 0.56 km (Greene 1987), and were 11 dB higher when bow thrusters were operating than when they were not (Greene 1985, 1987). The *Robert Lemeur* has nozzles around the thruster propellers. Broadband sound levels from ships lacking nozzles or cowlings around the propellers can be about 10 dB higher than those from ships with the nozzles (Greene 1987).

Baleen Whales

Reactions of baleen whales to boat sounds include changes in swimming direction and speed, blow rate, and the frequency and kinds of vocalisations (Richardson et al. 1995). Baleen whales, especially minke whales (*Balaenoptera acutorostrata*), occasionally approach stationary or slow-moving boats, but more commonly avoid boats. Avoidance is strongest when boats approach directly or when vessel sound changes abruptly (Watkins 1986; Beach and Weinrich 1989). Humpback whales responded to boats at distances of at least 0.5 to 1 km, and avoidance and other reactions have been noted in several areas at distances of several kilometres (Jurasz and Jurasz 1979; Dean et al. 1985; Bauer 1986; Bauer and Herman 1986). During some activities and at some locations, humpbacks exhibit little or no reaction to boats (Watkins 1986).

Right whales (*Eubalaena glacialis*) also show variable responses to boats. There may be an initial orientation away from a boat, followed by a lack of observable reaction (Atkins and Swartz 1989). A slowly moving boat can approach a right whale, but an abrupt change in course or engine speed will elicit a reaction (Goodyear 1989; Mayo and Marx 1990; Gaskin 1991). When approached by a boat, right whale mothers will interpose themselves between the vessel and calf and will maintain a low profile (Richardson et al. 1995). In a recent study, using a multi-sensor acoustic recording tag and controlled sound exposure experiments, right whales were found to show no response to playbacks of the sound of an approaching 120-m container ship or to actual vessels (Nowacek et al. 2004). The closely related bowhead whale typically begins avoiding diesel powered boats at distances of ~four kilometres; the whale often first attempts to "outrun" the vessel, but may turn to swim perpendicular to the boat’s track when it approaches within a few hundred metres (Richardson et al. 1985a,b; Koski and Johnson 1987). Bowheads may be displaced by a few kilometres when fleeing, although some return to the area within a day.

Toothed Whales

Some species of small toothed cetaceans avoid boats when they are approached to within 0.5-1.5 km, with occasional reports of avoidance at greater distances (Richardson et al. 1995). Some toothed whale species appear to be more responsive than others. Beaked whales and beluga whales seem especially responsive to boats.

Dolphins and Porpoises

Dolphins may tolerate boats of all sizes, often approaching and riding the bow and stern waves (Shane et al. 1986). At other times, dolphin species that are known to be attracted to boats will avoid them. Such avoidance is often linked to previous boat-based harassment of the animals (Richardson et al. 1995).

Coastal bottlenose dolphins that are the object of whale-watching activities have been observed to swim erratically (Acevedo 1991), remain submerged for longer periods of time (Janik and Thompson 1996; Nowacek et al. 2001), display less cohesiveness among group members (Cope et al. 1999), whistle more frequently (Scarpaci et al. 2000), and rest less often (Constantine et al. 2004) when boats were nearby. Pantropical spotted dolphins (*Stenella attenuata*) and spinner dolphins (*Stenella longirostris*) in the eastern Tropical Pacific, where they have been targeted by the tuna fishing industry because of their association with these fish, show avoidance of survey vessels up to six nautical miles away (Au and Perryman 1982; Hewitt 1985), whereas spinner dolphins in the Gulf of Mexico were observed bowriding the survey vessel in all 14 sightings of this species during one survey (Würsig et al. 1998).

Harbour porpoises tend to avoid boats. In the Bay of Fundy, Polacheck and Thorpe (1990) found harbour porpoises to be more likely to be swimming away from the transect line of their survey vessel than swimming toward it and more likely to be heading away from the vessel when they were within 400 m of it. Similarly, off the west coast of North America, Barlow (1988) observed harbour porpoises to avoid a survey vessel by moving rapidly out of its path within one kilometre of that vessel.

Beluga Whales

Beluga whales are generally quite responsive to vessels. Belugas in Lancaster Sound in the Canadian Arctic showed dramatic reactions in response to icebreaking ships, with received levels of sound ranging from 101 dB to 136 dB re 1 μPa in the 20–1,000-Hz band at a depth of 20 m (Finley et al. 1990). Responses included emitting distinctive pulsive calls that were suggestive of excitement or alarm and rapid movement in what seemed to be a flight response. Reactions occurred out to 80 km from the ship.

Although belugas in the St. Lawrence River occasionally show positive reactions to ecotourism boats by approaching and investigating those boats, one study found the belugas to surface less frequently, swim faster, and group together in the presence of boats (Blane and Jaakson 1994). Another study found belugas to use higher-frequency calls, a greater redundancy in their calls (more calls emitted in a series), and a lower calling rate in the presence of vessels (Lesage et al. 1999).

Beaked Whales

Most beaked whales tend to avoid approaching vessels (e.g., Würsig et al. 1998). They may also dive for an extended period when approached by a vessel (e.g., Kasuya 1986). Northern bottlenose whales sometimes are quite tolerant of slow-moving vessels (Reeves et al. 1993; Hooker et al. 2001).

Sperm Whales

Sperm whales generally show no overt reactions to vessels unless they are approached to within several hundred meters (Watkins and Schevill 1975; Würsig et al. 1998; Magalhães et al. 2002). Observed reactions include spending more (Richter et al. 2003) or less (Watkins and Schevill 1975) time at the surface, increasing swimming speed or changing heading (Papastavrou et al. 1989; Richter et al. 2003), and diving abruptly (Würsig et al. 1998).

Pinnipeds

Ship and boat sound do not seem to have strong effects on seals in the water, but the data are limited. When in the water, seals appear to be much less apprehensive of approaching vessels. Some will approach a vessel out of apparent curiosity, including noisy vessels such as those operating seismic airgun arrays (Moulton and Lawson 2000). Grey seals have been known to approach and follow fishing vessels in an effort to steal catch or the bait from traps. In contrast, seals hauled out on land often are quite responsive to nearby vessels. Terhune (1985) reported that Northwest Atlantic harbour seals were extremely vigilant when hauled out, and were wary of approaching (but less so passing) boats. Suryan and Harvey (1999) reported that Pacific harbour seals commonly left the shore when powerboat operators approached to observe the seals. Those seals detected a powerboat at a mean distance of 264 m, and seals left the haul-out site when boats approached to within 144 m.

Transient Sounds: Aircraft

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. Because of the large difference in the acoustic properties of water and air, the pressure field is doubled at the surface of the water, resulting in a 6-dB increase in pressure level at the surface.

For a passing airborne source, peak received levels at and below the surface diminish 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.

Baleen Whales

Minke, bowhead, and right whales sometimes react to aircraft overflights at altitudes of 150-300 m by diving, changing dive patterns, or leaving the area (Leatherwood et al. 1982; Watkins and Moore 1983; Payne et al. 1983; Richardson et al. 1985a,b, 1995). However, the majority of the bowheads do not react noticeably even to a low-altitude (~150 m) overflight. Helicopter disturbance to humpback whales is a concern off Hawaii, where helicopters are prohibited from approaching humpbacks to within 305 m (Tinney 1988; Atkins and Swartz 1989; NMFS 1987). 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).

Toothed Whales

Most species of toothed whales do not appear to react overtly to aircraft overflights, except when the aircraft fly at low altitudes. Beaked whales, pygmy sperm whales (*Kogia breviceps*), dwarf sperm whales (*K. sima*), and Dall’s porpoises appear to react more strongly to low-level aircraft overflights than do bottlenose dolphins or sperm whales. Whales that do react dive hastily, turn, or swim away from the flight path. Feeding or socialising whales and dolphins are less likely to react than those engaged in other activities.

Bottlenose dolphins did not react as strongly to the presence of an aircraft as did some other odontocete species during aerial surveys from Twin Otter turboprop aircraft operating at 230 m altitude and 110 knots. The bottlenose dolphins changed their behaviour in response to the overflights during only a relatively small proportion of the encounters (Würsig et al. 1998). They were most likely to change their behaviour (usually by diving) when they were milling or resting. Spinner dolphins reacted in all cases to aircraft overflights at 230 m, while pantropical spotted, Atlantic spotted (*S. frontalis*), clymene (*S. clymene*), and striped (*S. coeruleoalba*) dolphins reacted less than half the time (Würsig et al. 1998). During earlier surveys with a similar aircraft and methodology, bottlenose dolphins did not appear to react aversively to the aircraft except when its shadow passed directly over them, in which case they would make a startled dive (Mullin et al. 1991).

Larger toothed whales show variable reactions to aircraft. Some belugas ignored aircraft at flying at 500-m altitude but dove for longer periods and sometimes swam away when it was at 150-200 m (Bel'kovich 1960; Kleinenberg et al. 1964). Lone animals sometimes dove in response to flights at 500 m. Off Alaska, some belugas showed no reaction to airplanes or helicopters at 100-200-m altitude, whereas a minority dove abruptly or swam away in response to overflights at altitudes up to 460 m (Richardson et al. 1995). Belugas in the Alaskan Beaufort Sea reacted to a Twin Otter aircraft and a helicopter with immediate dives, changes in heading, changes in behavioural state, and apparent displacements, with most reactions occurring when the aircraft was at an altitude ≤ 182 m and a lateral distance from the animals of ≤ 250 m (Patenaude et al. 2002). Narwhals (*Monodon monoceros*) dove in response to helicopters flying at altitudes below 244 m and, to a lesser degree, at 305 m (Kingsley et al. 1994). Beaked whales responded almost 90% of the time to the overflight of a Twin Otter aircraft at an altitude of 230 m and speed of 110 knots in the Gulf of Mexico (Würsig et al. 1998).

Some sperm whales showed no reaction to helicopters and airplanes flying over at altitudes of 150 m, but some dove immediately (Clarke 1956; Mullin et al. 1991). Sperm whales in the Gulf of Mexico were more responsive to the overflight of a survey aircraft when they were encountered resting (the animals dove 40% of the time) and nonresponsive when they were encountered travelling (Würsig et al. 1998). Male sperm whales off Kaikoura, New Zealand, spent more time at the surface and showed more frequent heading changes in the presence of small fixed-wing planes and helicopters involved in whale-watching activities (Richter et al. 2003). Smultea et al. (2001) report only occasional reactions (consisting of a quick dive) by sperm whales when their small-fixed wing aircraft passed within 360 m from the whales, typically at an altitude of 244 m and speed of 100 knots, and one case of defensive posturing by a group of 11 sperm whales (including one calf) when their aircraft was circling them at altitudes of 245–335 m.

Pinnipeds

Seals hauled out for pupping or moulting have variable sensitivities to aircraft disturbance, but at times react strongly, generally by moving abruptly into the water (Richardson et al. 1995). Fixed-wing aircraft flying at altitudes below 60-120 m and helicopters flying below 305 m at times cause panic among adult common seals and mortality of young at haul-out beaches (Johnson 1977; Bowles and Stewart 1980; Osborn 1985). However, seals that have become habituated to aircraft may show little or no reaction (M. Bigg *in* Johnson et al. 1989:53). There are few observations of the reactions of seals in the water to aircraft. Overflights at low altitudes cause some animals to dive (Richardson et al. 1995).

4.1.5.5 Sea Turtles

There have been far fewer studies of the effects of airgun sound (or indeed any type of sound) on sea turtles than on marine mammals and fish. Three such studies have focused on short-term behavioural responses of sea turtles in enclosures to single airguns. Comparisons of results among studies are difficult, because experimental designs and reporting procedures have varied greatly, and only one of the studies provided specific information about the levels of the airgun pulses received by the turtles. We are not aware of any studies on responses of free-ranging sea turtles to seismic sounds or on the long-term effects of seismic or other sounds on sea turtles. Results from some recent seismic monitoring programs provide some data.

The most recent of the studies of caged sea turtles exposed to airgun pulses was a study by McCauley et al. (2000a,b) off Western Australia. This is apparently the only such study in which received sound levels were estimated carefully. McCauley et al. (2000a,b) exposed caged green and loggerhead sea turtles (one of each) to pulses from an approaching and then receding 20 in^3 airgun operating at 1,500 psi and 5 m gun-depth. The single airgun fired every 10 s. There were two trials separated by two days; the first trial involved ~2 h of airgun exposure and the second ~1 h. The results from the two trials showed that, above a received level of 166 dB re 1 μPa (rms), the turtles noticeably increased their speed of swimming relative to periods when no airguns were operating. The behaviour of the sea turtles became more erratic when received levels exceeded 175 dB re 1 μPa (rms). The authors suggested that the erratic behaviour exhibited by the caged sea turtles would likely, in unrestrained turtles, be expressed as an avoidance response (McCauley et al. 2000a,b).

O'Hara and Wilcox (1990) tested the reactions to airguns of loggerhead sea turtles held in a 300 × 45 m area of a canal 10 m deep in Florida. Nine turtles were tested at different times. The sound source consisted of one 10 in^3 airgun plus two 0.8 in^3 "poppers" operating at 2,000 psi [5] and gun-depth 2 m for prolonged periods: 20–36 hours in duration. The turtles maintained a standoff range of about 30 m when exposed to airgun pulses every 15 sec or every 7.5 sec. It was also possible that some turtles remained on the bottom of the enclosure when exposed to airgun pulses. O'Hara and Wilcox (1990) did not measure the received airgun sound levels. McCauley et al. (2000a,b) estimated that "the level at which O'Hara saw avoidance was around 175–176 dB re 1 μPa (rms)". The levels received by the turtles in the Florida study probably were actually a few dB less than 175–176 dB because the calculations by McCauley et al. (2000a,b) apparently did not allow for the shallow 2 m gun depth in the Florida study. The effective source level of airguns is less when they are near 2 m depth than at 5 m (Greene and Burgess 2000).

Moein et al. (1994) investigated the avoidance behaviour and physiological responses of loggerhead turtles exposed to an operating airgun, as well as the effects on their hearing. The turtles were held in a netted enclosure about 18 m by 61 m by 3.6 m deep, with an airgun of unspecified size at each end.

[5] There was no significant reaction by five turtles during an initial series of tests with the airguns operating at the unusually low pressure of 1,000-psi. The source and received levels of airgun sounds would have been substantially lower when the air pressure was only 1,000-psi than when it was at the more typical operating pressure of 2,000-psi.

Only one airgun was operated at any one time; firing rate was one shot every 5–6 sec. Ten turtles were tested individually, and seven of these were retested several days later. The airgun was initially discharged when the turtles were near the center of the enclosure and the subsequent movements of the turtles were documented. The turtles exhibited avoidance during the first presentation of airgun sounds at a mean range of 24 m, but the avoidance response waned quickly. Additional trials conducted on the same turtles several days later did not show statistically significant avoidance reactions, although there was an indication of slight initial avoidance followed by rapid waning of the avoidance response. The authors described the rapid waning of the avoidance response as "habituation". Their auditory study indicated that exposure to the airgun pulses may have resulted in temporary hearing impairment (TTS, see later section). Reduced hearing sensitivity may also have contributed to the waning response upon continued exposure. There was some evidence from the physiological measurements of increased stress in the sea turtles, but this stress could also have been a result of handling of the turtles.

Inconsistencies in reporting procedures and experimental design prevent direct comparison of Moein's study with either McCauley et al. (2000b) or O'Hara and Wilcox (1990). Moein et al. (1994) stated, without further details, that "three different decibel levels (175, 177, 179) were utilized" during each test. These Figures probably are received levels in dB re 1 μPa, and probably relate to the initial exposure distance (mean 24 m), but these details were not specified. Also, it was not specified whether these values were measured or estimated, or whether they are expressed in peak-peak, peak, rms, SEL, or some other units. Given the shallow water in the enclosure (3.6 m), any estimates based on simple assumptions about propagation would be suspect.

Despite the problems in comparing these three studies, there is a consistent trend showing that, at some received level, sea turtles show avoidance of an operating airgun. McCauley et al. (2000b) found evidence of behavioural responses when the received level from a single small airgun was 166 dB re 1 μPa *rms*, and avoidance responses at 175 dB re 1 μPa (rms). Based on these data, McCauley et al. (2000b) estimated that, for a typical airgun array (2,678 in^3, 12-elements) operating in 100–120 m water depth, sea turtles may exhibit behavioural changes at ~two kilometres and avoidance around one kilometre. These estimates are subject to great variation, depending on the seismic source and local propagation conditions.

There have been no specific studies of free-ranging sea turtles exposed to seismic pulses, and potential long-term behavioural effects of seismic exposure have not been investigated. Sea turtle sightings have been made during L-DEO seismic monitoring programs. During the L-DEO seismic monitoring program in the Eastern Pacific, six sea turtle sightings (two green, two leatherback, and two Olive Ridley sea turtles) were made (Smultea and Holst 2003). Five of these sightings occurred during airgun operations (all within 100 m of the seismic ship), and one turtle appeared to react to the airguns. This turtle was initially sighted ~100 m from the bow, floated by the ship to within 10 m of the airgun array, and then swam away. During the L-DEO seismic monitoring program in the Northwest Atlantic, 26 sea turtle sightings (25 unidentified and one leatherback sea turtle) were made (Haley and Koski 2004). Nine of the 25 sea turtles seen during seismic periods (one 75 in^3 airgun) were actively moving away from the vessel. The 16 other sea turtles did not exhibit avoidance response. Sea turtles were also observed during seismic operations in the SE Caribbean by L-DEO (Smultea et al. 2004). Two sea turtles (hawksbill and unidentified sea turtle) were seen between 10-20 m from the 20-airgun array. Both turtles swam vigorously away from the seismic vessel.

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: (1) avoid the entire seismic survey area to the extent that the turtles move to less preferred habitat; (2) 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 (3) 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.

In summary, most studies have been conducted in shallow water, enclosed areas and thus are somewhat directly applicable to the Study Area. The limited available data indicate that sea turtles will hear airgun sounds. Based on available data, it is likely that sea turtles will exhibit behavioural changes and/or avoidance within an area of unknown size near a seismic vessel. Seismic operations in or near areas where turtles concentrate are likely to have the greatest impact. There are no specific data that demonstrate the consequences to sea turtles if seismic operations do occur in important areas at important times of year. The Western Newfoundland and Labrador Offshore Area Study Area is not a breeding area for sea turtles and it is not known or thought to be an important feeding area, and thus high concentrations of sea turtles are unlikely.

Hearing Impairment and Physical Effects

There have been few studies that have directly investigated hearing or sound-induced hearing loss in sea turtles.

Moein et al. (1994) used an evoked potential method to test the hearing of loggerhead sea turtles exposed to a few hundred pulses from a single airgun. Turtle hearing was tested before, within 24 h after, and two weeks after exposure to pulses of airgun sound. Levels of airgun sounds to which the turtles were exposed were not specifically reported. The authors concluded that five 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; the turtle was about 30 m from the airgun at the start of each trial, but it could then either approach the airgun or move away to a maximum of about 65 m during subsequent airgun pulses. 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.

Studies with terrestrial reptiles have also demonstrated that exposure to impulse sound can cause hearing loss. Desert tortoises (*Gopherus agassizii*) exhibit TTS after exposure to repeated high intensity sonic booms (Bowles et al. 1999). Recovery from these temporary hearing losses was usually rapid (<1 h), which suggested that tortoises can tolerate these exposures without permanent injury (Bowles et al. 1999).

The apparent occurrence of Temporary Threshold Shift in loggerhead turtles exposed to many pulses from a single airgun ≤65 m away suggests that sounds from an airgun array could cause at least temporary hearing impairment in sea turtles if they do not avoid the (unknown) radius where TTS occurs. There is also the possibility of permanent hearing damage to turtles close to the airguns. However, there are few data on temporary hearing loss and no data on permanent hearing loss in sea turtles exposed to airgun pulses.

The study by Moein et al. (1994) indicates that sea turtles can experience TTS when exposed to moderately strong airgun sounds. However, there are no data to indicate whether or not there are any plausible situations in which exposure to repeated airgun pulses at close range could cause permanent hearing impairment in sea turtles.

Behavioural avoidance and hearing damage are related. If sea turtles exhibit little or no behavioural avoidance, or if they acclimate to seismic sound to the extent that avoidance reactions cease, sea turtles might sustain hearing loss if they are close enough to seismic sources.

Turtles in the area of seismic operations prior to start-up may not have time to move out of the area even if standard ramp-up (=soft-start) procedures are in effect. It has been proposed that sea turtles require a longer ramp-up period because of their relatively slow swimming speeds. However, it is unclear at what distance from a seismic source sea turtles might sustain temporary hearing impairment, and whether there would ever be a possibility of exposure to sufficiently high levels for a sufficiently long period to cause irreversible hearing damage (PTS).

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. It is noted above that sea turtles are unlikely to use passive reception of acoustic signals to detect the hunting sonar of killer whales, because the echo-location signals of killer whales are likely inaudible to sea turtles. Hearing is also unlikely to play a major role in their navigation. 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.

Non-auditory Physiological Effects

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. This is unlikely to occur in a deep-water open-ocean situation where there is no nearby land or shoals to confine the movements of the animals. Long-term exposure to anthropogenic sound may have the potential of causing physiological stress that could affect the health of individual animals or their reproductive potential, which in turn could (theoretically) cause effects at the population level (Gisiner [ed.] 1999). It is doubtful that any single sea turtle would be exposed to strong seismic sounds for sufficiently long that significant physiological stress would develop.

In summary, very little is known about the potential for seismic survey sounds to cause auditory impairment or other physical effects in sea turtles. Available data suggest that such effects, if they occur at all, would be limited to short distances. However, the available data do not allow for meaningful quantitative predictions of the numbers (if any) of sea turtles that might be affected in these ways.

Effects of Helicopter Overflights

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.

Effects of Presence of Vessels

To the best of our knowledge, 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.

Effects of Accidental Spills

It is possible that small amounts of Isopar could leak from the streamers or that a fuel spill may occur from the seismic ship and/or its support vessels. Any spills would likely be small and quickly dispersed by wind, wave, and ship’s propellor action. The effects of hydrocarbon spills on sea turtles are discussed in Section 4.3.3.5. Sea turtles are thought to be more susceptible to the effects of oiling than marine mammals but any effects are believed to be sublethal (Husky 2000). Effects of an Isopar spill on sea turtles would be negligible.

Effects of Other Activities Associated with Seismic Surveying

There is potential for sea turtles to interact with the lights, domestic and sanitary wastes, and air emissions from the seismic ship and its support vessels. As discussed previously, any effects from these interactions are predicted to be negligible.

4.1.5.6 Mitigations and Planning

There are standard environmental mitigative measures that are required during geophysical surveys in the offshore Newfoundland and Labrador area consistent with the *Geophysical, Geological, Environmental and Geotechnical Program Guidelines* (C-NOPB 2004). The following items are a list of typical mitigations that must be conducted in a manner consistent with the Guidelines (C-NOPB 2004).

Ramping up

Ramping-up or 'soft starting' the airgun 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.

Shutdown of Seismic Array

The operator is required to shut down the airgun array if a Species at Risk is observed within a 500 m radius of the array.

Observers

The placement of trained observers aboard the seismic vessel to monitor the immediate area for presence of marine mammals and sea turtles is a typical practice during seismic operations. If marine mammals are observed within a set distance (i.e., 500 or 1,000 m monitoring zone) from the vessel during ramp-up, airguns are shut down. Shutdowns of the airgun array could be implemented if deemed necessary due to the proximity of particular species of concern. Shutdown 'triggers' may vary by location and species. Fishery liaison observers (FLOs) are used to communicate and mitigate potential conflicts with fishing vessels.

Optimal Scheduling of Seismic Surveys

Selected timing of the seismic surveys to minimize conflict with biota for fisheries in key areas (e.g., spawning, feeding, migration) at particular times of the year can mitigate any potential effects. These spatial and temporal scheduling mitigations could potentially apply to the identified sensitive fish/fisheries areas in the Study Area. Optimal scheduling to avoid sensitive life stages is particularly important in regards to species deemed to be Species at Risk. Surveys also should be coordinated with DFO to avoid conflicts with research vessel surveys.

Seismic activities should be scheduled to avoid heavily fished areas, to the extent possible. The operator 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).

Guard Vessels

Guard vessels, preferably crewed by commercial fishermen, may accompany the seismic vessel in order to monitor the immediate area for active commercial fishing vessels and thereby minimize potential conflict between the seismic survey activities and commercial fishing activities through good communication.

Communication Between Operators and Marine Users

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.

Compensation for Gear and Vessel Damage

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.

Other Mitigations

The Laurentian Subbasin SEA (C-NOPB and C-NSOPB 2003), Orphan Basin SEA (C-NOPB 2003) and the TGS-NOPEC 2002 EA (Canning and Pitt 2002) listed other mitigations including:

- Minimization of airgun source level to one practical for the survey
- Compliance with all applicable regulations concerning discharges

Planning Implications

Special mitigation measures may be required to reduce impacts in areas such as the Cape St. George Cod Spawning Area, lobster spawning and nursery areas, and herring spawning areas, and will be determined in consultation with regulatory agencies. Mitigations could include timing restrictions for seismic surveys to avoid sensitive life stages of Atlantic cod, lobsters and other relevant species.

4.1.5.7 Data Gaps

Data gaps specific to seismic exploration include the lack of sound measurement and modeling in the Western Newfoundland and Labrador Offshore Area Study Area. Sound measurements and modeling may be useful in impact assessment and in designing mitigations.

Data gaps specific to the marine fauna groups potentially affected by seismic operations are numerous. The fauna of greatest concern would vary depending on the location of proposed exploration activities. Data gaps relating to marine fauna include information on the general biology and distribution as well as information on the specific effects of seismic energy on the animals.

4.2 Routine Exploratory/Delineation Drilling and Production Activities (Non-Sound Issues)

4.2.1 Drilling Activities

Drilling is conducted by the oil and gas industry for three main reasons: (1) to confirm the presence of petroleum subsequent to geophysical surveys, (2) delineate the resource, and (3) during production to increase access to the resource. The first two can be considered exploratory and the third production drilling. They all involve similar equipment and activities and thus no real distinction is made in the description and discussion that follow. Drilling and testing the typical exploration well on the shelf may take about 40 days for drilling and an additional 20 days for testing if hydrocarbons are found.

At present, every exploratory drilling program on the East Coast is subject to a site-specific environmental assessment (EA) under the *Canadian Environmental Assessment Act* (*CEAA*).
Typical issues addressed in site-specific EAs include:

- Noise generated by well site geohazard or vertical seismic profiling (VSP) surveys (i.e., small scale seismic of short duration), drill rig machinery, supply vessels, and helicopters
- Effluents and emissions of the drill rig (e.g., sanitary, grey water, mud and cuttings, etc.)
- Accidental events (e.g., blowouts and spills)
- Well abandonment activities

Normally if there any concerns with offshore drilling, they tend to revolve around the disposition of mud and cuttings on the sea floor, discharge and disposal of cuttings from onshore to offshore directional drilling activities, accidental events such as spills or blowouts, and disturbance of marine birds and mammals, if the area is deemed to be an important area for these species. To date, all EAs for drilling have predicted that any environmental effects will be not significant with the possible exception of a major oil blowout (e.g., Petro-Canada 1996; Husky 2000, 2002, 2003; LGL 2005, and others). In the case of offshore West Newfoundland, additional issues will likely concern aesthetics (i.e., effects on viewscapes) and nearshore oil spill impacts because of the importance of the tourist industry there and the proximity to shore of at least some potential developments. Onshore to offshore drilling operations are considered to be safer from an environmental effects perspective compared to drilling in the offshore.

The following sections provide a brief description of typical exploratory drilling equipment, procedures and activities.

4.2.1.1 Drill Rigs

Worldwide, there is a wide variety of drill rigs in common use. The offshore drill rig usually contains the drilling equipment, working and living quarters and is serviced by helicopters and supply vessels.

To date, the most common drill rig on the Grand Banks has been the semi-submersible (e.g., the *Glomar Grand Banks*) (Figure 4.4). Semi-submersibles are normally anchored but some can be dynamically positioned without anchors. Most of Hibernia's drilling is conducted from the concrete, gravity base structure (GBS) that also houses the production facilities. (Figure 4.5) In Nova Scotia, 'jack-up', bottom-founded rigs have been typical and this type of rig has been used on the west coast of Newfoundland (Figure 4.6). This rig type has been recently approved for the Grand Banks under certain conditions (e.g., ice-free season) and was drilling there in 2005. As drilling moves into deep water off the continental shelf there will be a trend toward semi-submersibles or drill ships.

The widest variety of drilling equipment occurs in the Gulf of Mexico where offshore drilling has been conducted since the 1940s over thousands of wells and ranges from drilling barges in very shallow water (i.e., a few metres), bottom-founded and jack-ups at moderate depths, semi-submersibles in deeper water and drill ships in very deep water (a few thousand meters). There are also multi-use platforms that can drill, produce and service wells.

Any of the above-mentioned rig types could be used on the west coast depending upon the water depth, proximity to land, nature of the resource, and other factors.

Another drilling scenario relevant to the west coast is directional drilling from land. This approach is presently only feasible if the resource is close to shore but the technology has already been used on the Port au Port Peninsula on the west coast of Newfoundland (e.g., Shoal Point K-39, Long Point M-16, Long Range A-09). To date, only conventional rotary drill rigs have been used for the directional drilling on the west coast. Coil tubing drilling is another technology being applied to directional drilling but to date has not been employed on the west coast (D. Hawkins, C-NLOPB, pers. comm., W. Foote, Government of Newfoundland and Labrador, pers. comm.). Hibernia has directional drilled (i.e., horizontal or deviated) at least as far as about six kilometres from the GBS and the technology is capable of at least 10 km (CAPP 2001a).

There may be some minor differences between and within rig types in terms of capabilities, treatment facilities, effluent discharge depths, and so forth but, for the most part, each rig is fairly 'typical' in terms of characteristics, volumes and types of discharges. All must conform to the *Offshore Waste Treatment Guidelines* (*OWTG*) (NEB et al. 2002). Rig types do differ in terms of the noise emitted with dynamically positioned drill ships being the noisiest and the 'jack-up' being the quietest.

Drill mud handling is an important duty of the rig (see below). Other equipment and material includes casings, cement to bond the casings, risers and blowout preventers (BOP).

Figure 4.4. Semi-submersible Drill Rig *Glomar Grand Banks*.

Figure 4.5. *Hibernia* GBS.

Figure 4.6. ***Rowan Gorilla*** **Jack-up Rig.**

4.2.1.2 Drill Muds

Drilling mud is needed to convey drill cuttings out of the hole and to keep formation fluids from entering the well. Hibernia re-injects some 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 on 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 (D. Hawkins, C-NLOPB, pers. comm., W. Foote, Government of Newfoundland and Labrador, pers. comm.). 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, drilling fluids are stored in tanks at the rig site and eventually trucked to lined pits/containment areas for storage (D. Hawkins, C-NLOPB, pers. comm., W. Foote, Government of Newfoundland and Labrador, pers. comm.). All drilling fluids should be handled and treated in accordance with C-NLOPB policies, the *OWTG*, 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 Board 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 Board approval but a typical depth on the Grand Banks might be about 250-m as measured from the rotary table (i.e., MD). The typical surface casing setting depths may be on the order of 1,200-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.

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), the White Rose baseline studies (Husky 2001, 2003), and Husky exploratory drilling EAs (Husky 2002, 2003; LGL 2005) all of which discuss the discharge of mud and

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

	Unit	Casing Strings		
		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 (2003).

cuttings and associated effects. These recent reports have further confirmed the conclusions of the White Rose work that routine drilling, particularly small scale drilling, has no significant effect on the marine environment of the Grand Banks. The salient points are briefly summarized in the two following sections.

Water-Based Muds

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 Board, 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* (NEB et al. 1999).

- 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).
- 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 in anywhere from several months to several years (and most likely within one year) after the drilling ceased, based upon the published literature (reviewed in Husky 2000, 2001; MMS 2000; CAPP 2001b). Actual monitoring data from other operators indicate that the actual area of smothering appears to be much less than predicted (Fechhelm et al. 2001; JWEL 2001; 2002).

Synthetic-based Muds

Synthetic-based muds (SBM) 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 west 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 250-500-m from the drilling platform (Husky 2000, 2001, 2002, 2003; 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.
- 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 Boards and discharge of whole SBM is not permitted. The limit at present is 6.9% synthetic fluid on cuttings.

There are numerous synthetic fluid drilling systems. Petro-Canada has had 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).

4.2.1.3 Vertical Seismic Profiles and Geohazard Surveys

A checkshot survey is required by the C-NLOPB for all exploration and delineation wells. The Board, in conjunction with the Operator, may request a vertical seismic profile (VSP) where it would contribute to resolving uncertainty associated with seismic interpretation. A sound source (airgun array, typically smaller than that used for seismic surveys) is deployed from the rig or supply vessel. Receivers are located in the water and within the well. The sound source is located at a fixed distance from the wellhead from as close as possible to as distant as 2.0-km. Surveys typically run from about 8 to 36 hours, although they may run as long as a week, and procedures require approval by C-NLOPB.

Shallow geohazard surveys are conducted prior to drilling to determine the potential for hazards such as slope instability or shallow gas. These surveys may consist of multi-beam sonar, side scan sonar, bottom sampling and/or video and a small seismic array.

Typical mitigations include ramp-ups and a safety zone for marine mammals and sea turtles. Refer also to the *Guidelines for Geophysical Surveys* (C-NOPB 2004).

4.2.1.4 Well Abandonment

Offshore exploratory wells are abandoned and decommissioned by removal of the wellhead and mechanical severance one metre or so below the mudline. If mechanical severance is not possible then a small shaped charge may be detonated below the mudline. Well termination programs require approval from the C-NLOPB and will include mitigations such as marine bird, turtle, and mammal monitoring to maintain a safe 'stand-off' distance. Also, careful attention should be paid to the shape and size of the charge.

4.2.1.5 Discharge of Other Fluids and Solids

Other fluids associated with the drilling include cement slurry and BOP fluid. Mitigations include careful selection and use of chemicals in order to minimize any potential toxic effects.

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. The effects (either negative or positive) of the cement on benthos are likely negligible.

Blowout preventer (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. In any event, periodic releases of this small amount of glycol likely have a negligible effect on marine biota.

If produced water is encountered during flow testing, then it is either treated prior to discharge, atomized in the flare, or disposed of on shore.

Concerns about birds and mammals are normally related to accidental events and/or the perceived importance of a particular area. For example, bird (particularly petrels) attraction to rigs was an issue during both Terra Nova and White Rose hearings because the areas are known to support large numbers of petrels, which may be particularly sensitive to this type of disturbance. Similarly, noise of drilling and support activities may be an issue near known concentrations of whales (e.g., bottlenose whale population in the Gully, offshore Nova Scotia). Sensitive areas and times on the west coast are detailed in Section 3.0.

Other discharges and emissions of potential concern are galley and sanitary waste and air emissions.

4.2.2 Production

Production infrastructure and activities on the west coast, of course, will only occur if commercial quantities of oil and/or gas are discovered and all permits and approvals (including a review under the *Accord Acts* and the *Canadian Environmental Assessment Act*) can be successfully obtained. Based on the history of East Coast offshore developments to date, from the time a discovery is made to the submission of a development application can take over ten years. Given that the production scenarios will vary drastically with technologies and regulations current at the time of development, the type, quantity, and location of the resource, only general information can be provided at this time.

4.2.2.1 Platform Types

Production platform types in use on the East Coast include Hibernia's concrete GBS, the Terra Nova and White Rose FPSOs (floating production, storage and offloading), and leg or jacket structures (e.g., Sable Offshore Energy Project) (see Figures 4.4 to 4.6). The GBS sits on the bottom and is a more or less permanent structure that drills and maintains wells; gathers the petroleum, processes and separates water, sand, gas and oil, and stores it for subsequent offloading. The FPSO is anchored, revolves on a turret, and performs all the production and storage functions except the drilling and maintaining of production wells. The jacket structures are anchored to the bottom with pilings driven into the seabed, and in the case of offshore Nova Scotia, gather and produce the gas, which is subsequently transported to shore via underwater pipeline.

All of the above systems contain accommodations and topsides processing facilities and are supported by supply vessels and helicopters. Any of these systems could be used on the west coast depending upon the specific development scenario. Other potential development systems could include barge-mounted, subsea, or land-based facilities, or various combinations of any of the above, including numerous pipeline configurations.

4.2.2.2 Discharges and Emissions

Discharges and emissions associated with production usually include:

- Produced water
- Air emissions
- Domestic and sanitary waste

- Cooling water
- Noise
- Light

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 discharge of produced water is regulated by the *OWTG*. It may not be particularly toxic as determined by routine toxicity testing or through environmental monitoring (in fact it is often difficult to locate the plume). Nonetheless, there is concern because of the potential light hydrocarbon content and often (but not always) the sheer volume of discharge.

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 is contained in Table 4.3 (from Røe and Johnsen 1996).

Air emissions during production originate from flaring, fugitive emissions from storage tanks, generator exhaust, support vessel exhausts, helicopter exhaust, and so forth. To date, air 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, prevailing onshore winds, and potential proximity to land, air emissions may be a larger issue on the west coast than on the east coast of Newfoundland.

Domestic and sanitary waste originates from perhaps 50-100 personnel on a production facility. These discharges can be mitigated to a negligible effect level and thus should be of little concern in most situations.

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.

Broadband noise is generated by production 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.

As with drill rigs, lights may attract certain species of birds which may then become stranded on the rig. 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).

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
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

Table 4.3 Concluded.

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).

An exploration well is drilled first to determine if ‘traps’ identified by seismic surveys contain oil, and then if hydrocarbons are found, delineation drilling may be conducted to define the size and shape of the reservoir. The activities and discharges are essentially the same and they are both defined as exploration activity under the *Newfoundland Offshore Petroleum Drilling Regulations* and thus they are considered together here as the same activity.

Offshore drilling has been occurring since the 1940s and thus the state of knowledge is reasonably advanced, including data on many of the direct and indirect effects on the environment. There have been some extensive baseline surveys, research studies and environmental effects monitoring studies conducted in the Gulf of Mexico (e.g., GOOMEX), the North Sea, and the Canadian East Coast (Scotian Shelf and Sable Island, Hibernia, Terra Nova and White Rose). While accidental oil and gas blowouts and spills are rare offshore, there is extensive information on their probabilities, fate and effects from the study of accidental events such as the Ixtoc blowout in the Gulf of Mexico, the Exxon Valdez tanker spill in Alaska, Ekofisk in the North Sea, and Uniake G-72 gas blowout off Nova Scotia, and others.

There are a number of potential concerns related to offshore activity ranging from the relatively minor ones such as galley waste to major ones such as large oil spills. Most of these concerns are now essentially eliminated by modern industrial, more or less standard, practices. Nonetheless, there are a number of outstanding and recurring issues and concerns on offshore exploratory drilling on the East Coast. Outstanding issues include:

- Area of benthos affected under different environmental conditions
- Attraction of birds such as storm-petrels (and potentially Dovekies) to the rigs
- Noise disturbance of marine animals, primarily whales
- Effects on little known sensitive deep sea fauna such as deepwater corals
- Effects of discharges on receiving environment
- Major blowouts or spills
- Cumulative effects

Disturbance to fisheries is an ever-present concern either directly through temporary displacement of activity due to the exclusion zone, loss or damage to gear, effects on marketability due to perception of taint in the event of a blowout, or indirectly through effects on plankton or benthos. To date, mitigations of communication and design of compensation programs have alleviated most of these concerns.

These issues are discussed further in following sections.

4.2.3 Ice Management

In areas subject to ice encroachment, operators are required to have an ice management plan in place. Typical elements of the plan include a description of the proposed ice management system for detecting, tracking, predicting movements of icebergs that may jeopardize the safety and integrity of the drilling operations (P. Rudkin, PAL, pers. comm.). Personnel duties, operational procedures and safety zones are described in the plan.

A drilling operator in the Western Newfoundland and Labrador Offshore Area will have access to some regional iceberg data but will essentially be responsible for collecting data relevant to their specific operations using a combination of rig-based radar, aerial and/or ship-based surveys, specialized software and personnel. Techniques available for altering iceberg behaviour include towing, ice cannons or propwash, operated by offshore supply vessels and crews experienced in ice management. In general, large icebergs are more amenable to towing than the small ones (Rudkin and Dugal 2000). Icebergs are not expected to be an issue in the Study Area whereas sea ice could be at certain times and locations.

4.2.4 Interactions and Potential Effects

4.2.4.1 Effects on Benthos

Drilling muds and cuttings, and their potential effects were discussed in detail in the White Rose EA/Comprehensive Study (Husky 2000) and Supplement (Husky 2001), Orphan Basin Exploratory Drilling EA (LGL et al.-in prep.), and Husky’s Jeanne d’Arc Basin Exploratory Drilling EA (LGL 2005). Modeling of the fate of drill mud and cuttings discharges was conducted for the White Rose EA, for the Lewis Hill exploratory drilling EA (Husky 2003), and for the Orphan Basin Exploratory Drilling EA (LGL et al.-in prep). 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.

Additional relevant documents not available during the White Rose EA include MMS (2000), CAPP (2001b) and NEB et al. (2002), all of which discuss the discharge of mud and cuttings and associated effects. These recent reports have further confirmed the conclusions of the White Rose work. In addition, a number of presentations at a recent BIO workshop (26-30 May 2003) concerning the Gulf of Mexico, the North Sea, and the East Coast concluded that effects on benthos are generally confined to within 500 m of the drill rig (review presentation of Buchanan et al. 2003; Hurley and Ellis 2004; Armsworthy et al. 2005; Cranford et al. 2005).

4.2.4.2 Seabird Attraction to Rigs

Seabirds, particularly storm-petrels, are known to be attracted to offshore rigs on the East Coast, presumably due to attraction by light (Montevecchi et al. 1999; U. Williams, Petro-Canada, pers. comm.; 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 flew into the flare, flew around the flare until exhausted, or collided with the rig. Dovekies have also been mentioned as a potential concern. This issue has recently been addressed on the Grand Banks by:

- Production and drilling installations in the Newfoundland and Labrador offshore area are involved in a seabird and marine mammal monitoring programs
- An ESRF-funded study to conduct seabird surveys from supply boats to provide some data on densities on vessel routes and near the drilling rigs
- An ESRF study on seabird and marine mammal monitoring protocols.
- An ESRF study on remote technologies for monitoring bird movements relative to the flare boom
- Programs undertaken by operators to gently capture, hold and release petrels that become stranded on offshore vessels or rigs (Williams and Chardine nd).

4.2.4.3 Effects of Onshore to Offshore Drilling on Marine Biota

Since the rig used in onshore to offshore drilling is located on land, there is potential for the drilling operations to interact with shorebirds and nesting seabirds and waterfowl. Identification of these habitats and knowledge regarding the timing of use of these habitats would allow operators to minimize impact on the birds through spatial and temporal scheduling mitigations. The probability of interaction between onshore to offshore drilling operations and other marine biota is negligible, particularly with the construction of an impermeable berm around the rig site.

4.2.4.4 Effects of Underwater Sound (Other than Seismic) on Marine Animals

All sound sources associated with exploratory/delineation drilling and production, and the potential effects of exposure to these sounds were discussed in Section 4.1 on ‘Sound’.

4.2.5 Mitigations and Planning

4.2.5.1 Drill Muds and Cuttings

Mitigation measures for the drilling include the selection of non-toxic or low toxicity chemicals and muds and treating any oil-contaminated cuttings to meet the *OWTG*. In addition to the treatment mitigations, drilling fluids produced by onshore to offshore directional drilling operations are typically stored temporarily in tanks at the rig site and then trucked to remote lined-pits for storage. The post-treatment non-toxic muds and cuttings are often put into a landfill. Hibernia now re-injects SBM-related cuttings as mitigation for production (not exploration) drilling. However, the Hibernia situation is atypical for the East Coast being a very large production development that does all its drilling from a centrally located gravity-base structure.

4.2.5.2 Potential Conflicts with Fisheries

Potential Effects

Routine exploratory and production activities could affect the commercial fisheries as a result of interference with fishing activities (caused by the presence of structures in the water and/or on the seabed, safety zones, ships and the use of seismic equipment during site profiling), behavioural effects on fish and invertebrates (caused by lights, or sound from drilling, vessels and vertical seismic profiling using airgun arrays and/or sonar), and physical effects on commercial species (from the placement of structures on fish habitat, and routine emissions and discharges, such as drilling muds and cuttings, produced water, greywater, deck drainage, etc). Behavioural and physical effects on fish and invertebrates are not discussed here. They were addressed in previous sections of the SEA (i.e., Section 4.1.5.1 on effects of sound and Section 4.2.4 on interactions and potential non-sound induced effects).

For drilling activities this SEA considers the following: (1) interference with fishing resulting from the presence of the drill rig, subsea hazards, and necessary safety zones; (2) changes in catch rates from sound-induced behavioural changes (changes in catch rates resulting from drilling-sound induced behavioural changes); and (3) interference owing to the presence of support vessels. Impacts related to possible VSP activities consider the following: (1) changes in catch rates from sound-induced behavioural changes (scaring) of fish caused by the sound source array; and (2) interference with fishing activities, particularly fixed gear, owing to gear/vessel conflicts.

It is also important to address potential effects of routine exploratory and production activities on stock assessments/DFO research activities, considering that they are used for the setting fishing quotas and exploration for new fisheries. Effects on assessment/research surveys would occur either as a result of behavioural responses, fishing interference or displacement, the same as impacts on commercial fish harvesting.

Mitigations

Communications/Notification

Fisheries representatives have frequently noted that good communication at sea is an effective way to minimize interference between offshore oil and gas exploration projects and fishing activities. Communications will be maintained (directly at sea by the rig and Project vessels) via marine radio to facilitate information exchange with fisheries participants. Relevant information about the rig locations, the safety zone and other relevant operations will also be publicized using established communications mechanisms, such as the *Notices to Shipping* (Continuous Marine Broadcast and NavTex) and CBC Radio's (Newfoundland and Labrador) *Fisheries Broadcast.*

Avoidance

With the information provided to the fishing industry, potential impacts on fishing (catch success as well as fishing gear interactions) can be mitigated by fishers avoiding the drilling locations and the designated safety zone. This area will be kept as small as feasible to ensure mutual safety and minimize interference with fishing activities.

Fishing Gear Interactions

Although there is typically very little fishing within the entirety of the Project Area, the great majority of the fish harvesting that does occur there (and in nearby waters) uses fixed gear, i.e., crab pots for snow crab. This poses more of a risk for gear conflict than does mobile gear.

In case of accidental damage to fishing gear, the operator will implement gear 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.

Structures

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 zones 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.

Survey Vessel Streamers

In previous surveys, concerns have been raised about seismic vessels or streamers becoming entangled with fishing gear, most specifically fixed gear (e.g., gillnets) if it is concurrent and co-locational with survey operations. In general, survey vessels will seek to avoid fishing gear in their path. Operators are required to have a gear compensation program in place to deal with any gear conflicts that may arise during program activities.

Other Project Vessels

Other project vessels, as well as the drill rig itself when in transit, will not pose a risk greater than other routine shipping and fishing vessels in the area. This study (and the fisheries maps) will help inform vessel operators of the likely locations of fixed fishing gear so that areas can be avoided. If other project vessels damage fishing gear, compensation will be assessed in accordance with the operator's gear compensation program.

DFO Research Surveys

Protocols to reduce interference between drilling activities and DFO research surveys must be established between the operator and DFO prior to the commencement of drilling activities.

4.2.5.3 Conflicts with Marine-associated Birds and Mammals

Concerns about birds and mammals are normally related to accidental events and/or the perceived importance of a particular area. For example, bird (particularly petrels) attraction to rigs was an issue during both Terra Nova and White Rose hearings because the areas are known to support large numbers of petrels, which may be particularly sensitive to this type of disturbance. It should be noted that while they are humane attempt to save individual animals impacted by oil, rehabilitation programs cannot be considered a form of mitigation for population recovery. Similarly, noise of drilling and support activities may be an issue near known concentrations of whales (e.g., bottlenose whale population in the Gully, offshore Nova Scotia). Section 4.1 discusses the interaction between industrial sound and marine mammals. Sensitive areas and times on the west coast are detailed in Section 3.0.

4.2.5.4 Planning Implications

Standard mitigative measures for routine exploratory/delineation drilling and production activities will be employed (see Section 5.4.3).

Planning considerations for VSP and wellhead severance include the standard mitigations and monitoring programs such as marine mammal monitoring and that acoustic or chemical explosives (e.g., during wellhead severance) are not to be released when marine mammals are within a certain distance from the energy source.

4.3 Accidental Events

Accidental events with potential for environmental damage offshore may range from small spills of fuels and chemicals (e.g., during loading or unloading), to medium spills of diesel fuel during a fuel tank rupture, to oil or gas blowouts. This section, based on work done by SL Ross for Husky (2003), addresses diesel fuel and oil blowouts as they are of most concern.

4.3.1 Blowout and Spill Probabilities

4.3.1.1 Blowout and Spill Probabilities

Two types of accidents that could occur during an exploratory drilling program are blowouts and "batch" spills. Blowouts are continuous spills lasting hours, days or weeks that could involve the discharge of petroleum gas into the atmosphere and crude oil into surrounding waters. Batch spills are instantaneous or short-duration discharges of oil that could occur from accidents on the drilling platforms where fuel oil and other petroleum products are stored and handled. The following sections provide estimates on the probability of these spills (based on SL Ross 2002a *in* Husky 2003).

4.3.1.2 Spill History of the Offshore Oil and Gas Industry

The industry of exploring, developing and producing offshore oil and gas has a relatively good record compared with other industries that have potential for discharging petroleum oil into the marine environment. The U.S. National Research Council (NRC 2002 *in* Husky 2003) indicates that accidental petroleum discharges from platforms contribute only 0.07% of the total petroleum input to the world's oceans (0.86 thousand tonnes per year versus 1,300 thousand tonnes per year - Table 4.4).

The spill record is particularly good for the U.S. Outer Continental Shelf (OCS) where 28,000 wells were drilled and over 10 billion (10^9) barrels[6] of oil and condensate were produced from 1972 to 2000. During that time, only ten blowouts occurred that involved any discharge of oil or condensate. The total oil discharged in the ten events was only 751 barrels.

Newfoundland and Labrador offshore operations are probably comparable from a safety viewpoint to operations in U.S. OCS waters and the North Sea (see Section 4.3.1.4).

[6]The petroleum industry usually uses the oil volume unit of petroleum barrel (which is different than a US barrel and a British barrel). There are 6.29 petroleum barrels in one cubic metre (m^3). Most spill statistics used in this report are taken from publications that use the oil volume units of petroleum barrels.

Table 4.4. Best Estimate of Annual Releases [1990-1999] of Petroleum by Source.

	North America (tonnes x 10^3)	Worldwide (tonnes x 10^3)
Natural Seeps	**160**	**600**
Extraction of Petroleum	**3.0**	**38**
Platforms	0.16	0.86
Atmospheric Deposition	0.12	1.3
Produced waters	2.7	36
Transportation of Petroleum	**9.1**	**150**
Pipeline Spills	1.9	12
Tank Vessel Spills	5.3	100
Operational Discharges [Cargo Washings]	na[1]	36
Coastal Facility Spills	1.9	4.9
Atmospheric Deposition	0.01	0.4
Consumption of Petroleum	**84**	**480**
Land-Based [River and Runoff]	54	140
Recreational Marine Vessel	5.6	nd[2]
Spills [Non-Tank Vessels]	1.2	7.1
Operational Discharges [Vessels 100 GT]	0.10	270
Operational Discharges [Vessels <100 GT]	0.12	nd[3]
Atmospheric Deposition	21	52
Jettisoned Aircraft Fuel	1.5	7.5
TOTAL	**260**	**1300**

Source: NRC (2002) *in* Husky (2003).

1. Cargo washing is not allowed in U.S. waters, but is not restricted in international waters. Thus, it was assumed that this practice does not occur frequently in U.S. waters.
2. World-wide numbers of recreational vessels were not available.
3. Insufficient data were available to develop estimates for this class of vessels.

4.3.1.3 Spill Sizes

It is convenient to categorize spill sizes to correspond to statistical databases such as that maintained by the U.S. Minerals Management Service (MMS). The first category used here is "extremely large" spills, arbitrarily defined as spills larger than 150,000-bbl (23,800-m^3). The second and third categories are for "very large" and "large" spills, defined by the MMS as spills larger than 10,000 barrels (1590-m^3) and 1,000 barrels (159-m^3) respectively. The fourth category is for spills in the range of 50 to 999-bbl, and the fifth category is for spills in the 1 to 49-bbl category. The spill size classifications used here are summarized in Table 4.5. Note that the top three categories in the table are cumulative; that is, the large-spill category (>1,000-bbl) includes the very large and extremely large spills, and the very large category includes extremely large spills.

Table 4.5. Spill Size Categories.

Spill Category Name	Spill Size Range (in barrels)	Spill Size Range (in-m^3 and tonnes)
Extremely Large spills	>150,000-bbl	(>23,850-m^3 or >20,830-tonnes)
Very Large spills	>10,000-bbl	(>1590-m^3 or >1390-tonnes)
Large spills	>1,000-bbl	(>159-m^3 or >139-tonnes)
Medium spills	50 – 999-bbl	(7.95-m^3 - 158.9-m^3)
Small spills	1 - 49.9-bbl	(0.159-m^3 - 7.94-m^3)

4.3.1.4 Offshore Newfoundland

Spill frequencies for exploration units and development drilling/production units off Newfoundland are shown in Table 4.6. Here, both exploration and development wells were used to normalize the spill numbers. Small-spill frequencies will inevitably decrease over time as operators on the Grand Banks gain experience, as suggested by the experience in the Gulf of Mexico (Husky 2003).

Table 4.6. Platform Spills[1], Offshore Newfoundland, 1997-2000.

Spill Size	Number of Spills[3]	Spills Per Wells Drilled[2]
0 to 1.0-bbl	22	0.55
1.1 - 9.9-bbl	8	0.20
10.0-49.9	1	2.5×10^{-2}
50.0-499.9	0	0
500.0-999.9	0	0
1,000-bbl and greater	0	0

[1]Oil spills includes crude oil and refined petroleum products.
[2]Based on 40 exploration and development wells drilled from 1997 to 2000.
[3] Spill and well data provided by C-NOPB, March/April 2001.

In summary, large spills and blowouts are now very rare for offshore U.S. and the North Sea, and the same record can probably be expected for the Western Newfoundland and Labrador Offshore Area.

Based on recent spill statistics (see www.cnlopb.nl.ca) for offshore Newfoundland, the number of spills per year from 1997 to 2004 ranged from 10 to 55, and averaged ~27 spills per year (Table 4.7). In all but one year (2002) considered here, the number of crude oil spills was much less than the number of spills of "Other Hydrocarbons" (e.g., diesel, hydraulic and lubricating oils, diesel, condensate, synthetic-based drilling fluid). Similarly, in most years, the largest volumes of hydrocarbons accidentally released were of "Other Hydrocarbons". In 1997-2004, total spill volumes per year ranged from 1731 L to 274,603 L (Table 4.7), and averaged ~43,339 L per year. The average total spill volume per year is skewed upwards by the relatively large volumes of crude oil (165,000 L) and synthetic-based mud (96,600 L) spilled during late 2004. Average volume of hydrocarbons spilled per year excluding 2004 is 10,301 L.

Table 4.7. Summary of Offshore Newfoundland Hydrocarbon Spills for 1997-2004, Subdivided by Crude and Other Hydrocarbon Spill Types. Data derived from statistics posted on www.cnlopb.nl.ca.

	Exploration and Production		
	Crude	Other hydro-carbons	Total
1997			
Number of spills	2	9	11
Volume spilled (L)	1004	727	1731
1998			
Number of spills	8	20	28
Volume spilled (L)	1045	4747	5792
1999			
Number of spills	19	28	47
Volume spilled (L)	1812	8423	10235
2000			
Number of spills	2	8	10
Volume spilled (L)	222	4701	4923
2001			
Number of spills	2	14	16
Volume spilled (L)	<6	5726	5732
2002			
Number of spills	15	11	26
Volume spilled (L)	10.5	12270.5	12281
2003			
Number of spills	5	20	25
Volume spilled (L)	11.7	31403.3	31415
2004			
Number of spills	12	43	55
Volume spilled (L)	166409	108194	274603
TOTAL 1997-2004			
Number of spills	65	153	218
Volume spilled (L)	170514	176191.8	346712

Note: "Other hydrocarbons" includes synthetic-based drilling fluid. 1 bbl = 159 L.

During 1997-2004, most hydrocarbon spills from offshore Newfoundland oil and gas structures occurred during development drilling and production vs. exploration drilling. Overall, in 1997-2004, there were 35 spills totaling 5508 L during exploration drilling and 183 spills totaling 336,803 L during development drilling and production (Table 4.8). However, these data have not been standardized to account for amount of drilling activity.

Table 4.8. Summary of Offshore Newfoundland Hydrocarbon Spills for 1997-2004, Subdivided by Exploration Drilling vs. Development Drilling and Production. Data derived from statistics posted on www.cnlopb.nl.ca.

	1997-2004		
	Crude Oil	Other hydro-carbons	Total
Exploration Drilling			
Number of spills	17	18	35
Volume spilled (L)	1471	4037	5508
Develop. Drilling & Prod.			
Number of spills	48	135	183
Volume spilled (L)	167728	169075	336803
TOTAL			
Number of spills	65	153	218
Volume spilled (L)	169199	173112	342311

Note: "Other hydrocarbons" includes synthetic-based drilling fluid. 1 bbl = 159 L.

4.3.2 Fate and Behaviour

Oil releases in the marine environment from a spill or blowout may have quite different behaviours, depending upon the depth and size of the blowout, physical and chemical characteristics of the petroleum, physical environment, season, and so forth. The behaviour of a deepwater blowout can be quite complex and oil may surface some distance from the well, if at all. Diesel fuel is more immediately toxic in the marine environment, particularly to plankton, than an oil or gas release but it dissipates quickly in the offshore environment (e.g., sinking of *FV Katsheshuk* containing 200,000 litres of diesel that created a 1,300 m^2 slick off Cape St. Francis, NL in 2002; while there were some murres that likely succumbed to the spill there were no large scale bird mortalities reported to government).

A number of physical characteristics that enhance the biodiversity of the Study Area may, at the same time, potentially increase the adverse effects of an accidental event. As indicated in Section 2, ocean currents in the Gulf of St. Lawrence flow in a counter-clockwise direction while winds blow predominantly onshore along the western Newfoundland coast in the Study Area. Considering the enclosed nature of the Gulf of St. Lawrence combined with the cyclonic current flow and predominant onshore winds, there is a high probability that an accidental event would result in oil reaching the Study Area shoreline. Pack ice could potentially complicate efforts of oil spill remediation in the Study Area.

Modelling of potential oil spill trajectories was conducted for Newfoundland Hunt Oil Company Inc.'s Exploration Licence No. 1009, St. George's Bay A-36 (Davidson and Pinhorn 1995). This well is located off the Port au Port Peninsula at 48º 25' 05''N, 59º 19' 29''W, less than 10 km southwest of Cape St. George. The oil from the western Newfoundland that has been examined to date is a lighter crude than that encountered on the Grand Banks (51º API) (Newfoundland and Labrador Oil and Gas Report, March 2005). In Canada, crude oil is classified as either light oil (> 25.7º API) or heavy oil (< 25.7º API). These values measured in degrees refer to the oil's gravity as measured by the American Petroleum Institute (API) Scale (www.centreforenergy.com).

Modelling results were produced for the period of April to January, based on 30 years of available wind data. Wind was assumed to be the dominant advective force which would drive the displacement of oil slick from the spill site. This assumption was based on previously assembled knowledge of the rather weak nature of the residual surface currents in the area. The monthly probability plots produced by the modelling indicated a general northeastward slick movement. Results indicated a 50 to 100% probability that oil would reach the western tip of the Port au Port Peninsula in all months included in the model (i.e., April to January). Results indicated a 20 to 50% probability that oil would reach much of the southern and northwestern shore of the Port au Port Peninsula, and the southeastern shore of St. George's Bay in all months included in the model (i.e., April to January). The heads of St. George's Bay and Port au Port Bay were not touched by the oil in any of the monthly scenarios. Probability plots were most widespread in April, May, November and December (as far north as Parson's Pond in 4Rb). In all months, there was a 3 to 5% probability that the oil would reach shore north of Port au Port Bay (Davidson and Pinhorn 1995).

Reviews of the fate and behaviour of Grand Banks hydrocarbons are contained in Mobil (1985), Petro-Canada (1996), Husky (2000, 2001, 2002, 2003), and those of Nova Scotia in LGL et al. (2000).

4.3.3 Interactions and Effects

In this section, interactions between accidental spills and VECs and subsequent potential effects are discussed for the scenarios described in the preceding sections.

Interaction of coastal bird habitats and areas sensitive to oil contamination occur where areas are islands, archipelagos and/or in direct contact with the coastal ocean environment. In other words, estuarine components of habitats such as Grand Codroy, Stephenville Crossing and St. Paul's Inlet are less likely to be directly impacted because of isolation from the ocean by the bar lagoon; or alternatively contamination of such sites can be more easily contained because of narrow 'gut' through which the tidal waters move.

Outer beaches are vulnerable to oil contamination and this would implicate most of the critical habitats used by the *endangered* Piping Plovers. The offshore islands that receive extensive use as nesting habitat by terns and eiders in such areas as St. Paul's Inlet and St. John Bay, and St. George's Bay with the unique concentrations of shorebirds and waterfowl at Sandy Point/Flat Bay Island, are very vulnerable to oil contamination.

In pelagic areas interactions of seabirds with spilled oil is a function of location and time of year. The overall densities of pelagic seabirds in the Study Area are relatively low hence the prediction for mortality in event of a spill would be relatively low.

4.3.3.1 Effects on Fish and Fish Habitat

There has been extensive study of the effects of oil spills on fish and fish habitat (e.g., Armstrong et al. 1995; Rice et al. 1996, and many others).

Juvenile and Adult Fish

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 et al. 1997). Effects of oil spills on adult and juvenile fish are predicted to be negligible. For example, findings in the White Rose EA/Comprehensive Study, the Hibernia and Terra Nova EISs, the Lewis Hill EA, and the Jeanne d'Arc Basin EA concluded that neither surface spills nor subsea blowouts posed significant risks to either pelagic or demersal fish stocks (Mobil 1985; Petro-Canada 1996; Husky 2000, 2002, 2003).

Juvenile and adult fish in shallow/enclosed areas could be more susceptible to impact from accidental events such as oil spills in that the oil might be more persistent in these areas. Therefore, exposure of the fish to the oil could potentially be of longer duration. At the same time, juvenile and adult finfish are mobile and can avoid the contaminated areas. Less mobile invertebrates could not so easily avoid the oil. Contamination of shoreline habitats that are particularly important to fish with specific habitat requirements could potentially result in more adverse effects on the fish.

<u>Fish Eggs and Larvae</u>

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 3.2 for a description of ichthyoplankton in the Western Newfoundland and Labrador Offshore Area). 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 (*Clupea pallasi*) 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.

Typically, the occurrence, abundance and distribution of ichthyoplankton 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 unlikely event of a blowout or spill, 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.

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).

<u>Fish Habitat</u>

The highest polyaromatic hydrocarbon (PAH) concentration found in Prince William Sound at one and five metre depths within the six-week period following the *Exxon Valdez* spill was 0.00159 ppm, well below levels considered acutely toxic to marine fauna (Short and Harris 1996). The Hibernia and Terra Nova EISs and the White Rose and Jeanne d' Arc Basin EAs predicted that environmental (biophysical) effects on water quality and habitat would not be significant. As indicated in the preceding section, the chance of an accidental event is extremely low.

Plankton

Strictly speaking, plankton is not a VEC; however, the fish habitat VEC includes plankton because it is a source of food for larvae and some adult fish (i.e., the fish VEC). 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. Zooplankon 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 1,800 ppm of aromatic heating oil and mortality can occur after a 6-h exposure (Berdugo et al. 1979). Exposure to concentrations of 1,000 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 1,000 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).

In summary, 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.

Benthic Animals

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).

4.3.3.2 Effect on Commercial Fisheries

Although physical effects on fish from a spill are deemed not significant, economic impacts might occur in the event of a spill, 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 fishers were required to cease fishing, harvesting might be disrupted (though, depending on the extent of the slick, alternative fishing grounds might be available). An interruption could result in an economic impact because of reduced catches, or extra costs associated with having to relocate 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 and if it were to reach harvesting areas.

4.3.3.3 Effect on Marine-associated Birds

Marine-associated birds are the marine animals most at risk from oil spills and blowouts.

The Study Area is adjacent to the major shipping route that traverses the St. Lawrence River estuary and across the Gulf of St. Lawrence immediately south of Anticosti Island. Traffic density in this vicinity is four to eight ships per day, many of which are container vessels and potential sources for bunker C bilge waste that is a chronic source of pollution along the southeast coast of Newfoundland. Further north there is activity from commercial fishing vessel traffic from Port Au Choix to St. Anthony accessing the northern fishing banks (Lock et al. 1994).

Oil spills have been reported in marine waters proximate to Stephenville/Stephenville Crossing (UA 4Rd), Bay of Islands (UA 4Rc), Hawkes Bay (UA 4Rb), Port au Choix (UAs 4Rab) and St. Anthony, essentially anywhere where there is marine traffic. More spills are reported for the May to December period likely reflecting the fact that the Strait of Belle Isle is ice locked for significant portions of the winter (Lock et al. 1994).

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), recent studies suggest that even spills of great magnitude may not have significant long-term effects on seabird populations (Clark 1984; Wiens 1995).

Considering the proximity of the Study Area to the coast of western 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.

Immediate Effects

External exposure to oil occurs when flying birds land in oil slicks, diving birds surface from beneath oil slicks, and swimming birds swim into slicks. The external exposure results in matting of the feathers which effectively destroys the thermal insulation and buoyancy provided by the air trapped by the feathers. Consequently, oiled birds are likely to suffer from hypothermia and/or drown (Clark 1984; Hartung 1995). Most seabird losses occur during the initial phase of oil spills when large numbers of birds are exposed to floating oil (Hartung 1995). Birds living in coldwater environments are most likely to succumb to hypothermia (Hartung 1995).

Short-term Effects

Oiled birds that escape death from hypothermia and/or drowning often seek refuge ashore where they engage in abnormally excessive preening in an attempt to rid themselves of the oil (Hunt 1957 in Hartung 1995). The preening leads to the ingestion of significant quantities of oil which, although apparently only partially absorbed (McEwan and Whitehead 1980), can cause lethal effects. Noted effects on Common Murres and Thick-billed Murres oiled off Newfoundland’s south coast include emaciation, renal tubular degeneration, necrosis of the duodenum and liver, anemia and electrolytic imbalance (Khan and Ryan 1991). Glaucous-winged Gulls (*Larus glaucescens*) experienced similar effects after they ingested bunker fuel oil during preening (Hughes et al. 1990). Another commonly observed effect is adrenal hypertrophy. This condition tends to make birds more vulnerable to adrenocortical exhaustion (e.g., Mallards [Hartung and Hunt 1966; Holmes et al. 1979], Black Guillemots [Peakall et al. 1980], and Herring Gulls [Peakall et al. 1982]). The adrenal gland maintains water and electrolyte balance that is essential for the survival of birds living in the marine environment. Hartung and Hunt (1966) found that ingested oils can cause lipid pneumonia, gastrointestinal irritation, and fatty livers in several species of ducks. Aromatic hydrocarbons have been detected in the brains of Mallards (Lawler et al. 1978) and are probably associated with observed symptoms (e.g., lack of coordination, ataxia, tremors and constricted pupils) of nervous disorders (Hartung and Hunt 1966).

Birds exposed to oil are also at risk of starvation (Hartung 1995). For example, oiled Common Eiders generally deplete all of their fat reserves and much of their muscle protein (Gorman and Milne 1970). In addition, energy demands are higher because the metabolic rate of oiled birds increases to compensate for the heat loss caused by the reduced insulating capacity of their plumage. This can expedite starvation (Hartung 1967; McEwan and Koelink 1973).

Long-term Effects

It appears that direct, long-term sublethal toxic effects on seabirds are unlikely (Hartung 1995). The extent of bioaccumulation of the chemical components of oil in birds is limited because vertebrate species are capable of metabolizing them at rates that minimize bioaccumulation (Neff 1985 *in* Hartung 1995). Birds generally excrete much of the hydrocarbons within a short time period (McEwan and Whitehead 1980). However, nesting seabirds that are contaminated with oil but still survive generally exhibit decreased reproductive success.

Nesting seabirds transfer oil from their plumage and feet to their eggs (Albers and Szaro 1978). Very small quantities of oil (1 to 20 µl) on eggs have produced developmental defects and mortality in avian embryos of many species (Albers 1977; Albers and Szaro 1978; Hoffmann 1978, 1979a; Macko and King 1980; Parnell et al. 1984; Harfenist et al. 1990). The resultant hatching and fledging success of young appears to be related to the type of oil (Hoffman 1979b; Albers and Gay 1982; Stubblefield et al. 1995) and the timing of exposure during incubation. Embryos are most sensitive to oil during the first half of incubation (Albers 1978; Leighton 1995). Breeding birds that ingest oil generally exhibit a decrease in fertilization (Holmes et al. 1978), egg laying and hatching (Hartung 1965; Ainley et al. 1981), chick growth (Szaro et al. 1978) and survival (Vangilder and Peterle 1980; Trivelpiece et al. 1984). Similar effects on ducklings occur when they ingest oil directly (Miller et al. 1978; Peakall et al. 1980; Szaro et al. 1981). Oil spills can also cause indirect reproductive failure. Eppley and Rubega (1990) suggest that exposure to an Antarctic oil spill caused changes in the normal parental behaviour of South Polar Skuas (*Catharacta maccormicki)*, thus exposing young to increased predation and contributing to reproductive failure in that population. In another case, abandonment of nesting burrows by oiled adult Leach's Storm-Petrels may have contributed to reproductive failure in that population (Butler et al. 1988). Therefore, a spill that occurs during the reproductive period could cause mortality of young even if the adults survived the exposure to oil.

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.

Sensitive Species

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 Black Guillemots, murres, Atlantic Puffins, Dovekies, eiders, Oldsquaws, scoters, Red-breasted Mergansers, and loons 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. They were the only group of seabirds to show an annual increase over a 13-yr period (2.7 percent) in the proportion of oiled birds (Wiese and Ryan 1999, 2003). Within the diving species group, murres appear to be the most affected by exposure to oil. Also, there also appears to be a strong seasonal effect as significantly higher proportions of alcids (along with other seabird groups) are oiled in winter versus summer (Wiese and Ryan 1999, 2003).

Other species such as Northern 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). The greatest decrease in use of contaminated habitats immediately following a spill occurs in species that feed on or close to shore, and that either breed along the coast or are full-year residents (Wiens et al. 1996). In the Project 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). Gannets do not nest in the Study Area so most of the concern relating to effects on nesting seabirds is with waterfowl and larids (gulls and terns). 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 Study Area. Sandy beaches are rare on the coast of Newfoundland 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).

For the west coast of Newfoundland and areas around the Port aux Port Peninsula, sedimentary habitats (i.e., beaches) are prevalent and highly used by migratory birds. Species most vulnerable would be the *endangered* Piping Plover, other shorebirds, gulls, terns and waterfowl. Storm-petrels are not as great an issue.

Past Oil Spills in Eastern Canada

Several major 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. "Mystery" spills, most likely from ships that illegally dump waste oils into the ocean, killed an estimated 18,000 seabirds in Placentia Bay, Newfoundland (Anon. 1990). Many ships frequent the waters off the south coast of Newfoundland as they traverse between Europe and North America, thereby exposing seabirds to chronic levels of oil pollution (Chardine and Pelly 1994). In February 1970, the *Irving Whale* spilled between 3,000 and 7,000 gallons of Bunker C oil near St. Pierre and Miquelon, which subsequently spread along Newfoundland's southeast coast. It was estimated that 7,000 birds, primarily Common Eiders, were killed (Brown et al. 1973). During the same month, the *Arrow* ran aground in Chedabucto Bay, Nova Scotia. Approximately 2.5 million gallons of Bunker C fuel oil were spilled and at least 2,300 birds were killed in the bay itself (Brown et al. 1973). Primarily diving birds were affected, most notably Oldsquaws, Red-breasted Mergansers, murres, Dovekies, and grebes (Brown et al. 1973). The spill spread offshore to Sable Island where mostly murres, Dovekies, and Northern Fulmars were killed. The lowest estimate of seabird mortality due to this part of the slick was 4,800 birds (Brown et al. 1973).

On a broader geographical scale, it is estimated that 21,000 birds die annually from operational spills on the Atlantic coast of Canada and that 72,000 birds die annually from all operational spills in Canada (Thomson et al. 1991). Wiese and Robertson (2004), using a general mathematical Oiled Seabird Mortality Model (OSMM), estimated that between 1998 and 2000, an average of 315,000±65,000 Common Murres, Thick-billed Murres and Dovekies were killed annually in southeastern Newfoundland due to illegal oil discharges from ships. They estimated that Thick-billed Murres made up about 67% of the kill. Clark (1984) estimates that 150,000 to 450,000 birds die annually in the North Sea and North Atlantic from oil pollution of all sources. 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).

In November 2004, a spill of crude oil occurred from the production platform of the Terra Nova oil field. Canadian Wildlife Service has estimated that mortality to seabirds in the area may have been in the order of 10,000. Other seabird experts have cautioned that such estimates are not supported by sufficient data because surveys of the site did not occur for five days following the incident, and there was no information on drift trajectories of dead or contaminated birds. Possible mortality of seabirds has been speculated to range from hundreds to 100,000 or more (see www.mun.ca/acwern/terranova.html). It is known that many thousands of pelagic seabirds occur in the Terra Nova area in November.

Even small spills can cause cumulative mass mortality of seabirds (Joensen 1972). A major spill that persists for several days near a nesting colony could kill a high proportion of the pursuit-diving birds (e.g., murres) within the colony (Cairns and Elliot 1987). In contrast, relatively low mortalities have been recorded from some huge spills. For example, the *Amoco Cadiz* spilled 230,000 tonnes of crude oil along the French coast, causing the recorded deaths of 4,572 birds (Clark 1984).

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).

Although rehabilitation is a humane attempt to save animals impacted by oil, it cannot be considered as a form of mitigation for population recovery. Success of rehabilitation cannot be measured in terms of numbers of birds released from treatment centres because cleaned seabirds often die shortly after release (Sharp 1996). Oiled and cleaned Black Guillemots, White-winged Scoters, and Western Grebes (*Aechmophorus occidentalis)* in North America had a much lower survival rate than non-oiled controls, regardless of cleaning techniques (Sharp 1996).

Piatt et al. (1990) estimated that 100,000 to 300,000 birds were killed by oil from the *Exxon Valdez*. Therefore, the massive rescue attempts associated with the *Exxon Valdez* spill managed to release (not save) only 0.3 to 0.8 percent of the birds that were potentially fatally oiled by the spill.

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 *endangered* species that might be affected by an incident;
- Collection of birds offshore for cleaning and rehabilitation during a spill incident will be conducted with strict regard for safety of personnel involved.

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. Approaches have included releasing captive-reared fledgling birds at natural sites, for example, the hatching, rearing and release of Common Eiders in Hare Bay, Newfoundland, and releasing juvenile and adult birds into selected receiving areas (e.g., Atlantic Puffins off the Maine coast and along the Brittany coast, and Canada Geese in many areas).

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 case most relevant to the Project Area involves the successful re-establishment of colonies of Common Eiders in Hare Bay, Newfoundland (Gilliland, CWS, in prep.), and Atlantic Puffins in New England and France (Duncombe and Reille 1980; Clark 1984). Puffins are alcids, close relatives of the murres and Black Guillemots that also nest abundantly in southern Newfoundland. However, the puffins nest in burrows, whereas murres are cliff-nesters and Black Guillemots nest among rocks and coastal debris. Consequently, it is unclear whether the techniques used in the successful reestablishment of nesting puffins would also work with these other alcids.

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 1980's (Goudie 1989, 1991c). Common Eider females nest preferentially in well-protected areas near logs and among driftwood and rocks (Johnson and Herter 1989). Therefore, on barren islands, numbers of nesting sites can be increased and/or nest success improved by adding artificial shelters and/or rearranging driftwood on breeding sites. In Iceland, the nesting habitat of eiders is manipulated to improve nesting success and to facilitate the collection of the eider down that lines the nests (Doughty 1979).

One option for enhancing recovery of depleted species is the elimination of hunting of that species, if it is a hunted species. Depending upon the severity of the situation, hunting could be spatially and temporally curtailed to whatever degree necessary.

The techniques to rescue and rehabilitate oiled birds are not very effective. Consequently, the best mitigation technique is to do all that is possible to avoid an oil spill in the first place. Otherwise, deploy countermeasures that reduce the numbers of birds that become oiled (e.g., directing the oil away from seabird concentration areas). It is much better to direct efforts to techniques that prevent birds from becoming oiled in the first place. Successful and efficient techniques are not yet available to restore bird populations and habitat once they are oiled.

Of the marine-associated bird species occurring in the Study Area, eiders, cormorants, kittiwakes and Black Guillemots are the most likely species to be oiled in the event of a spill (Lock et al. 1994). Inshore, loons, grebes and other species of diving ducks are equally vulnerable to oiling.

4.3.3.4 Effects on Marine Mammals

Most marine mammals, with the exception of fur seals, polar bears, and sea otters, are not very susceptible to deleterious effects of oil. However, newborn hair seal pups, and weak or highly stressed individuals, may be vulnerable to oiling. Other marine mammals exposed to oil are generally *not at risk* because they rely on a layer of blubber for insulation and oiling of the external surface does not appear to have any adverse thermoregulatory effects (Kooyman et al. 1976; 1977; Geraci 1990; St. Aubin 1990). Population-level effects are unlikely, as no significant long-term and lethal effects from external exposure, ingestion, or bioaccumulation of oil have been demonstrated.

Cetaceans

There is no clear evidence that implicates oil spills, including the much studied *Santa Barbara* and *Exxon Valdez* spills, with mortality of cetaceans (Geraci 1990). Migrating gray whales were apparently not adversely affected by the *Santa Barbara* spill. There appeared to be no relationship between the spill and mortality of marine mammals. The higher than usual counts of dead marine mammals recorded after the spill was a result of increased survey effort related to the spill (Geraci 1990). The conclusion was that whales were either able to detect the oil and avoid it or were unaffected by it (Geraci 1990).

There was a significant decrease in the size of a killer whale pod resident in the area of the *Exxon Valdez* spill, but no clear cause and effect relationship between the spill and the decline could be established (Dahlheim and Matkin 1994). There were no evident effects on humpback whales in Prince William Sound after the *Exxon Valdez* spill (von Ziegesar et al. 1994). There was some temporary displacement of humpback whales out of Prince William Sound, but oil contamination, boat and aircraft disturbance, or displacement of food sources could have caused this displacement.

Avoidance and Behavioural Effects

Studies of both captive and wild cetaceans indicate that they can detect oil spills. Captive bottlenose dolphins avoided most oil conditions during daylight and darkness, but had difficulty detecting a thin sheen of oil (St. Aubin et al. 1985). Wild bottlenose dolphins exposed to the *Mega Borg* oil spill in 1990 appeared to detect, but did not consistently avoid contact with, most oil types (Smultea and Würsig 1995). This is consistent with other cetaceans behaving normally in the presence of oil (Harvey and Dahlheim 1994; Matkin et al. 1994). It is possible that cetaceans swim through oil because of an overriding behavioural motivation (for example, feeding). Some evidence exists that indicates dolphins attempt to minimize contact with surface oil by decreasing their respiration rate and increasing dive duration (Smultea and Würsig 1995).

Oiling of External Surfaces

Whales rely on a layer of blubber for insulation and oil has little if any effect on thermoregulation. Effects of oiling on cetacean skin appear to be minor and of little significance to the animal’s health (Geraci 1990). 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).

Ingestion and Inhalation of Oil

Whales could ingest oil with water, contaminated food, or oil could be absorbed through the respiratory tract. Species like the humpback whale, right whale, beluga, and harbour porpoise that feed in restricted areas (for example, bays) may be at greater risk of ingesting oil (Würsig 1990). Some of the ingested oil is voided in vomit or feces but some is absorbed and could cause toxic effects (Geraci 1990). When returned to clean water, contaminated animals can depurate this internal oil (Engelhardt 1978; 1982). Whales exposed to an oil spill are unlikely to ingest enough oil to cause serious internal damage (Geraci and St. Aubin 1980; 1982). Only small traces of oil were found in the blubber of a gray whale and liver of a killer whale exposed to *Exxon Valdez* oil (Bence and Burns 1995).

Cetaceans may inhale vapours from volatile fractions of oil from a spill and blowout. The most likely effects of inhalation of these vapours would be irritation of respiratory membranes and absorption of hydrocarbons into the bloodstream (Geraci 1990). Stressed individuals that could not escape a contaminated area would be most at risk.

Fouling of Baleen

In baleen whales, crude oil could coat the baleen and reduce filtration efficiency. However, effects are minimal and reversible. Baleen experimentally fouled with oil did not change enough to alter its filtration efficiency (St. Aubin et al. 1984) and most adherent oil was removed within 30 min after fouling (Geraci and St. Aubin 1985 *in* Geraci 1990). The effects of oiling of baleen on feeding efficiency appear to be only minor (Geraci 1990).

<u>Pinnipeds</u>

Reports of the effects of oil spills and blowouts have shown that some mortality of hair seals may have occurred as a result of oil fouling; however, large-scale mortality has never been observed (St. Aubin 1990). The largest effect of a spill was on young hair seals in cold water (St. Aubin 1990).

Effects on seals have not been well studied at most spills because of lack of baseline data and/or the brevity of the post-spill surveys. There is little information about the mortality rate of harp seals exposed to oil from a ruptured storage tank in New Brunswick in 1969. It is believed that 10,000 to 15,000 harp seals were coated with oil but the exact number of dead seals recovered is unknown (Sergeant 1991). The release of fuel oil from the *Arrow* into Chedabucto Bay, Nova Scotia in 1970 resulted in the fouling of 500 seals within the bay and 50 to 60 harbour and 200 grey seals on Sable Island (200 km south of the spill). Twenty-four seals were found dead and some had oil in their mouths and stomachs (Anon. 1970; 1971 *in* St. Aubin 1990). Oiled grey and harbour seals were found on the coast of Nova Scotia and Sable Island again in 1979 when the oil tanker *Kurdistan* sank in Cabot Strait. No causal relationship between oiling and death was determined (Parsons et al. 1980 *in* St. Aubin 1990). No mortalities were reported after a well blowout near Sable Island in 1984 and only two oiled grey seals were observed (St. Aubin 1990).

Intensive and long-term studies were conducted after the *Exxon Valdez* spill in Alaska. There may have been a long-term decline of 36% in numbers of moulting harbour seals at oiled haul-out sites in Prince William Sound, following the *Exxon Valdez* spill (Frost et al. 1994). Harbour seal pup mortality at oiled beaches was 23 to 26%, which may have been higher than natural mortality (Frost et al. 1994). However, attributing cause to the decreasing trend in harbour seal numbers since the spill (4.6% per year) is complicated because seal populations were declining prior to the spill (Frost et al. 1999).

Further analyses of harbour seal population trends and movements in Prince William Sound does not support high mortality, but indicates that seals moved away from some oiled haul-out sites (Hoover-Miller et al. 2001).

Avoidance and Behavioural Effects

There is conflicting evidence on whether seals detect and avoid spilled oil. Some oiled seals hauled out on land are reluctant to enter the water, even when disturbances from intense cleanup activities occur nearby (St. Aubin 1990; Lowry et al. 1994). In contrast, several thousand grey and harbour seals apparently left Chedabucto Bay, Nova Scotia, after the grounding of the *Arrow* (Mansfield 1970 *in* St. Aubin 1990), although this movement may have been caused by the increased human disturbance during cleanup activities rather than by the presence of oil (St. Aubin 1990). Harbour seals observed immediately after oiling appeared lethargic and disoriented, which may be attributed to lesions observed in the thalamus of the brain (Spraker et al. 1994). Other seals have been observed swimming in the midst of oil spills (St. Aubin 1990). Oiling of both mother and pups does not appear to interfere with nursing (Lowry et al. 1994).

Oiling of External Surfaces

Adult and juvenile hair seals (includes harbour, grey, harp and hooded seals) are at virtually no risk of thermal regulatory effects from oil fouling because their blubber, not their fur, provides insulation (Kooyman et al. 1976; 1977; St. Aubin 1990). It is questionable whether young seal pups, which rely on their birth coat and brown fat stores, could survive the deleterious effects of oiling (St. Aubin 1990). Contact with oil on the external surfaces can cause increased stress and can irritate the eyes of ringed seals (Geraci and Smith 1976; St. Aubin 1990). Harbour seals oiled during the *Exxon Valdez* spill had difficulty keeping their eyes open and experienced conjunctivitis (Spraker et al. 1994). These effects seem to be temporary and reversible, but continued exposure of oil to eyes could cause permanent damage (St. Aubin 1990). Damage to a seal’s visual system would likely limit foraging abilities, as vision is an important sensory modality used to locate and capture prey (Levenson and Schusterman 1997). Mucous membranes that line the oral cavity, respiratory surfaces, and anal and urogenital orifices are also sensitive to oil exposure (St. Aubin 1990). Seals fouled externally with heavy oil may also encounter problems with locomotion. The flippers of young harp seals and grey seal pups were impeded by a heavy coating of oil that became stuck to their sides (Davis and Anderson 1976; Sergeant

1991). This led to the drowning of the grey seal pups. The coating of seals and their subsequent deaths were also observed in seals exposed to heavy bunker oil during the *Arrow* and *Kurdistan* spills (Engelhardt 1987 *in* Lowry et al. 1994).

Oil Ingestion and Inhalation

Seals can ingest oil if their food is contaminated or by nursing contaminated milk. Oil can also be absorbed through the respiratory tract (Geraci and Smith 1976; Engelhardt et al. 1977). Some ingested oil is voided in vomit/feces or metabolized at rates that prevent significant bioaccumulation (Neff 1985 *in* Hartung 1995) but some is absorbed and can cause toxic effects (Engelhardt 1981). These effects may include minor kidney, liver and brain lesions (Geraci and Smith 1976; Spraker et al. 1994). When returned to clean water, contaminated animals can depurate this internal oil (Engelhardt 1978; 1982; 1985). Seals exposed to an oil spill and especially a blowout are unlikely to ingest enough oil to cause serious internal damage (Geraci and St. Aubin 1980; 1982) and any effects are probably reversible (Spraker et al. 1994). There were no significant quantities of oil in the tissues (liver, blubber, kidney and skeletal muscles) of harbour seals exposed during the *Exxon Valdez* spill (Bence and Burns 1995).

Seals are also at risk from hydrocarbons and other chemicals that evaporate from spills and blowout areas. Seals generally keep their nostrils close to the water surface when breathing, so they are likely to inhale vapours if they surface in a contaminated area. Grey seals that presumably inhaled volatile hydrocarbons from the *Braer* oil spill exhibited a discharge of nasal mucous, but no causal relationship with the oil was determined (Hall et al. 1996). Laboratory studies of ringed seals indicate that the inhalation of hydrocarbons may cause more serious effects like kidney and liver damage (St. Aubin 1990). However, exposure conditions were much higher than would be expected in a natural setting.

Factors Affecting the Severity of Oil Exposure

Seals that are under some type of natural stress, such as lack of food or a heavy infestation by parasites, could die as a result of the additional stress of oiling (Geraci and Smith 1976; St. Aubin 1990). Seals that are not under natural stress would most likely survive oiling.

Seals exposed to heavy doses of oil for prolonged periods of time could die. Harbour seals may be particularly at risk because they exhibit site fidelity (Boulva and McLaren 1979; Yochem et al. 1987). Prolonged exposure from oil at a preferred haul-out site could cause the death of some seals. However, Jenssen (1996) reported that oil has produced little visible disturbance to grey seal behaviour and there has been little mortality despite the fact that approximately 50 percent of grey seal pups at Norway's largest breeding colony are polluted each year by oil.

4.3.3.5 Sea Turtles

It is not known whether sea turtles can detect and avoid oil slicks. Gramentz (1988) reported that sea turtles did not avoid oil at sea, while sea turtles exposed to oil under experimental conditions had a limited ability to avoid oil (Vargo et al. 1986).

Loggerhead sea turtles experimentally exposed to oil had marked gross and histologic lesions present in the skin. Most effects were reversed by the tenth day following cessation of oil exposure (Bossart et al. 1995). Other effects of oil on sea turtles include reduced lung diffusion capacity, decreased oxygen consumption, decreased digestion efficiency, and damaged nasal and eyelid tissue (Lutz et al. 1989).

There are few field observations of sea turtles exposed to oil. After the Ixtoc 1 oil well blowout in 1979, seven live and three dead sea turtles were recovered (Hall et al. 1983). Two of the three carcasses had oil in the gut but no lesions. There was no evidence of aspirated oil in the lungs but hydrocarbon residues were found in kidney, liver, and muscle tissue of all three dead turtles. The authors suggested prolonged exposure to oil may have disrupted the feeding behaviour and weakened the turtles.

4.3.3.6 Species at Risk (SAR)

Species that are legally protected under *SARA* (i.e., Schedule 1 *threatened* or *endangered*) and which may occur in the Study Area include the following:

- Blue whale
- North Atlantic right whale
- Piping Plover
- Leatherback sea turtle
- Northern wolffish
- Spotted wolffish
- Beluga whale

Critical habitat of Species at Risk is also protected under *SARA*. The protection of critical habitats is a major aspect of *SARA* Recovery Strategies (e.g., identified Piping Plover critical habitat sites in the southern part of the Study Area).

Sections 4.3.3.1 to 4.3.3.5 address the potential interactions and effects between accidental events and the animals presently listed on Schedule 1 of *SARA* that could occur in the Study Area. It is likely that shallow subtidal, intertidal and backshore habitats would be most susceptible to impact by accidental events.

Of the species listed above, Piping Plover and their habitat could be the most affected depending upon the timing and location of a spill.

4.3.3.7 Summary of Interactions and Effects

The literature on the effects of petroleum hydrocarbons is very extensive. Thorough reviews are contained in Mobil (1985), Petro-Canada (1996), Husky (2000, 2001, 2003), LGL et al. (2000), and others, and they are not repeated here. It should be noted that at the project-specific EA stage, environmental effects assessment of accidental events are required in accordance with the C-NOPB *Guidelines Respecting Drilling Programs* (2000). Spill trajectory analysis is also often required. The key points of relevance to offshore planning for the Western Newfoundland and Labrador Offshore Area Study Area are listed below.

- Magnitude, geographic extent, and duration of effects are very sensitive to oil behaviour (see preceding section), timing and location of the blowout or spill.

- Plankton, particularly sensitive eggs and larvae, may be affected by an oil spill.

- Benthos may be unaffected by an oil or gas blowout or surface release that will rise to the surface. A subsurface blowout will physically disrupt benthic communities near the well as the gas escapes under pressure.

- Adult fish can likely detect and avoid a spill or blowout; however, ichthyoplankton (planktonic eggs and larvae) cannot avoid it and can suffer lethal and sublethal effects.

- Marine mammals and sea turtles are generally believed to be able to avoid most spills. Sea turtles may be somewhat more sensitive than marine mammals in this regard.

- Seabirds, particularly those such as murres and Dovekies that spend a lot of time on the surface, are the most sensitive group to the effects of oil because they lose the insulation value of their feathers in contact with even small amounts of oil, they tend to congregate in groups, and because they are also affected by other human pressures such as hunting (sea ducks and murres) and illegal dumping of oily bilges by disreputable tankers and freighters in Canadian waters.

- All seabirds are vulnerable to oil pollution but those that spend most of their time on the water's surface and dive are the most vulnerable (Wiese 1999). Diving-feeders occurring within the Western Newfoundland and Labrador Offshore Area Study Area include Greater Shearwaters, Sooty Shearwaters, Manx Shearwaters, Northern Gannets, Terns, Dovekies, Common Murres, Thick-billed Murres, Razorbills, Black Guillemots, and Atlantic Puffins.

- Coastal marine bird habitats and sensitive areas are vulnerable to oil pollution and possibly to other activity aspects associated with onshore to offshore directional drilling.

- As implied by the potential interactions with the various VECs, sensitive areas within the Study Area (e.g., Cod Spawning Area, lobster spawning and nursery areas, The Hole) are vulnerable to oil pollution.

- Intertidal and shallow subtidal benthos is vulnerable to oil washing ashore. Given the proximity of any future oil drilling in Parcels 4 to 7, typical onshore winds, there is likely a high probability that at least some oil from an accidental spill or blowout could reach the shoreline.

- Proximity to major shipping routes or offshore production sites can also increase the potential for exposure. Ninety-seven percent of oil encountered on birds or on beaches in the Newfoundland area originates from large ships (T. Lock, pers. comm. *in* Montevecchi et al. 1999). The threat of oil pollution to seabirds in the Atlantic Region of Canada is highest during non-breeding season when populations are dominated mainly by aquatic species (auks), water temperatures are lowest and populations expand their range into oil development or shipping areas (Lock et al. 1994; Montevecchi et al. 1999). The life history strategy of seabirds characterized by a long lifespan, delayed sexual maturity, small numbers of offspring, and aggregative behaviour (breeding colonies) render seabirds highly vulnerable to quick declines in the numbers of breeding individuals.

- The only potential biophysical effect at the population level from a large offshore oil spill or blowout may be with seabirds or waterfowl in situations where the releases coincided in time and space with large concentrations of birds. This conclusion was reached by all previous offshore EAs on the Grand Banks and is likely true for western Newfoundland as well, although further analysis would need to be done for site-specific situations.

- A large offshore spill could affect the commercial fishery by exclusion and market perception issues, again depending upon timing and location.

4.3.4 Mitigations and Planning

The effects conclusions presented in the previous sections assume that mitigations will be in place and thus the effects could be considered what is termed 'residual.' The oil industry operating in Newfoundland and Labrador waters has strict policies and procedures concerning spills of all sizes, which must be reported to the C-NLOPB. All offshore operators are required to submit to the Board and operate under an Oil Spill Response Plan (OSRP), or equivalent. In addition, all operators are required to have an arrangement with a spill response agency to provide spill response capabilities in the event of a spill.

Impermeable berms are constructed around the rig site in the case of onshore to offshore directional drilling operations in order to contain any accidentally released substances at the land-based site. Buffer areas are typically established to provide separation between the rig site and proximate water bodies, and are typically established on a project by project basis D. Hawkins, C-NLOPB, pers. comm., W. Foote, Government of Newfoundland and Labrador, pers. comm.).

Given the proximity of potential drilling activities to coastal areas and identified sensitive areas, spill response capabilities are even more critical than when activities are conducted further offshore. The increased probability of oil reaching shore or any of the identified offshore sensitive areas further necessitates that operators be prepared with a spill response strategy.

In summary, the most effective planning tool for minimizing the effects of oil spills is by all parties concentrating their efforts on avoidance firstly on accidents and secondly on sensitive areas and times. The latter are identified through efforts such as this SEA, generic EAs (where a scenario approach can be used to analyze different areas time and spill variables), and the site-specific EA. All operators are required to submit OSRPs to the Board.

4.3.5 Data Gaps

While the effects of different types of petroleum hydrocarbons are fairly well known, the physical characteristics of hydrocarbons in the Study Area are not well known. The crude oil discovered in the Study Area to date is lighter than that on the Grand Banks (51º API). The distribution of the fisheries in the Study 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 Study Area are not completely understood.

Specific characteristics, fate and behaviour of oil spills in most of the Western Newfoundland and Labrador Offshore Area are unknown. Only one oil spill trajectory modelling exercise has been conducted thus far in the Study Area. It was for a nearshore well located southwest of Cape St. George in Unit Area 4Rd. Trajectory analyses as per guidelines will be run as part of the project-specific EA process.

4.4 Cumulative Effects

In consideration of the number of parcels offered in the 2005 Call for Bids, it could be assumed for the purposes of the SEA that there would be a maximum of four exploration licenses issued if the 2005 Call is successful. Under the Boards' rights issuance processes for the 2005 Call, licenses must be relinquished if a well is not spudded within the first period of the license (typically five years, with an option for a 6th year). The current level of information available on the resource potential of the area does not permit an exact prediction of the number of exploration wells likely to be drilled during the period of these licenses. There are also five active exploration licences in the Study Area.

The following estimate is used for planning purposes without attempting explicitly to take into account the area's resource potential. Since the mid-1980's, approximately 75% of exploration licenses that expired or were relinquished in the Newfoundland and Labrador offshore area did not have a well drilled on the license.

Further, historical experience in the Newfoundland and Labrador offshore area indicates that (to end 2002) 23 significant discoveries have been made as a result of 129 "wildcat" exploration wells - a proportion of about 18% or 1 in 5.5. Of these discoveries, four to date (Hibernia, Terra Nova, White Rose and the potential Hebron development) have resulted in more than one delineation well (approximately 3% of exploration wells or 1 in 32). Full pre-development field delineation offshore Newfoundland and Labrador to date has involved 7-9 wells in addition to the initial discovery well; this drilling typically has extended considerably beyond the nine-year period of the original exploration license.

Given today's high oil prices and increasing worldwide demand for oil and gas, it is difficult to predict future levels of offshore activity based upon past history. Nonetheless, given the relatively small area covered by the parcels in question, what is known of past decisions offshore Newfoundland, and other factors, the following may be a reasonable scenario for the west coast.

There likely would be no more than two seismic programs running concurrently. This is deduced based on past history, the high demand for seismic vessels, the need to maintain distance to avoid affecting each other's data, and the general propensity of the oil industry to utilize resources sequentially to realize potential cost savings. [There is presently one 30 day 2-D/3-D program planned for 2005/2006 by Ptarmigan Resources Ltd. according to the C-NLOPB website.]

There likely would be no more than two exploratory drill rigs (one shallow and one deep), excluding any drilling from land, operational at any one time. This is deduced based on past history, the high demand for drill rigs, and the general propensity of the oil industry to utilize resources sequentially to realize potential cost savings.

There is typically no more than two exploratory wells drilled per parcel; given that there are four parcels and that exploration licenses typically last for five years then one may see eight wells over five years plus whatever activity existing licenses may generate over the next few years.

In the statistically unlikely event that enough significant discoveries are made to justify a production development, one would be the maximum number.

If a production development was proposed it can be speculated that in shallow water, say less than 100 metres, a bottom-founded unit might be used, whereas in deeper water an FPSO might be used. Production platforms would be tied into some unknown number of satellite wells with flow lines. Production developments could also be on land if directional drilling was used.

4.4.1 Oil and Gas Activities

4.4.1.1 Seismic Surveys

Any geophysical programs (2-D, 3-D, VSP, or other) will not overlap as they would interfere with data collection. Effects of noise may be additive on those animals such as certain species of fish (e.g., herring) and marine mammals (e.g., humpback whales) that may be sensitive to seismic survey noise. Although migratory animals may be subject to disturbance from noise outside the Study Area from other surveys on the East Coast. Mitigations such as ramp-ups and avoidance of sensitive areas and times should mitigate any potential cumulative effects to acceptable levels.

Considering that environmental assessments to date have concluded that the effects of individual seismic programs on marine animals (e.g., marine mammals, marine birds, sea turtles, fish, and invertebrates) are not significant given the proper implementation of mitigation measures (Davis et al. 1998) and that spatial and temporal overlap between different seismic programs can be readily minimized, seismic cumulative effects should be minimal. Nonetheless, individual seismic programs will require a site-specific EA pursuant to CEAA which will examine cumulative effects in detail. The more detailed cumulative effects assessment, including background noise levels, would be contained in the site-specific EA. Standard mitigations such as a marine mammal monitoring program, ramp-up procedures and the use of FLOs are typically employed by operators to reduce potential effects.

4.4.1.2 Drilling

Any cumulative effects will not be overlapping or synergistic within the Western Newfoundland and Labrador Offshore Area, unless supply vessels follow the same routes at the same time. Cumulative effects will, however, be additive; this is a potential issue with migratory species that may be subject to repeated disturbances as they transit the East Coast.

Any cumulative effects on the Gulf of St. Lawrence ecosystem from routine exploratory drilling in the Study Area will probably not overlap in time and space and thus, will be additive but not multiplicative. This level of activity will not change any effects predictions when viewed on a cumulative basis unless significant oil spills or blowouts occur.

Barring major accidents, effects of a single exploratory well in the Study Area should be minimal (Buchanan et al. 2003). In any event, it is unlikely that any effects, mostly confined to within 500 m, would overlap with another exploratory well, on or off the shelf; they will be simply additive. An exception could be the effects of drill rig noise and/or supply vessel noise. [The lack of modeling and measurements of noise in the Study Area has been identified as a data gap.]

4.4.2 Commercial Fisheries

The Study Area undergoes intensive fishing pressure (Section 3.4.4), so much so that the environmental effects of trawling on benthos and fish, the effects of longlines and gillnets on fish populations, seabirds, sea turtles, and marine mammals greatly exceed any potential effects from oil exploration. Nonetheless, effects of exploration activities will add some negligible, but not measureable, additional stress on fish and fisheries.

4.4.3 Shipping

The west coast sees some shipping activity, nationally through ports in Stephenville and Corner Brook, and internationally through the Strait of Belle Isle, mostly active during summer for ships coming from Europe. There is also local boat traffic, mostly fishing vessels. Seabirds, marine mammals, and sea turtles are the primarily affected VECs. These issues are typically considered at the EA stage.

4.4.4 Other Activities

Other activities with some potential for cumulative effects are hunting (marine birds), naval exercises (marine mammals), and research activity (e.g., DFO surveys). The specifics of these activities and potential effects will be considered during any site-specific assessments.