Section 7

Impact assessment for seismic activities

7 Impact assessment for seismic activities

7.1 Introduction

This section considers the environmental impacts that may arise from seismic survey activities that may occur following implementation of the licensing round. It addresses those impacts identified during the scoping and assessment process as having the potential to be significant (see Section 6). The assessment takes account of the range of possible scenarios and alternatives within these, and of the potential for cumulative and transboundary impacts.

In this section, sound pressure levels are quoted in units of decibels referred to 1 μPa (dB re 1 μPa). Wherever the term dB is used by itself, it should be read as dB re 1 μPa. Also, all logarithmic values refer to $\log_{10}$.

7.2 Noise generation

Sound is readily transmitted underwater and there is potential for the noise produced by the oil and gas industry to cause detrimental effects to marine animals. The use of underwater sound is important for animals such as marine mammals (eg seals, whales, porpoises and dolphins) in order to navigate, communicate and forage effectively. The introduction of additional noise into the marine environment could potentially (through masking effects) interfere with these animals' ability to determine the presence of predators, food and underwater land features and obstructions. It could therefore cause short-term behavioural changes and, in more extreme cases, cause auditory damage. In addition, underwater noise may also cause behavioural changes in other animals such as fish and cephalopods.

7.2.1 Noise in the marine environment

Natural sounds in the sea are produced by wind, waves, currents, rain, ice-breaking, echo-location and communication noises generated by cetaceans and other natural sources such as tectonic activity. Table 7.1 displays some of the different types of natural sounds found in the marine environment.

Table 7.1 Examples of natural sounds in the marine environment (source: McCauley, 1994)

Sound source	Dominant frequency range (kHz)	Sound pressure density spectrum level (dB re 1 μPa^2/Hz)	Noise characteristics
Wind	1 to 25 kHz	100 to 200 Hz 65 dB (force 3) 85 to 95 dB (force 12)	Greatest levels at higher wind speeds, noise is continuous on a scale of hours to days
Rain	Broad spectrum	0 dB (no rain) to 80 dB (heavy rainstorm)	Flat frequency spectra (white noise)
Earthquake events	5 to 15 Hz	0 dB (no earthquake) to 200 to 240 dB (at 10 km from earthquake of ML 4 to 6, broadband)	Short-term transitory events on a scale of minutes, noise levels may be high

In addition to the natural occurring sounds there are anthropogenic sounds generated by air traffic, shipping activity, and the oil and gas industry (including drilling, seismic activity, construction and decommissioning, production, and associated vessels). Table 7.2 shows various anthropogenic sources and received levels of sound in the marine environment.

Table 7.2 Sound sources from various maritime activities (adapted from Evans & Nice, 1996; Richardson *et al*, 1995)

Activity	Frequency range (kHz)	Average source level (dB re 1µPa-m)	Estimated received level at different ranges (km) by spherical spreading*			
			0.1 km	1 km	10 km	100 km
High resolution geophysical survey; pingers, side-scan, fathometer	10 to 200	<230	190	169	144	69
Low resolution geophysical seismic survey; seismic air gun	0.008 to 0.2	248	210**	144**	118**	102***
			208	187	162	87
Production drilling	0.25	163	123	102	77	2
Jack-up drilling rig	0.005 to 1.2	85 to 127	45 to 87	24 to 66	<41	0
Semi-submersible rig	0.016 to 0.2	167 to 171	127 to 131	106 to 110	81 to 85	6 to 10
Drill ship	0.01 to 10	179 to 191	139 to 151	118 to 130	93 to 105	18 to 30
Large merchant vessel	0.005 to 0.9	160 to 190	120 to 150	99 to 129	74 to 104	<29
Military vessel	-	190 to 203	150 to 163	129 to 142	104 to 117	29 to 42
Super tanker	0.02 to 0.1	187 to 232	147 to 192	126 to 171	101 to 146	26 to 71

* *Spherical spreading is calculated using the formula presented in Section 7.1.3, except where indicated differently.*
** *Actual measurements in St George's Channel, Irish Sea.*
*** *Extrapolated figure as presented by Evans & Nice, 1996.*

7.2.2 Effects of anthropogenic noise on marine animals

In recent years there has been growing awareness of the potential for man-made underwater noise to impact marine animals, particularly marine mammals. Available information on the effects of noise on marine mammals indicates that cetaceans and pinnipeds can react differently to the introduction of additional noise into the marine environment. Their reactions are attributable to sound source level, propagation conditions and ambient noise, as well as to animal type, age, sex, habitat, individual variation, and previous habituation to noise (Richardson *et al,* 1995).

The complexity and uncertainties of marine mammal reactions to underwater noise, and the variability of the strength of noises in the marine environment, mean it is difficult to establish definite areas of influence around an anthropogenic sound source. However, several general zones of noise influence have been identified as follows:

- Zone of audibility – the furthest reaching zone, in which marine mammals can hear anthropogenic noises because they are louder than ambient noise. Although the animal can hear the noise, it is unlikely that the sound will have any deleterious effects at such large distances. The size of this zone can vary greatly as ambient noise fluctuates between the seasons and differs between locations.
- Zone of responsiveness – a more localised area around a sound source, in which animal behavioural responses to noise are observed. The size of the zone is a combination of the sound source level, propagation conditions and ambient noise, in addition to animal age, sex, habitat, individual variation, and previous habitation to noise. In this zone individuals and even entire populations may show almost no signs of disturbance because of habituation or toleration of the sound, or the fact that the noise may be outwith the hearing sensitivities of a particular animal. If noises produce a response then the effects can vary greatly between species and individuals. Marine mammals may become distracted, disturbed, annoyed, or even fearful of these noises which could cause potential physiological upset. Common marine mammal responses to noise are changes to dive behaviour, respiration and surfacing rates; quantifiable indicators which can be used to measure animal stress (Richardson *et al*, 1995). Variation in responsiveness among different individuals, or for one individual at different times, may greatly affect the radius of responsiveness. In general, several physical and biological factors are known, or suspected, to affect the responsiveness, actual or apparent, of a given species of marine mammal to man-made noise. As a result, the maximum radius of responsiveness can vary widely among individuals, locations and over time. Thus the radius of responsiveness, even for a specific type of man-made sound and a particular species, is a variable, not a constant (Richardson *et al*, 1995).
- Zone of masking – an area in which faint noises produced by the animals are masked by anthropogenic noises of a similar frequency. Any increase in background noise, either man-made or naturally occurring, can interfere with an animal's ability to detect a sound signal, especially if the sound signal is weak relative to the total noise level (Richardson *et al*, 1995).

- In general, (man-made) pulsed noise has a smaller potential for masking than temporally continuous noise. Furthermore, masking depends on the amount of energy that the call and the (man-made) noise share in the so-called critical frequency bands, which are characteristic of the animal's auditory capacity (Gisiner, 1998).
- Zone of discomfort or hearing loss – an area in which there is a possibility of auditory injury to an animal from underwater sound. The extent of this zone is somewhat speculative because of the scarcity of any direct measurements on marine mammal hearing systems, particularly in the wild. However, it is proposed that continual exposure to significant sound levels, or brief exposure to extremely high noise levels, could create permanent or temporary hearing impairment in marine mammals. Seismic exploration produces noise pulses that are intermittent but considerably more intense than the continuous noise emitted by most industrial noises in the ocean. There are few direct 'cause-and-effect' studies into the potential for these pulses to damage the auditory systems of marine mammals per se. However, extensive information on the impacts of anthropogenic sound and zones of discomfort on marine mammals is available (eg Richardson *et al*, 1995; Gordon *et al*, 2004), including sound produced by seismic vessels. It is generally considered unlikely that marine mammals would remain for any length of time close to any noise source that causes discomfort.

It should be noted that marine mammals may react differently to stationary noise, sudden bursts of noise, and noises that appear to be coming towards them. Studies suggest that most cetaceans will alter their course or display avoidance reactions to a noise that appears to be moving directly towards them. Stationary noises, such as drilling and production noises, outwith an immediate zone of discomfort to the animal, seem to have a lesser effect in disturbing migration patterns and animal feeding, although data and observations are limited (Davis *et al*, 1990).

Cetaceans

Toothed whales rely on sound for echolocation, foraging and communication. Their auditory sensitivities range from 75 Hz to 150 kHz, with greatest sensitivities around 20 kHz. This means their hearing is most sensitive at frequencies of around 100 times higher than that of baleen whales, and outside the peak energy range (0 to 120 Hz) of seismic air guns. However, air gun arrays can occasionally produce significant sound at frequencies of 1 to 20 kHz, levels that can overlap the hearing range of many toothed whale species at short distances and mask their ability to communicate with each other, for example (Evans, 1998). Beaked whales may be particularly sensitive in this respect (Gordon *et al*, 2004).

Since the hearing of most toothed whales is largely outwith the sound frequencies of seismic surveys, reactions are rarely recorded. In fact, there have been observations of dolphins bow riding seismic survey vessels. There is concern raised that toothed whales may be affected by the temporal avoidance reaction of fish during seismic survey. If fish are forced to move away from their habitats over a period of a few days or more, it is likely that the toothed whales preying on them will move away too. Evidence of such predator-prey interactions is difficult to obtain and is an area in need of more research before any long-term consequences can be drawn.

There are no direct measurements of hearing sensitivity for baleen whales yet it is presumed that they hear over the approximate frequency range as the sounds they produce. It is therefore assumed that baleen whales have greatest hearing sensitivity ranges between 10 Hz to 10 kHz, with greatest sensitivities usually below 1 kHz (Evans, 1998). It is clear that this hearing range overlaps with the low frequency sounds produced by seismic surveys, which may mask long distance communication between whales over significant distances and prevent the detection of other faint sounds (Evans & Nice, 1996).

Reactions of baleen whales to seismic survey noise occur at received sound pressure levels in excess of 160 to 170 dB. Sound pressure levels over 220 dB may cause permanent damage and, in some extreme cases, even death. Studies of bowhead whales and grey whales indicate that reactions vary from subtle changes in surfacing, breathing, and diving behaviour to avoidance of the sound source and cessation of feeding and social interaction. Such behavioural responses are generally short lived and occur within 2.5 to 8 km from a seismic sound source (Evans & Nice, 1996). However, it must be stressed that the long-term implication of these noise sources, including cumulative and synergistic impacts, are unknown.

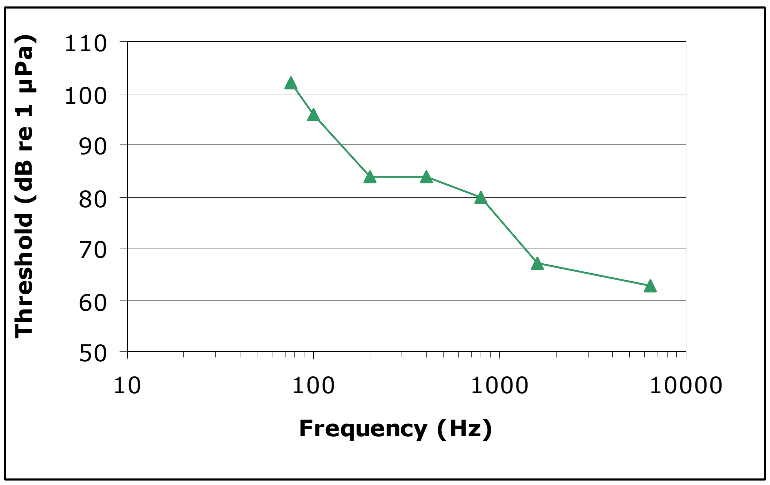
Pinnipeds

There have been very few studies of the effects of air gun noise on pinnipeds (seals), even though they are known to have good underwater hearing and their feeding grounds often overlap with seismic survey areas (Gordon *et al*, 2004). A review of the effects of seismic survey on marine mammals by

Gordon *et al* (2004) quotes one single study by Thompson *et al* (1998) on the research on behavioural and physiological responses of grey and harbour seals to (small) airguns. The study indicated that reactions observed in harbour seals included initial fright responses once the air guns were switched on, generally followed by strong avoidance behaviour, ie swimming rapidly away from the sound source. The seal ceased feeding during this time. It should be noted however, that one seal showed no detectable response and approached to within 300 m of the airgun (source levels of the airgun were 215 to 224 dB re: 1 m Pa peak-to-peak). The behaviour of the harbour seals seemed to return to normal soon after the air guns were switched off. Similar avoidance responses were documented during the trials with grey seals, ie they changed from making foraging dives to v-shaped transiting dives moving away from the sound source. The grey seals returned to normal behaviour within 2 hours after switching off the air guns.

Harbour seals are most sensitive to sounds between 6 to 12 kHz (Lawrence *et al*, 2003) although their threshold to hear and respond to sound lies at frequencies much lower than that. Kastak & Shusterman (1998) measured an underwater sound detection threshold of a harbour seal ranged between 101.9 dB and 62.8 dB for frequencies between 75 Hz and 6,400 Hz respectively (Figure 7.1).

Figure 7.1 Underwater sound detection thresholds (75 to 6,400 Hz) for a harbour seal *Phoca vitulina* (Kastak & Shusterman, 1998)



The audiograms of harbour and grey seals are very similar (Thompson, 1998), and their reaction to (anthropogenic generated) underwater sound is therefore expected to be similar as well. Using the formula for spherical spreading, this means seals could be able to hear sounds from seismic surveys over distances up to 105 km. The zone within which seals would react to the noise is expected to be considerably smaller, not extending much further than a few kilometres from the seismic survey vessel.

In addition to any direct response reactions, it has recently been shown that moderate levels of underwater noise can induce temporary reduction of hearing sensitivity (temporary threshold shift or TTS) in some marine mammals (including pinnipeds), provided that the exposure duration is relatively long (Kastak *et al*, 2005). Although such individual exposure events are not likely to have dramatic long-term or fitness consequences (except for cases of extremely high exposure levels resulting in acoustic trauma), they may result in short-term impairment in the ability to communicate, navigate, forage and detect predators. Additionally, behavioural reactions to noise exposure such as startle responses or avoidance may interrupt ongoing behaviours as severe as mother-offspring separation (Kastak *et al*, 1999).

It is clear, therefore, that marine seismic exploration activity has the potential to impact upon both species of seal commonly residing in Irish waters. The degree of impact within and adjacent to the IOSEA1 area is as yet unknown, due to the lack of information on grey and harbour seal foraging ecology at sea, away from terrestrial haul-out and breeding sites.

Grey seal distribution and movements have been extensively studied in the North Sea and off Scotland using satellite-linked telemetry. Movements generally describe two geographical scales: (i) long and distant travel (up to 2,100 km), and (ii) local, repeated trips to discrete offshore areas, generally considered to be foraging areas (McConnell *et al*, 1999). Data from harbour seals utilising sites in the UK suggests that foraging trips generally occur within 40 km of haul-out sites (Thompson *et al,* 1994).

However, longer-distance trips to foraging areas more than 850 km from haul-out sites have also been recorded (eg Rehberg & Small, 2001). The recent deployment of GPS tags on harbour seals in southwest Ireland is expected to provide data on movement patterns and dive behaviour of harbour seals in Irish waters. Research in Ireland heretofore has largely focused on coastal haul-out and breeding sites and considerable efforts will be required to determine important ecological areas for both species (Ó Cadhla & Mackey, 2002) within the waters of IOSEA1 and Ireland's EEZ.

Fish

The effect of seismic surveys on fish is related to their life cycle stage. Fish eggs and larvae of many fish species drift in or close to the upper sea surface and thus, their spatial movements are determined by ocean and tidal currents. They are therefore potentially at risk to injury from seismic operations because they cannot actively avoid sound sources and their habitat within the upper water layers coincides with the depth at which air guns are towed during survey. Research indicates that larval fish and eggs can be killed within 2 m of a detonating air gun source (Coull *et al*, 1998).

Adult and juvenile fish are rarely affected by seismic operations because they are able to detect and physically avoid the seismic source. For a 248 dB airgun array the potentially lethal range would extend to 8 m from the sound source, although the risk of actual deaths at this sound level remains small (Turnpenny & Nedwell, 1994). The physical damage effects are most pronounced on fish with a swimbladder because the organ is unable to adapt quickly enough to the high intensity seismic pressure waves. If the received sound wave vibrations are too intense the bladder may be damaged or destroyed, the fish may become stunned and disorientated, or trauma can occur to fish hearing (McCauley, 1994).

Fish can detect seismic sound sources at large distances (up to 30 km) yet they seldom react to the sound before it is above a certain threshold. Alarm responses are expected 1 to 5 km from the seismic array, depending upon their threshold and the sound transmission loss (Nakken, 1992). To avoid the sound, adult fish swim away from the sound source. Review work by Turnpenny & Nedwell (1994) indicates that there are two different types of fish avoidance towards seismic sound; demersal fish will dive towards the bottom or into deeper waters and pelagic fish will swim horizontally away from the sound source. Demersal fish may also display a secondary horizontal movement in their diving reaction. In one study on fish avoidance and catch reduction, an array of four air guns operating at 239 dB in 185 m off the coast of Norway, catches of cod declined by 55 to 80% of initial levels within a 9 km radius of the survey area and the effect lasted for 24 h (Løkkeberg, 1991 in Turnpenny & Nedwell, 1994). In another study, an array of 18 air guns operating at 250 dB in 250 to 280 m in the Barents Sea caused a reduction in cod densities and catches of 50% within a 33 km radius and a 70% reduction in catch in the immediate survey zone (Engås *et al*, 1993 in Turnpenny & Nedwell, 1994). This catch reduction lasted for at least 5 days. The effects on the fish themselves appear to be short-lived, possibly only for the actual duration of the exposure, but where fish are displaced over long distances, re-invasion may rely on a diffusion-like process. This would inevitably take longer than the initial directed movement of fish out of the affected area (Turnpenny & Nedwell, 1994). However, such movement is expected to have insignificant effects on stock distribution when natural variability in abundance and distribution are taken into account.

The IOSEA1 area lies within or close to spawning and nursery grounds for several fish species. The effects of seismic surveys on these areas may lead to a cessation of fish spawning, spawning occurring in a less suitable location, or fish temporarily or permanently moving to a more suitable spawning ground. Nursery areas will be affected to a lesser extent as juvenile fish are able to swim away from sound sources. However, if they move away to another area the conditions may not be suitable enough to sustain them and these small fish may not be able to swim the long distances required to avoid the sound source.

Knowledge of sensitive fish spawning areas and periods could allow more effective planning of seismic activities. To facilitate this, Coull *et al* (1998) have produced a series of maps illustrating sensitive spawning areas by month. These areas combine the spawning areas of all individual species, with the exception of a few with very wide spawning distributions. In February, the southeast corner of the IOSEA1 area has been classified as being sensitive to seismic disturbance (Figure 7.2a). From March to July, the majority of the IOSEA1 area, along the length of the continental shelf break and slope, has classified as being sensitive to seismic disturbance since these are spawning periods for blue whiting and mackerel (Figures 7.2b and c). The inshore area to the northwest of Ireland, extending into the northern Quadrants of the licensing area, has been classified sensitive to seismic survey disturbance during August and September due to herring spawning (Figure 7.2d). From October to January inclusive, no fish spawning grounds are considered sensitive to seismic activity, in the area to the north and west of Ireland.

Seabirds

Few studies have been undertaken to analyse the effects of underwater noise upon seabirds. Stemp (1985) studied the effects of seismic exploration on three seabird species. The conclusions were that seismic air gun sound emissions caused no fatalities and that the variations in bird abundances were less than the normal variation caused by weather and seasonal conditions. Seismic surveying is only likely to disturb birds rafting on the sea surface, within 5 m of the air gun. However, when the seismic vessel approaches groups of birds sitting on the sea surface they are likely fly or swim out of the way of the vessel and, as the air gun is towed behind the vessel, there will be a clear, bird free path in front of the air gun. The vessel bow wave and bird movement away from the boat means that they will be over 5 m away from the operative air gun. In addition, the physical presence of the vessel will itself create no greater disturbance to birds than that created by any other sea vessel in the area.

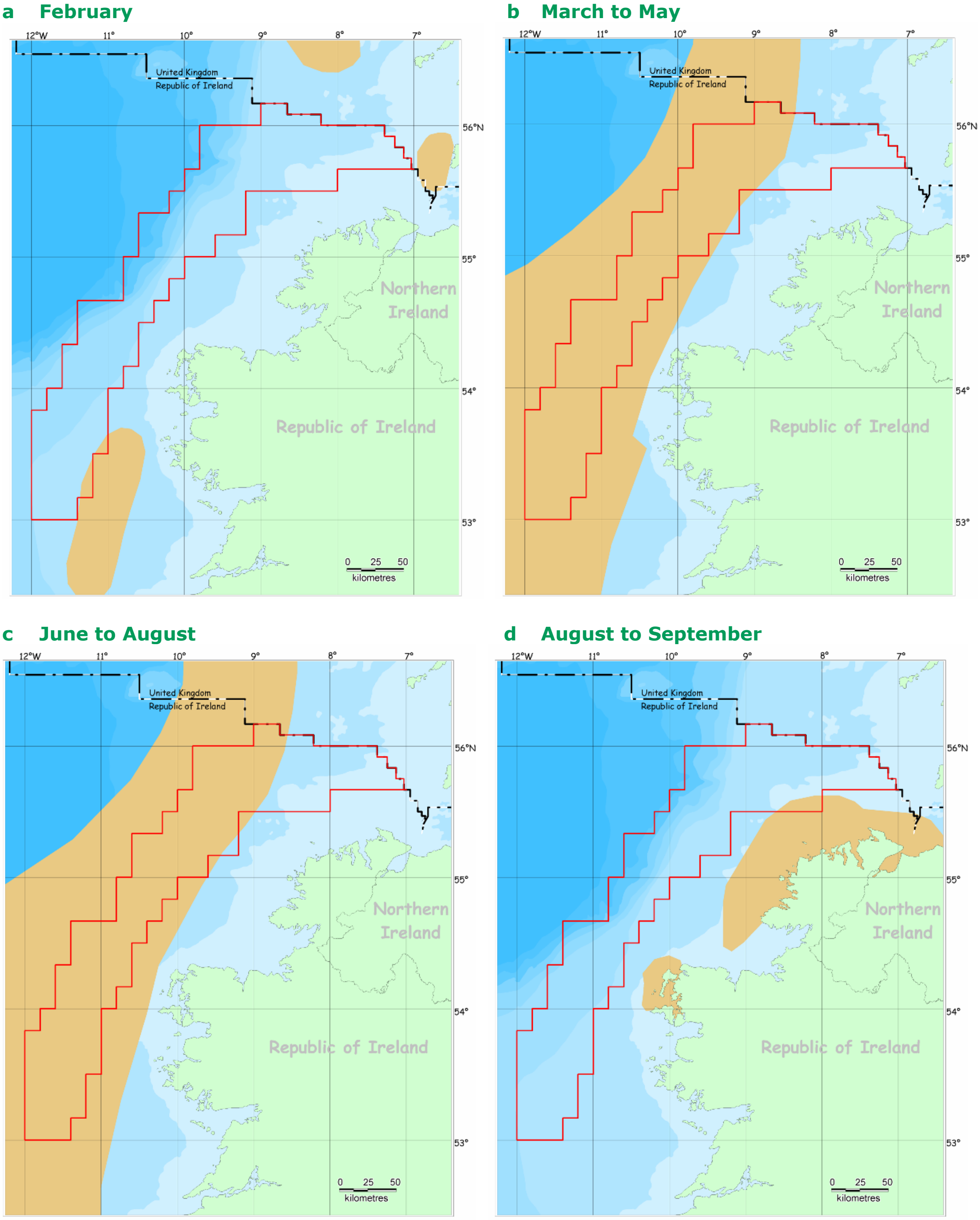
Turtles

A small scale behavioural test with a loggerhead turtle and a green turtle in Australia indicated that at seismic sound levels over 155 dB the turtles began to noticeably increase their swimming activity, and above 164 dB they began to show more erratic swimming patterns, possibly indicative of them being in an agitated state (McCauley *et al*, 2000).

Cephalopods

In tests with the squid species *Sepioteuthis australis* a noticeable increase in alarm response was observed once the air gun level exceeded 156 to 161 dB. No consistent avoidance responses were seen, but there was a general trend for the squid to increase their swimming speed on approach of the air gun, but then to slow down at the closest approach and for them to remain close to the water surface during air gun operations. Squid were the only animals observed during these tests to make use of the sound shadow measured near the water surface (an almost 12 dB difference was consistently observed between hydrophones at 3 and 0.5 m depth in trials. The common fish response to the air gun was the opposite, to go towards the bottom which would take them into the part of the water column with the highest sound levels of air gun (McCauley *et al*, 2000).

Figure 7.2 Fish spawning areas sensitive to seismic survey the vicinity of the IOSEA1 area (source: Coull *et al*, 1998)



7.2.3 Calculating the effects of seismic noise

A typical seismic survey array will produce short, sharp sound pulses with very high peak levels of short duration with a source level of around 248 dB re 1 μPa @1 m.

As sound spreads underwater, it decreases in strength with distance from the source. This sound transmission loss is the sum of spreading loss and attenuation loss. Spreading loss is the geometric weakening of a sound signal as it spreads outwards from a source. Attenuation losses are the physical processes in the sea that distort the mathematical spreading laws. Factors include sound absorption or scattering by organisms in the water column, reflection or scattering at the sea bed and sea surface, and the effects of temperature, pressure, stratification and salinity. Variations in temperature and salinity with depth cause sound waves to be refracted downwards or upwards causing increases or decreases in sound attenuation and absorption. Actual sound transmission therefore has considerable temporal and spatial variability that is difficult to quantify. Approximation of sound transmission loss for deep (>50 m) and unbound water bodies can be modelled approximately using the following equation:

Sound Transmission Loss (STL) = 20 log R + linear range term

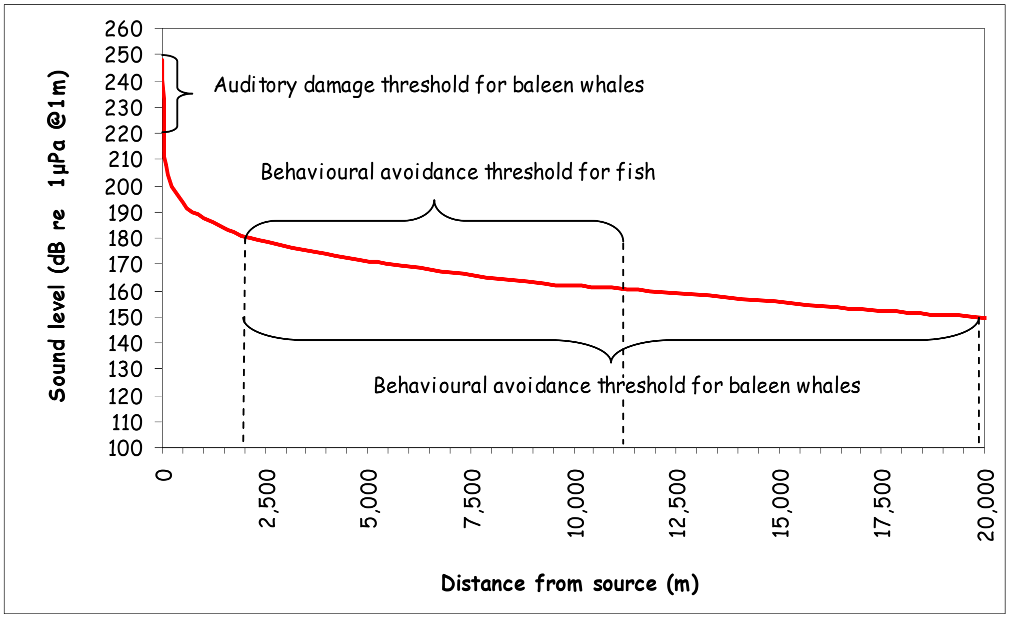
Where R = range (m)
Linear range term = absorption and scattering losses. It is represented by a coefficient of -0.61 dB/km (Evans & Nice, 1996).

Behavioural avoidance by fish has been observed to occur at the lower levels of 160 to 180 dB (Evans & Nice, 1996). Baleen whales may be physically damaged at sound levels in excess of 220 dB and will show behavioural avoidance reaction to sound levels of 150 to 180 dB (Gordon *et al*, 2004). Calculations of the received sound levels at various distances from the survey vessel including the threshold levels have been estimated using the sound transmission loss equation above (Table 7.3 and Figure 7.3).

Table 7.3 Estimated distances at which threshold levels for physical damage and avoidance effects will occur from a seismic survey (source: Evans & Nice, 1996; Gordon *et al*, 2004)

	Physical damage	Behavioural avoidance
Adult fish		**160 to 180 dB**
Distance from multiple seismic array (at 248 dB re 1μPa @1 m)	no data	2,150 to 11,325 m
Baleen whales	**220 dB**	**150 to 180 dB**
Distance from multiple seismic array (at 248 dB re 1μPa @1 m)	25 m	2,150 to 19,790 m

Figure 7.3 Underwater sound levels generated by the air guns (compiled by ERT from data in Evans & Nice, 1996; Gordon *et al*, 2004)



7.2.4 Estimating the effects of seismic noise

Between 2006 and 2011 it is forecast that 2D seismic operations within the IOSEA1 area will only take place during the first two years. A maximum of 1,000 and 1,500 km of 2D seismic survey will be shot in 2006 and 2007 respectively (Table 4.1), representing an average of approximately 1,250 km per year over the 2 years.

Between 2008 and 2010, it is predicted that the Draft Plan will result in a maximum of 7,000 km^2 of 3D seismic survey (Table 4.1); ie a maximum of 3,000 km^2 per year, or a mean of approximately 2,333 km^2 per year.

2D seismic survey

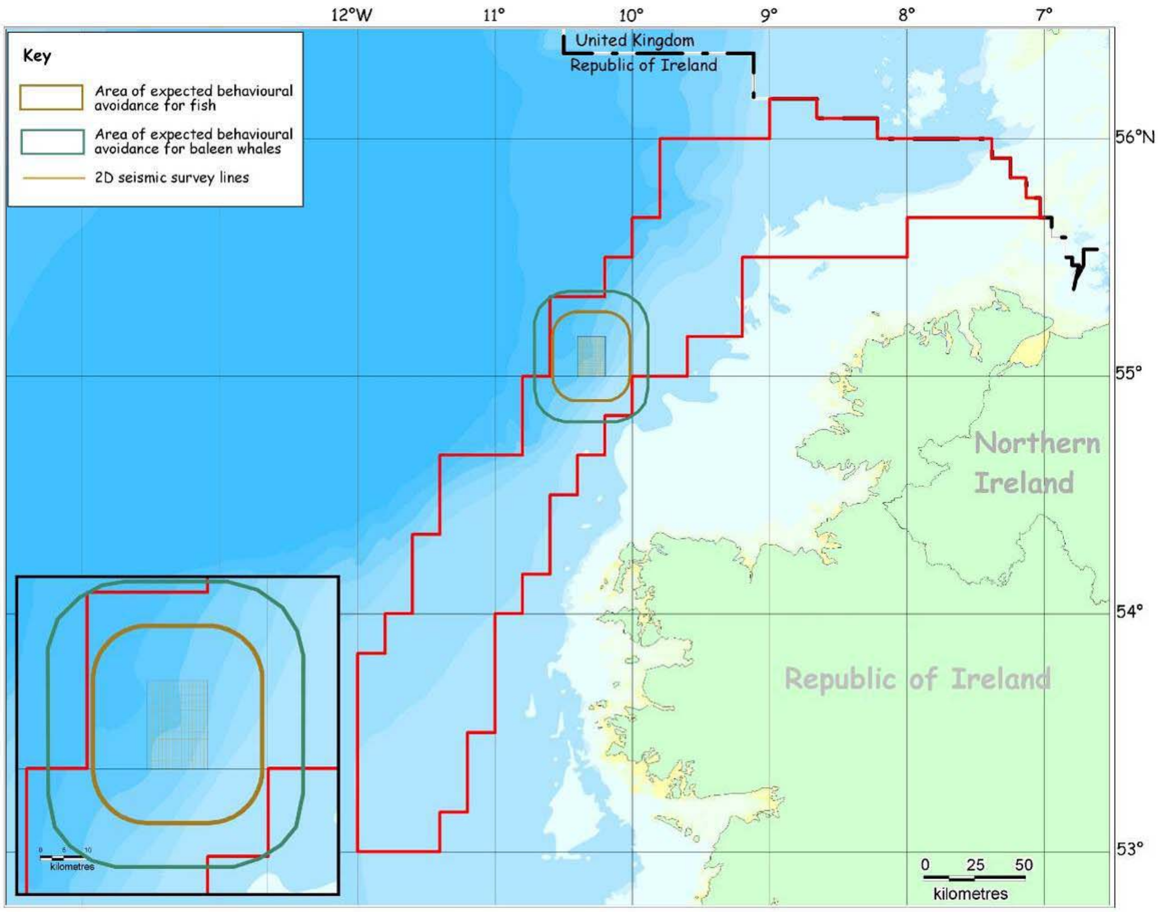
To survey a single licence block, approximately 250 km of lines will be shot over a period of about 10 days. Taking into account the predicted 2D survey effort for 2006 and 2007, the area covered will amount to approximately six and four licence blocks respectively. It is unlikely that areas of this size will be surveyed on a single occasion, by a single operator, although it is not uncommon for operators to share a survey vessel and to combine several surveys in one cruise. Bearing this in mind it is estimated that a maximum of two to three cruises will take place in 2006 and 2007. Some 39,232 km of 2D data have been acquired between 1972 and 2002 (PAD, 2006b). This averages out at 1,308 km per year, which is comparable with the level of 2D acquisition (2,500 km over 2 years) envisaged for 2006 to 2007.

The IOSEA1 area is an open sea area with waters deeper than 50 m. Therefore, the laws of spherical spreading are believed to best represent the attenuation of underwater sound here. Assuming spherical spreading and a sound source of 248 dB, it has been calculated that avoidance behaviour may occur in adult fish within 11,325 m of the air guns (Figure 7.3). Field research by Engås *et al* (1993 in Turnpenny & Nedwell, 1994) suggested that fish avoidance may occur at up to 33 km from the seismic sound source. However, Gausland (2003) subsequently questioned these findings. The overview study by Gausland (2003) looked at six studies of seismic impacts on fish and concluded that fish avoidance behaviour generally occurred within 2 km of the sound source.

Under the same conditions described above, the sound level at which avoidance behaviour may be observed in most baleen whales (150 to 180 dB) corresponds to a distance of 2,150 to 19,790 m from the sound source. However, avoidance behaviour has observed for western gray whales off Sakhalin island in response to received noise levels of 163 dB at a distance of 24 km from the sound source (Gordon *et al*, 2004), although local conditions such as bathymetry and the sound intensity of the sound source, are not known in this example.

Figure 7.4 shows an estimation of the area impacted during an individual survey covering one licence block, for a period of approximately 10 days. The area indicated in the figure outlines the potential area of expected behavioural avoidance of whales and fish for a seismic survey covering one licence Block for a 10 day survey period. At present it is not known whether individual surveys would occur in adjacent areas simultaneously, consecutively, or whether or not they will be more spatially and temporally separated.

Figure 7.4 Potential area of 2D seismic survey and the outer boundary of behavioural avoidance reaction distances of fish and baleen whales



3D seismic survey

A 3D seismic survey differs from a 2D seismic survey in the fact that the survey boat will tow multiple streamers, effectively making up a dense grid of 2D lines. The maximum amount of 3D seismic data likely to be acquired in any one year within the IOSEA1 area is 3,000 km^2 (Table 4.1), comparing to an area roughly covering 13 licence blocks. As described above, it is very unlikely that such a large area will be covered in a single survey, and it is therefore expected such a survey effort will be spread out over a number of surveys.

Between 1997 and 2002 some 5,015 km^2 of 3D seismic data were obtained within the IOSEA1 area (PAD 2006b). This equates to roughly 836 km^2 per year, which is significantly less than the 1,000 to 3,000 km^2 per year envisaged for the period 2008 to 2010. The reason for this future increase in 3D surveys is advancing technology and decreasing costs making 3D surveys cheaper and hence more common.

Although the sound levels involved with 3D surveys are generally slightly lower than those generated from a single streamer array 2D seismic survey, the fact that there are more streamers present means that the overall amount of energy (in the form of sound) entering the marine environment will be higher. Therefore, it is generally assumed that the effects of 2D and 3D are more or less the same.

The complex seabed topography and current systems found in the IOSEA1 area mean that sound propagation from a seismic survey will also be complex. Noise may become focused in deep water layers, due to discontinuities such as the strong thermocline/halocline known to be present between 800 and 1,000 m water depth, and travel long distances (the SOFAR channel effect). Alternatively, noise may be reflected and refracted off the slopes as it radiates away from the sound source. Noise travelling from deep to shallow along an upwardly-sloping sea bed will increase the instances of surface and seabed sound reflection, leading to quicker noise attenuation. Sound is therefore likely to be propagated further in deeper water (>50 m) where there is less interference from reflecting surfaces (Turnpenny & Nedwell, 1994; Richardson *et al*, 1995).

7.2.5 Mitigation measures

Existing measures

Reducing the noise entering the marine environment is the main measure in minimising the impacts of seismic survey operations. Therefore, all seismic operations should use the lowest practicable power levels throughout the survey and only discharge pressure waves into the marine environment when necessary and after a suitable 'soft' start.

Under Section 2.1 of the Rules and Procedures (PAD, 2005a) applicants are required to submit an Application for Approval to PAD to conduct any Geophysical or other Exploration Survey, Site Survey or Route Survey prior to the planned commencement of the survey. This should include information on the specific impact mitigation and monitoring practices that will be applied during the survey in relation to marine mammals. Operators are required to ensure that current best industry practices are applied with regard to impact mitigation and monitoring measures in relation to marine mammals. Currently, best practice requires that a qualified and experienced Marine Mammal Observer (MMO) should be present on board the vessel emitting the sound (whether produced by multi-beam or an air-gun).

Guidelines have been proposed by NPW to minimise any potential impacts on marine mammals in Irish waters. These guidelines require a qualified and experienced MMO to survey the sea surface for the presence of cetaceans prior to the commencement of activities. The intensity of the survey effort, both the duration and survey area, will depend on water depth. If marine mammals are present, seismic operations will be delayed until the animals move out of range. The power in the air guns will be built up slowly over at least 20 minutes (but no longer than 40 minutes) to give marine mammals adequate time to hear the noise and leave the vicinity. This 'soft' start process should be adopted every time air guns are used, even if no marine mammals are seen, and if air guns have stopped and not restarted after five minutes.

In the event there is a requirement for multiple surveys in the same area and at the same time, it is advised these are combined into consecutive surveys through appropriate planning and cooperation. If surveys must be carried out simultaneously, consideration should be given to the location of surveys in relation to each other, so that marine mammals have the chance to avoid these areas where necessary and migration routes are not impeded. Seismic surveys tend to interfere with each other if carried out simultaneously and within 100 km of each other, so the issue of survey co-ordination in this respect should also meet this concern.

Potential additional measures

The timing and location of cetacean calving and migrations should be considered when planning a seismic survey, and if possible avoided. This will have to be assessed at a later stage, on a case by case basis, as current knowledge of these sensitivities is very limited and is still developing. At present, SOSUS data have indicated the possibility of a winter migration to the south along the Rockall Basin for humpback whales in late winter or early spring (Charif & Clark, 2000), although there is no indication yet of any returning northward migration, and animals of the same species also appear to be present in the offshore area throughout the year.

As fish eggs and larvae are most at risk from the impacts of seismic activities, sensitive fish spawning areas as (for which the current state of knowledge is illustrated in Figure 7.2, Section 5 and the Annex to this report) should be avoided at known breeding times. On the basis of information from Coull *et al* (1998), the most sensitive areas would be those used for spawning by herring during August and September along the coast of Donegal and Northern Ireland (Figure 5.13), which overlap into the Donegal Basin part of the IOSEA1 area. In addition, the slope seaward of the shelf break through the Slyne and Erris Basins (Figure 5.13) is a peak spawning area for both mackerel and blue whiting over the period April to June each year.

At present, guidelines for minimising survey impacts to cetaceans, such as those promulgated in the UK by JNCC, are followed on voluntary basis. In Ireland the NPW has issued a draft document *Mitigating Measures for Acoustic Surveys*. However, it is recommended that these guidelines be made a requirement for all seismic surveys. Supplementary to the MMO guidelines, sufficient MMO personnel should be available to cover shift working if appropriate. In addition, The use of passive acoustic monitoring devices (PAM) should be reviewed in a workshop by the relevant authorities, industry and specialists.

The impact of noise generated by seismic surveys on other users of the sea is generally not considered to be a significant issue, and is regulated through the normal process of notifying the appropriate authorities and liaising with the respective industry organisations where necessary.

7.2.6 Data gaps

Comparatively little is known about the numbers and distribution of marine mammals in the offshore environment, their use of the area and its resources, and their vulnerability to anthropogenic impacts of various types at different times of the year. Visual survey effort is currently limited offshore of the continental shelf break in autumn and winter due to poor weather conditions and reduced daylight hours. There is therefore a need for a strategic co-ordinated survey and monitoring programme based on good science. Irish scientists recently carried out a programme of acoustic monitoring to complement their broadscale visual surveys. It is recommended that such acoustic work be continued over a wider area and throughout the year.

Although it is evident that fish respond to sounds emitted from air guns, the measurements and full extent of their reactions are still unknown. Marine mammals also clearly react to seismic signals at ranges up to a few kilometres, although it is unsure whether their reactions indicate a negative effect or whether it just triggers a behavioural reaction, such as curiosity. Very little is known about the prevalence and significance of possible effects of anthropogenic sound on either fish or marine mammals. At present, much of the evidence is circumstantial, largely based on correlations between stranding events and major deployments of underwater noise in the adjacent area, emphasising the need for additional supporting evidence from the observation of physiological damage (IACMST, 2006). However, the study of these effects is currently an active field of research. As a result, the discussion of the effects within this section should only be considered as indicative.

7.2.7 Conclusions

Modelling indicates that baleen whales and fish may show some form of avoidance reaction up to approximately 20 and 11.5 km respectively from a seismic sound source of 248 dB (re 1 μPa). However, field research has indicated that these zones of avoidance behaviour may be extended under certain conditions. Individual animals might leave or avoid this area, but may be expected to return soon after operations have ceased. There is very little information on the effects of seismic noise on seals but, on a conservative estimation, the avoidance behaviour might be considered similar to that of baleen whales. It is expected that seismic shots will be heard by marine mammals and fish over a much wider area, but that no significant impacts will result.

The animals most likely to be affected by sound produced from the survey are baleen whales (blue, fin, sei, minke and humpback whales) beaked whales and seals, as it is believed that most toothed whale species are less affected by the sound frequencies used in seismic operations. In order to minimise any possible impacts on marine mammals, the use of the NPW guidelines should be mandatory, including the use of risk assessment in survey planning and the employment of MMOs to undertake visual monitoring during the survey and ensure that the survey is conducted in line with the NPW guidelines. The use of slow, soft starts of the air guns would also alert marine mammals to the impending full seismic activity and give them time to vacate the immediate area. PAM devices could be used to monitor the area for cetaceans during the survey, particularly in areas or times of peak sensitivity, and seismic operations delayed if marine mammals are detected.

The behavioural response shown by fish is to move away from the seismic survey sound sources temporarily. Research indicates that such movements are short lived and that the fish stocks will most likely return to the area after completion of the survey. Surveys should be planned to avoid known fish spawning areas and spawning times.

In conclusion, if the mitigation measures proposed here are adopted, the direct, short-term environmental impact of noise, from individual seismic surveys within in the IOSEA1 area, will be minimal. It should also be noted that the effects of multiple surveys taking place at the same time are not well understood and, where possible, the timing of each survey should be considered carefully in order to avoid surveys taking place simultaneously. For this reason it is recommended that simultaneous surveys should be separated by a distance of 100 km, so that marine mammals and fish have the chance to avoid these areas and migration routes are not impeded.

7.3 Atmospheric emissions

7.3.1 Introduction

With the prevailing and increasing concern over global warming, air quality and acidification, atmospheric emissions from the proposed seismic survey activity were judged to be of concern. Exhaust emissions from ships include air pollutants, greenhouse gases and ozone-depleting substances that entail risks to human health and the environment. Ships are fast becoming the biggest source of air pollution in the EU. In 2000, European-flagged ships emitted almost 200 million tonnes of carbon dioxide (Entec, 2002). This is significantly more than emissions from EU aviation. Sulphur dioxide (SO_2) and nitrogen oxide (NO_x) are responsible for acid deposition, which can be harmful to the environment, as well as particulate matter harmful to health. NO_x and volatile organic compound (VOC) emissions contribute to the formation of ground-level ozone harmful to health and to the environment. NO_x emissions contribute to environmentally damaging eutrophication. Carbon dioxide (CO_2) emissions contribute to global warming and climate change. In November 2002, the EC adopted an EU strategy to reduce atmospheric emissions from seagoing ships. The strategy reports on the magnitude and impact of ship emissions in the EU and sets out a number of actions to reduce the contribution of shipping to acidification, ground-level ozone, eutrophication, health, climate change and ozone depletion.

7.3.2 Estimation of atmospheric emissions arising from seismic survey scenarios

The results of emissions calculations for the seismic survey scenario, as outlined in Section 4, are shown in Table 7.4. These show that, on an annual basis, CO_2 production will amount to something in the order of 3,360 tonnes per year, or 16,180 tonnes over the duration of planned exploration activity. Each year, the atmospheric emissions will have a global warming potential (GWP) of 5,003 tonnes CO_2 equivalent, whilst the total seismic survey activity will result in a GWP of 25,014 tonnes CO_2 equivalent.

Atmospheric emissions from fuel combustion also generally have the potential to cause acidification of rain. The main contributors to this are the SO_2 and NO_x content of the fuels in use. The total acidification potential of the estimated annual emissions from seismic survey is 31 tonnes of SO_2 equivalent (Table 7.4), whilst that for the whole period 2006 to 2010 is almost 155 tonnes.

Table7.4 Predicted exhaust emissions (tonnes) and global warming potential (tonnes CO_2 equivalent) from the PAD forecast of IOSEA1 exploratory seismic survey

	Survey ship effort, per year (70 days)	Total survey vessel effort for 2006 to 2010 (350 days)
Fuel consumption (tonnes)	1,050.00	6,000.00
CO_2	3,360.00	19,200.00
CO	8.42	49.80
NO_x	38.22	218.40
N_2O	0.23	1.32
SO_2	4.20	24.00
CH_4	0.12	0.66
VOC	1.26	7.20
Global Warming Potential (tonnes CO_2 equivalent)	**5,002.84**	**25,014.20**
Acidification Potential (tonnes SO_2 equivalent)	**30.95**	**154.77**

Calculations according to UKOOA (1999) with default sulphur concentration in diesel of 0.2%.

7.3.3 Environmental impacts resulting from atmospheric emissions

Assessing the impacts of these potential emissions at a local level is difficult due to the nature of the offshore environment. The impacts are generally mitigated circumstantially by the open and dispersive environment offshore. Shipping in general is built and operated to standards that preclude significant impacts to the health of their crews, whilst other environmental receptors (eg flora and fauna) tend to be sparsely distributed and/or transient in the local area. Impacts at this level are therefore both difficult to measure and to distinguish from background variation. On this basis, it is more profitable to consider emissions impacts at a regional or wider scale.

At a national level, no data have been seen specifically for shipping emissions to the atmosphere in Ireland. However, the proportion of emissions from road transport in Ireland is currently seen as dominating the national transport emissions statistics (EPA, 2004). Transport in general accounted for 11.5 million tonnes CO_2 equivalent in 2002, of which road transport contributed 93%. Shipping in Ireland is therefore a minor component of emissions nationally at the present time, and the seismic survey emissions estimated on an annual basis, and cumulatively until 2010, is most likely in turn to be a very small proportion of this.

National emissions of SO_2 and NO_x, together the main emission components responsible for acidification, were 76,370 tonnes and 119,750 tonnes respectively in 2003 (EPA, 2003). Against this, the total SO_2 and NO_x emissions from 1 year of seismic surveys are insignificant, as are the amounts contributed from the total planned survey programme to 2010 (Table 7.4).

7.3.4 Data gaps

No data gaps have been identified in regard to atmospheric emissions.

7.3.5 Mitigation

Under existing legislation, MARPOL Annex VI sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone depleting substances. SOx Emission Control Areas (SECAS) have been established in the Baltic Sea, North Sea and the English Channel where more stringent controls on sulphur emissions are required. In these areas the sulphur content of fuel oil used onboard ships must not exceed 1.5% m/m, or ships must be fitted with exhaust gas cleaning systems or use any other technological method to limit SOx emissions.

Annex VI prohibits deliberate emissions of ozone depleting substances, which include halons and chlorofluorocarbons (CFCs). New installations containing ozone-depleting substances are prohibited on all ships. However, new installations containing hydro-chlorofluorocarbons (HCFCs) are permitted until 1 January 2020.

Annex VI also sets limits on emissions of nitrogen oxides (NOx) from diesel engines. A mandatory NOx Technical Code, which defines how this shall be done, was adopted by the Conference under the cover of Resolution 2.

The Annex also prohibits the incineration onboard ship of certain products, such as contaminated packaging materials and polychlorinated biphenyls (PCBs).

7.3.6 Conclusions

Atmospheric emissions will arise from seismic survey vessels involved in the activity following the current licensing round. Seismic vessel activity will be approximately double that seen on average since the early 1970s, but would be sufficiently supported by the equivalent of one or perhaps two vessels operating during the summer months from 2006 to 2010. The resultant emissions will not have any significant localised impacts to health or the environment due to the dispersive nature of the offshore environment. They will contribute to issues such as global warming, acid rain and air pollution, but given their relative scale in relation to existing shipping levels and emissions nationally and at a European level, are considered not to be significant.

While the emission levels likely to arise from implementing the Draft Plan are small, their acceptability overall needs to be considered in the context of the national energy policy, and national policy for the management of greenhouse gases and commitments to the EU and the Kyoto Protocol.

7.4 Physical presence

7.4.1 Introduction

Certain interactions between likely seismic activity and aspects of physical presence were judged to be negligible, including visual impact and impacts associated with ports and shore-based infrastructure. The IOSEA1 area approaches to approximately 30 km from the coastline at two or three points, and comes within 20 km of Tory Island off the northwest coast. The coastline includes areas of significant landscape and seascape value, such as Achill Island, Connemara, the Cliffs of Moher, the Burren and the Giant's Causeway, and any impact on lines of sight could be seen as detrimental. Generally however, seismic survey activities being undertaken offshore as part of the Draft Plan will be indistinguishable from other normal shipping and will also be of short duration. Similarly, the additional shipping associated with the anticipated seismic survey activity, ie one or two vessels operating over the whole of the IOSEA1 area per year, was judged to be insignificant against the existing background of shipping and port facilities. These aspects will therefore not be considered further.

The main interaction of seismic operations with the fishing industry, merchant shipping and military activities will be the physical presence of the survey vessel and streamers. Both fishing and seismic vessels have limited manoeuvrability when towing their gear.

The environmental issues identification process together with the scoping responses identified interference with other sea users (especially the fishing industry) due to physical presence of the seismic survey vessel and streamers as having the potential to have a moderate impact and should be considered further.

7.4.2 Seismic survey vessels and streamers

Acquisition of 2D seismic data requires the towing of a single streamer of between 3 to 12 km in length at around 5m depth. Surveys operate in a grid shape and therefore need turning area at the end of each line. 3D seismic surveys, however, tow a number of streamers in parallel and the length of streamers are shorter than for 2D seismic, around 3 km in length. In both cases whilst the survey is being undertaken, the survey vessel has limited capability for taking avoiding action in respect of other shipping, and other shipping will therefore need to keep clear of the survey vessel.

Fishing vessels will be unable to fish in the vicinity of a seismic survey and will therefore lose access to grounds in the survey area for the duration of the survey. The number of seismic survey days in a year for IOSEA1 are estimated at ~100 for 2D seismic in 2006 to 2007 and ~250 days for 3D seismic over 2008 to 2010 (Section 4.4.1). The maximum length of 2D seismic is forecast at 3,000 km and maximum area of 3,000 km^2 per year for 3D seismic (Table 4.1 in Section 4.1). This is likely to be met by one to two vessels working during the summer months each year and when compared to the total area of 25,100 km^2 for the IOSEA1 area, seismic surveys are unlikely to exclude shipping or fishing activities from significant areas for significant periods of time.

Whilst it is known that offshore pelagic and demersal fisheries operate on the continental shelf, slope and in the deep sea, involving vessels from many nations, up-to-date fishing effort data were not made available with which to quantify the likely interactions with the Draft Plan. Coull *et al* (1998) present maps indicating that both pelagic and demersal fishing effort over the IOSEA1 area is generally 'low', although effort increases to 'medium' in the area of the Donegal Basin in the case of demersal fishing (Section 5). Similarly, fishing effort using static gears is 'low' over the whole IOSEA1 area, but again tends to increase towards the east of the Donegal Basin and into Scottish waters (see Annex). However, the sightings data from the Irish Naval Service (Figure 5.2 of the Annex) indicate a significant level of fishing activity along the shelf edge west of Ireland by Irish and other EU fleets.

Shipping routes to and from the Atlantic follow the Irish/UK median line along the top of the IOSEA1 area. The current level of shipping overall is estimated at 8,768 vessels per year in the IOSEA1 area, and on average 27 vessels area likely to be within this area at any one time (Anatec, 2006; Section 5 and Annex). Whilst this is relatively light compared to other areas in Europe, this 'routine' shipping will be concentrated along the routes crossing the Donegal and Erris Basins in the northern half of the IOSEA1 area. In addition, there will be the unquantifiable 'non-routine' traffic such as fishing boats and recreational craft, much of which will be concentrated along the coast rather than offshore. The majority of the IOSEA1 area is used by the military for fleet and submarine exercises.

7.4.3 Data gaps

Up-to-date and location-specific fishing effort data with which to quantify the likely interactions with the Draft Plan.

7.4.4 Mitigation

The mitigation measures here relate to existing control measures and best practice.

The oil and gas industry operators are required to check in advance with the Maritime Safety Directorate, the MRCC of the Irish Coast Guard, and Sea Fisheries Control of the DCMNR that the proposed survey will not be carried out in an area and at a time that would conflict with legitimate shipping and fishing operations, including both floating and stationary gear, with consequential disruption of both such activities. In addition, in the case of a survey planned in an area of intensive fishing, discussions with Sea Fisheries Control of the DCMNR shall be initiated as early as possible, and, in any case, at least 45 days before the planned date in order that the implications can be fully considered. Marine Notices advertising such operations are published by the Marine Safety Directorate. Also marine navigation warnings are issued while the survey is taking place, for the duration of the survey.

According to the PAD Rules and Procedures Manual (PAD, 2005a), it is recommended best practice that a fisheries liaison officer, with a knowledge of fisheries local to the survey area, is onboard seismic vessels during survey work.

7.4.5 Conclusion

Redirection of fishing effort from one area to another nearby for the duration of a seismic survey is unlikely to affect fishing revenue significantly. Profitability of fishing operations is influenced by factors such as fish prices, stock levels, quotas and fuel costs. Any effects to the fishery are considered to be limited. The number of 2D and 3D seismic surveys that may be undertaken as a result of this Frontier Exploration Licensing round are comparatively few, the duration of the surveys is short, and therefore the impact of physical presence of the seismic vessel and streamers is not considered to be significant.

7.5 Accidental events

7.5.1 Introduction

Oil may enter the marine environment during seismic operations as a result of accidental streamer rupture or collision with another vessel. The most likely scenario is that of spillages of several hundred litres of kerosene-like oil entering the environment from a streamer parting whilst deployed. However, seismic survey vessels may have numerous streamers deployed containing several thousand litres of oil in each and the potential for larger volume spills cannot be ruled out. Accidental collision with another vessel and complete loss fuel inventory and streamer reservoir would be a worst case scenario. The risk of a collision with another vessel in the IOSEA1 area is considered to be very low due to generally low levels of routine shipping off the west coast of Ireland and relatively low commercial fishing effort (Section 5 and Annex).

7.5.2 Potential impacts of a hydrocarbon spill

A kerosene spill from streamer failure is the most likely source of a hydrocarbon spill. The quantities of oil spilled into the marine environment would be relatively low in all but a worst case scenario.

Any seabirds on the water surface would be potentially at risk from any slicks that form, although the extent of such a slick would be expected to be limited. Marine mammals are considered to be less vulnerable to fouling than seabirds, as they would be expected to move away from any oil pollution. However, marine mammals are believed to be more at risk from inhaling volatile elements in the oil, although these would generally evaporate rapidly from the slick.

The relatively low volumes of oil involved in most streamer accidents and light nature of the oil in the streamers means that it would quickly evaporate and disperse. Complete loss of fuel inventory and streamer reservoir would result in an oil spill of more significant impact. The fate of hydrocarbons in the marine environment and impacts on wildlife and other sea users are covered in more detail in Section 8.6.

7.5.3 Data gaps

No data gaps have been identified.

7.5.4 Mitigation

The mitigation measures here relate to existing control measures and best practice.

Selection of a survey contractor with demonstrable planned preventative maintenance procedures will lead to fewer emissions and equipment failures. In addition, training of staff at all levels in environmental awareness will encourage best practice.

A full risk assessment against accidental events should be performed as part of survey design.

Procedural controls, stemming from industry-standard guidelines and best practice procedures, will limit the possibility of accidental events. Quality procedures, incorporating the tenet of continuous improvement, apply and should be considered at the contractor selection stage.

7.5.5 Conclusion

The risk of a major accident, such as a collision with another vessel, causing the loss of the streamer oil reservoir and/or diesel fuel from the vessel is considered to be very low. Historical data suggest that small diesel spills of less than one tonne and streamer oil spills of several hundred litres or less will represent the most likely oil spill scenario. Impacts from these spills are likely to be very minor.