Seismic Surveys & Marine Mammals

Joint OGP/IAGC position paper

OGP 30 years
International Association of Oil & Gas Producers

IAGC
International Association of Geophysical Contractors

Executive summary

Exploration and production in the offshore arena are essential if worldwide demand for oil and gas is to be met. As an industry, we recognise and promote the importance of managing activities we undertake in the marine environment in a responsible manner.

Recently, possible impacts from sound on the marine environment due to human activities have received increased attention. This document considers the sound introduced into the marine environment as a result of seismic exploration and its potential effect on marine mammals.

Seismic surveys are routinely conducted in offshore E&P operations to define subsurface geological structure. They represent the only feasible technology available to accurately prospect for offshore hydrocarbon reserves.

The sound produced during seismic surveys is comparable in magnitude to many naturally occurring and other man-made sound sources. Furthermore, the specific characteristics of seismic sounds and the operational procedures employed during seismic surveys are such that the resulting risks to marine mammals are expected to be exceptionally low. In fact, three decades of world-wide seismic surveying activity and a variety of research projects have shown no evidence which would suggest that sound from E&P seismic activities has resulted in any physical or auditory injury to any marine mammal species.

Nevertheless, mitigation measures are commonly implemented to further reduce the level of risk of harm to marine mammals. These measures include 'soft-start' and monitoring for the presence of marine mammals prior to and during the seismic survey.

In cases where behavioral reactions could lead to biologically significant effects, additional mitigation measures may be designed to reduce potentially adverse effects. Such plans take into account both the particular sensitivities of the species, as well as the nature and scope of the planned operation. In this manner the mitigation measures incorporated are commensurate to the risk and are case specific.

It is apparent that there are areas where a deeper understanding of the effects of sound in the marine environment is needed. Such knowledge will allow for more precise determination of risk, and so help identify appropriate mitigation strategies. The E&P industry will continue to be committed to developing a sound scientific understanding of the impacts of our operations on marine mammals.

It is the E&P industry's position that with the application of risk based mitigation measures, seismic surveys have, and will continue to be, undertaken with little or no impact to marine mammals and marine life in general.

Introduction

The world's oceans are a key component of an integrated international economy. Today, offshore exploration and production (E&P) activity contributes roughly 30% of the world's oil and gas output. As such it represents a significant contribution to the global economy in terms of promoting economic growth, improving living standards, creating valuable jobs, and generating significant government revenues. Continued E&P activity in the offshore sector is important now and in the future.

At the same time, the marine environment is also a vital component of the global ecosystem. As such, all human activities carried out within this environment should be undertaken in an environmentally responsible manner.

Recently, possible impacts from sound on the marine environment due to activities such as shipping, defence activities, oil and gas E&P, fishing, tourism and recreation have received increased attention. This document considers the sound introduced into the marine environment as a result of seismic exploration and its potential effect on marine mammals.

In over three decades of world-wide seismic surveying, there is no evidence to suggest that sound from E&P seismic activities has resulted in any physical or auditory injury in any marine mammal species. Nor have research studies and operations monitoring programmes designed to assess the potential impacts from seismic surveys indicated any physical injury, or suggested behavioural effects leading to impacts on the viability of any marine mammal population. That being said, recent studies have shown that marine mammal hearing sensitivity may be temporarily jeopardised if exposed at intense levels such as those encountered very close to an operating seismic sound source. For that reason, seismic surveys are conducted with measures in place designed to protect animals from high exposure levels.

A comprehensive and effective approach to ecosystem management, basing guidance actions on consideration of all potential sources of impact, was recently recommended by the U.S. Oceans Commission in a report designed to advise on a coordinated and comprehensive ocean policy [ref. 1]. In the case of marine mammals, this would include non-sound related anthropogenic (resulting from human activities) impacts that result in several hundred thousand mortalities each year. Within such perspective, the Commission report characterises the impacts of ocean sound on marine mammals as a "high-profile, lower impact issue". However, the E&P industry recognises the need for enhanced understanding and effective risk-based mitigation due, in part, to the compromised population status of several marine mammal species, and their extensive use of sound as a primary sensing system for foraging, defence, and social interaction.

Sounds in the marine environment

Sounds in the marine environment can be categorised as either naturally occurring or anthropogenic in origin. Typically, any given sound has to be louder than the background sound level to be distinguished, and any measure of the background sound level at a specific location will contain contributions from both naturally occurring and anthropogenic sources.

There are many natural sources of sound within the marine environment. These are often categorised in terms of their intensity (measured or expressed in decibels, dB), pitch or frequency, and their duration (*eg* continuous or impulsive). Marine mammal vocalisations, wind, rain, waves, and marine life all contribute to relatively high levels of ambient sounds. Other natural events such as sub-sea volcanic eruptions and earthquakes, and lightning strikes can also produce transient high intensity sounds. Man-made sounds in the ocean results from activities including shipping, fishing, E&P activity, sonar (navigation, fishing, defence), sonic booms and construction.

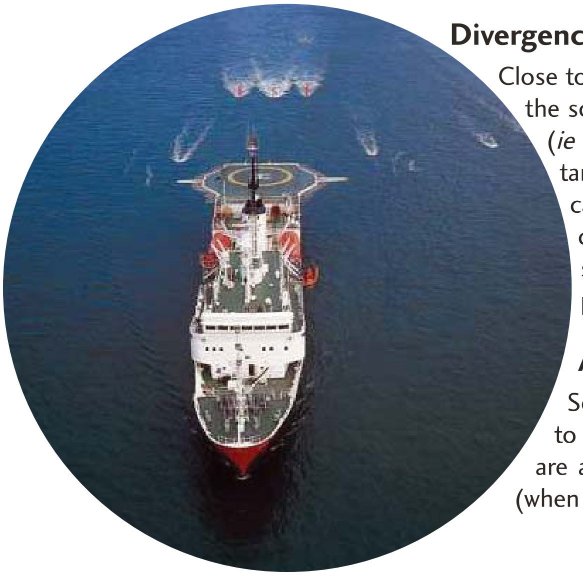
In Appendix 1, approximate source levels and frequency ranges are presented for a representative sample of both naturally occurring and anthropogenic sound sources. It can be seen that the sounds produced during E&P operations are comparable to levels of those occurring naturally in the ocean.

Ambient sound level

The ambient (background) sound level at a specific location consists of contributions from a range of natural and anthropogenic sound sources including wind and wave action, rain, distant shipping and marine life. It will vary with factors such as location, time of day, season and meteorological and oceanographic conditions. Typical received sound levels associated with ambient sound are in the range 80 to 120dB re $1\mu Pa^2/Hz$ over a wide frequency range, with much of the energy in the 2-200Hz frequency band.

Sound propagation

As sound propagates it changes due to a combination of divergence, attenuation and interaction with the seabed.



Divergence

Close to the source and in deep water, sound radiates from the source while the sound pressure level (SPL) decreases rapidly with increasing distance (*ie* spherical spreading where the SPL is inversely proportional to distance). In some environments, such as shallower water and at significant distance from the source, the SPL decreases at a slower rate (*ie* cylindrical spreading where the SPL is inversely proportional to the square root of distance). In practice the divergence must be computed as a combination of these two.

Attenuation

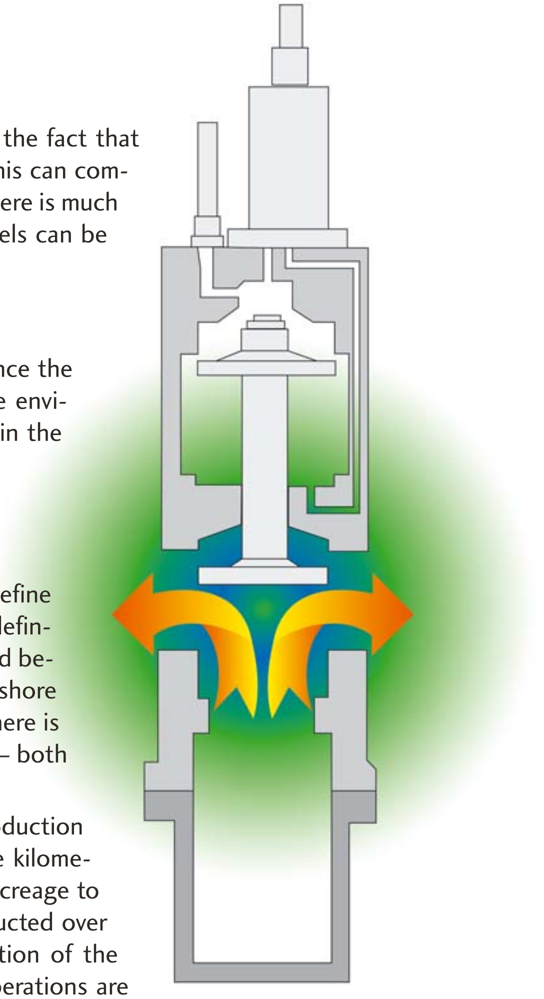
Sound is weakened (attenuated) due to scattering and from conversion to other forms of energy such as heat (absorption). Higher frequencies are attenuated more rapidly than lower frequencies. Attenuation losses (when expressed in dB) vary linearly with distance travelled.

Seabed effects

The propagation of sound in the marine environment is complicated by the fact that there is an interaction with the sediment and rocks below the seabed. This can complicate the simple mechanisms of divergence and attenuation. Although there is much uncertainty about the material properties of the seabed, computer models can be used to help estimate transmission loss where necessary.

Sound persistence

The nature of the sound associated with seismic activities is such that once the survey is complete then its contribution to the sound within the marine environment is removed. Transient sounds of this nature do not accumulate in the marine environment.



Seismic surveys

Seismic surveys are routinely conducted in offshore E&P operations to define subsurface geological structure. The use of seismic data is essential for defining drilling locations. Currently, using the seismic survey method described below is the only feasible technology available to accurately prospect for offshore hydrocarbon reserves. The aim is to prevent drilling “dry holes” (where there is no oil or gas present) and avoid inefficient recovery from producing fields – both of which may carry significant environmental costs.

Seismic surveys can be broadly categorised as exploration related or production enhancing. In the former, large areas – often several thousand of square kilometres in extent – are surveyed, usually as a pre-cursor to licensing of the acreage to the oil and gas companies. For the latter, much smaller surveys are conducted over known reservoirs or producing fields. In both cases, however, the duration of the survey in any one specific geographical location is very short. Survey operations are normally conducted at approximately 4.5 to 5 knots (~9km/hour). Thus the sound from the seismic source, which is typically operated every 10-15 seconds, does not persist in any one location.

The length of time taken for a survey varies depending on prevailing weather conditions, time of the year in which the survey is being conducted, the size of the survey itself, technical specifications and operating parameters, as well as the precise streamer/source configuration chosen. For a large exploration 3D (three-dimensional) survey in the North Sea during the summer, a daily survey rate of 25-30km^2/day would be a reasonable average. In West Africa this would increase by up to a factor of 2, primarily due to better weather/sea state. For a typical production related survey, which might only comprise 100 to 150km^2, the daily survey rate might drop to around 10km^2/day.

As the target geological features lie deep within the earth, the energy of the seismic source is predominantly composed of low frequencies (5 to 200Hz) that are able to travel farther with less attenuation. Approximately 98% of all the acoustic energy in a seismic pulse is within this band. The seismic source geometry is designed to focus the output from the array vertically downwards because any horizontally propagating sounds will constrain the ability to detect and record the very low amplitude signals as they are reflected back from the rock layers in the subsurface.

In modern marine seismic surveys, as many as 16 ‘streamers’ (cables containing the hydrophones used to detect the sound reflected from the subsurface) are towed behind the seismic vessel, at a depth of 5 to 10m. Each cable can be as long as 8-10km and is usually towed 50-100m away from its neighbours.

In addition to these streamers the vessel tows either one or two seismic source arrays comprising a number of airguns. Each airgun releases high pressure (2000psi) air into the water, forming a bubble that initially expands and subsequently collapses. By combining in each source array different airgun volumes that have different natural frequencies, the output of the array is “tuned” so that the oscillations which arise when a single airgun is operated are cancelled out to form a source pulse which has a duration of only a few tenths of a second.

The use of multiple streamers improves operational efficiency enormously compared to seismic operations conducted ten years ago. For each source array, the volume of seismic data is multiplied by the number of streamers towed, hence the area covered from a single source pulse is much greater than that obtained with a single streamer. Thus, with 16 streamers, the number of source pulses needed to record data over a given area is 16 times less.

Potential effects of sound associated with seismic activities on marine mammals

Effects from sound on marine mammals can generally be categorised as physical or behavioural. It is widely accepted that the auditory system is the most sensitive to physical damage from sound pressure. Therefore, mitigation strategies aimed at preventing auditory damage, should offer protection against other forms of physical impacts (*eg* tissue damage).

Physical (auditory) effects

Physical auditory impacts can occur from exposure to intense sound and may result in a loss of hearing sensitivity. Temporary threshold shift (TTS) is hearing loss that is subsequently recovered. It is sometimes referred to as "rock concert syndrome": the short-term loss in hearing sensitivity experienced by humans after exposure to loud music. The severity of TTS is expressed as the length of time that hearing is impaired, and the magnitude of the "shift" in hearing sensitivity (expressed in dB) as a result of the exposure, relative to pre-exposure. Normally, TTS is not considered physical injury.

There is no agreement as to what level of hearing threshold shift and time to recovery would present unacceptable risk to a marine mammal. Studies on dolphins and beluga whales (both odontocetes/toothed whales) suggest that TTS may depend on both the sound intensity and the length of exposure, as well as the spectra of the exposure sound relative to the frequencies of best hearing for the animal. Research using waterguns (which create impulsive sound very similar to airguns) has found that masked TTS (MTTS–TTS in the presence of background noise) did not occur in a beluga whale until exposure levels of 226dB re 1µPa (peak to peak) were reached [ref. 2]. In the same study a bottlenose dolphin experienced no MTTS up to the highest level tested of 228dB re 1µPa (peak to peak). This sound exposure level would only be realised within a few tens of metres of a typical airgun array.

Auditory injury occurs when the hearing sensitivity of an animal is permanently altered (permanent threshold shift, or PTS). This is a natural process of ageing but could also be induced by exposure to sound. There is growing concern that physical injury, including auditory impairment, may occur at very intense exposure levels, and that sound induced physical injury may lead to the direct mortality of individuals. Generally PTS will occur only after repeated TTS episodes, or exposure to higher levels of sound than cause TTS. Since normal mitigation strategies during seismic operations prevent exposure sufficient to cause TTS, the likelihood of PTS occurring is extremely remote.

While additional research is needed to expand our understanding of the effects of intense sounds on marine mammals, it is clear from the best available scientific information that the levels that will result in injury to animals may be much higher than previously thought (*ie* greater than 180 dB re 1µPa rms). Regulations and mitigation plans incorporating safety zones to prevent physical injury should base safe distances on this information. This is particularly applicable if odontocetes are the animals of primary interest, but may also be more broadly applied with safety factors used to account for uncertainty in extrapolating results across different species.

Behavioural effects

For sound to elicit a behavioural reaction, an animal must be able to hear the sound. To some extent, the dimension of a behavioural reaction will depend on the frequency and magnitude of the signal relative to the best hearing range of the animal, as well as the context of the stimulus. Context includes such factors as the activity the animal may be engaged in, previous exposure to the same signal and any experience associated with that exposure, and the characteristics of ambient sound at the time of exposure.

To determine the significance of a particular behavioural reaction, the potential for that reaction to culminate in changes to key parameters that may impact the viability of the population must be assessed. Populations can be characterized in terms of general parameters (*eg* abundance, density, immigration and emigration rates, age and sex composition) that interact in complex ways to determine the population's health. For long-lived species such as marine mammals, population sustainability is most sensitive to survival and reproductive rates. As such, effects on individuals or groups of individuals must be carefully considered however, the management of wildlife resources remains grounded in protection at the population level. Therefore, in assessing potential environmental impact, evaluation of the risk due to behavioural reactions must be based on the degree of impact to these key parameters termed "vital rates", or equivalently, on the viability of the population.

Perception – can the sound be heard?

Not all marine mammals hear the same frequencies equally well. Analogous to the differences in hearing between humans and bats or dogs, some marine mammals hear well at higher frequencies, and relatively poorly at lower frequencies. Others hear better at lower frequencies.

Seismic sound energy is focused in the frequency range below 200Hz. In general, mysticetes (baleen whales) are expected to be more sensitive to low frequency sound than odontocetes. To date, direct scientific data on cetacean hearing is limited to ten odontocete species. Scientists are currently working to develop models to infer hearing sensitivity from ear anatomy and vocalisation spectra. Based on the available information, it is generally accepted that the majority of odontocetes have peak sensitivities in the ultra sonic range (>20kHz) although most may have moderate sensitivity to sounds from 1 to 20kHz. While some functional hearing may be present, no odontocete has been shown to have best hearing sensitivity below 500Hz. Although no mysticete has been directly tested for hearing ability, their vocalisations are significantly lower in frequency than odontocetes (rarely above 10kHz) and models predict the upper functional range may extend to 20-30kHz. Several species, including blue, fin and bowhead whales are predicted to hear at infrasonic frequencies as low as 10-15Hz.

Reaction – how does the marine mammal react to the sound?

Marine mammals may react to sound by changes in dive patterns, changes in blow rate, shifts in migration routes, disruption of mating or foraging, proximity avoidance, or displacement from normal habitat. Perceptual disruption, due to masking of biologically useful vocalisations between animals of the same species, or for navigation, and/or use of sound for foraging or predator avoidance, may also be of concern. In many studies, observations have shown statistically significant changes in subtle behavioural patterns due to exposure to sound

however, in order to assess the significance of the disruption it is necessary to relate such changes to changes in vital rates as discussed previously.

The most commonly noted and obvious behavioural reaction to seismic activity is proximity avoidance. This small-scale avoidance behaviour can in fact be beneficial, as it reduces the risk for auditory trauma by deterring the animal away from areas of high exposure. The transient nature of seismic surveys and their small footprint relative to the range of many marine mammals reduces the significance of habitat abandonment to small scale, short term effects. As yet, there is no accepted scientific "transfer function" that can establish a link between observed behavioural effects and impacts on vital rates.

However, after more than 30 years of E&P seismic surveying using compressed air as the acoustic source, no evidence exists to suggest that seismic activity has resulted in any physical or auditory trauma, or behavioural effects leading to impacts on the viability of any marine mammal population. Industry continues to monitor the effectiveness of the mitigation strategies it employs, while funding research to better understand interactions between E&P operations and marine mammals.

Strandings

Natural occurrences of stranded marine mammals have been documented for many centuries, with records dating from the 7th century. It is estimated that more than 10,000 whales, dolphins, and porpoises have stranded worldwide since the British Museum of Natural History first started keeping records in 1913. Systematic records from other parts of the world began mainly in the mid 1970s, although most areas have anecdotal evidence going back many centuries.

Stranding records are used to build up a picture of why strandings occur. They can indicate causes of death and suggest what can be done to help reduce the number of marine wildlife that strand. Strandings can occur for a number of reasons, *eg* sickness, disorientation, natural mortality, extreme weather conditions or injury. Winter can be a critical time for strandings.

Although it has been hypothesized that seismic activities may lead to strandings, no correlation has been found. However, there is concern that mid-frequency military sonar systems may be implicated in recent beaked whale strandings. It is important to recognise that there are significant differences between these sonars and the sound sources used for seismic surveys, in particular, the frequency and duration of the signals, as well as the downward focus and the transient nature of the seismic surveys. Research is continuing on the effects of mid-frequency sonar on marine mammals.

Other marine life

Marine mammals are unique in their extensive use of sound as a primary sensing system for foraging, defence and social interaction, and the degree to which these functions may be affected at relatively large distances. Results from studies on other marine species have been primarily associated with physical impacts that can occur only at very high exposure levels (*eg* damage to fish larvae, or fish auditory system injury within a few metres of the sound source). Given such a small zone of impact and avoidance behaviours of mobile species, it is highly unlikely that a towed seismic array near the surface could physically impact significant numbers of any species.

Managing seismic surveys

The oil and gas industry is committed to conducting its operations in an environmentally responsible manner and abiding by all laws and regulations. In over three decades of world-wide seismic surveying activity, there is no evidence to suggest that sound from E&P seismic activities has physically injured any marine mammal or impacted the viability of any marine mammal population.

Industry supports a process of developing mitigation measures based on assessing the level of risk of significant impacts to marine mammals. Within this process mitigation measures may be identified to reduce the likelihood of marine mammals being adversely affected by the sound from a seismic survey. The advantage of this approach is that the scope of mitigation measures will be commensurate to the risk and specific to the local population of marine mammals and operation being undertaken.

In the base case, the most significant potential risk to marine mammals from seismic activities is exposure to high sound levels such as those found very close to an operating array. The following considerations are key in assessing potential risk in this case:

- the maximum sound pressure level produced by a seismic source relative to levels expected to result in injury;
- the small exposure area for high-received sound pressure levels, and the non continuous nature of the source;
- the mobility of marine mammals and evidence that many (especially cetaceans that have low frequency hearing specialities) may avoid seismic vessel activities [ref. 3]; and
- the temporary nature of seismic surveys and their small footprint relative to typical cetacean range.

Therefore, the risk of injury to marine mammals as a result of sound emitted during seismic surveys is expected to be very low.

Nevertheless, mitigation measures are commonly implemented, where feasible, to further reduce the level of risk. These measures include:

- Soft-start, also sometimes called ramp-up or slow build-up. This involves a pre-start-up visual observation to determine that no mammals are present within the safety zone, followed by the gradual increase in the source sound pressure from some basal level to full operational levels. The soft-start procedure reduces the chance that an animal will be close to the source when turned on, and allows time for the animal to move away, thus avoiding exposure to higher sound levels.
- Monitoring for the presence of marine mammals. This is conducted prior to the soft-start of the seismic source and continues for the duration of seismic operations.

In cases where behavioural reactions could lead to biologically significant effects, such as operations in close proximity to recognised baleen whale breeding or calving areas or critical migration corridors, additional mitigation measures may be designed to reduce potential adverse effects. Such plans take into account both the particular sensitivities of the species (*eg* population status, auditory system sensitivities, activity) as well as the nature and scope of the planned operation. In this manner the mitigation measures incorporated are commensurate to the risk and are case specific. Examples of mitigation methods that have been utilized during seismic activities include:

- buffer zones around critical habitats and operations timed to avoid crucial whale activities;
- safety zones with delay or sound source shut-down procedures in the event of close approach by whales; and
- enhanced visual monitoring plans using trained marine mammal observers or additional monitoring mechanisms.

By incorporating basic mitigation measures as standard operating procedure and, where warranted by assessment of risk, enhancing protection with additional measures, the oil and gas industry has demonstrated the ability to operate seismic exploration activities in a manner that protects marine mammals.

Future technology

Passive acoustic monitoring (PAM) systems detect marine mammals in real-time using hydrophones and computer programs to identify and track specific vocalising animals. PAM has been successfully used to detect and locate cetaceans from large, fixed, seafloor arrays of hydrophones and to detect them from hydrophones towed behind seismic survey vessels. It has also been used to record vocalisations and advise vessel based researchers of the presence of animals. In low visibility conditions, PAM may increase cetacean detection rates compared to visual methods alone. However, its capability as a mitigation tool currently has limitations such as:

- Mammals can only be detected if they are vocalising.

- Accuracy of bearing and particularly range is limited in towed systems.
- Limited number of species detectable, partly due to limited vocalisation database – operator interpretation is sometimes required to supplement auto-detection.
- Detection range is dependent on acoustic background noise levels.

It also requires some consideration of operational procedures and issues such as:

- Communications between PAM, existing visual efforts and seismic operation are important for effective mitigation.
- Choice of deployment platform during seismic surveys (seismic/guard vessel) depends upon various technical, operational and, sometimes, regulatory issues.
- Need for operational procedures in order to integrate the use of PAM systems with the overall seismic operation.

Although PAM is currently in use on a small number of surveys, to warrant its application as a mitigation tool, there is a need to improve the confidence with which it detects, locates and tracks vocalising mammals. Therefore industry is currently supporting further investigations into the feasibility of using for this technology as a mitigation measure during seismic surveys.

Conclusion

Exploration and production in the offshore arena are essential if worldwide demand for oil and gas is to be met. However, as an industry we recognise and promote the importance of managing activities we undertake in the marine environment in a responsible manner.

Seismic surveys are undertaken with due regard to the marine environment and, based on both available scientific knowledge and operational experience, there is no evidence to suggest that the sound produced during an oil and gas industry seismic survey has resulted in any physical injury. Nor have research studies or operations monitoring indicated any physical impacts, or suggested behavioural effects leading to impacts on the viability of any marine mammal population. The nature of the sound produced during seismic surveys and standard operational protocols are such that the risks to marine mammal species are expected to be exceptionally low.

It is apparent that there are areas where a deeper understanding of the effects of sound in the marine environment is needed. Research aimed at improving knowledge of the hearing sensitivities of different species, or to characterise the parameters specific to a given scenario (*eg* type of survey, environmental conditions, species present) will allow for more precise determinations of risk, and so help identify appropriate mitigation strategies. The E&P industry will continue to be committed to developing a scientific understanding of the impacts of our operations on marine mammals.

In conclusion, it is the E&P industry's position that with the application of risk based mitigation measures, seismic surveys have, and will continue to be undertaken with little or no impact to marine mammals and marine life in general.

Appendix 1: Sounds in the marine environment

Individual, identifiable sound sources	Source level as given by original ref. dB re 1µPa-m	~Source level dB re 1µPa-m (rms)	Frequency band of major amplitude	Normal duration	Directionality	Ref.
Naturally Occurring Sounds						
Undersea Earthquakes	272 Peak	269[A]	0.1-20Hz	10's of seconds to minutes	Omnidirectional	4
Volcanic Eruptions	255 Peak	252[A]	Broad band	Seconds to hours	Omnidirectional	5
Lightning Strike	260 Peak	248[B]	Very broad band	µs to s	Omnidirectional	5
Sperm Whale Click	236 rms	236	5-40kHz	10's of µs	Focused	6
Bottlenosed Dolphin	225 P-to-P	207[C]	Very broad band in kHz range	70µs	Focused	7
Killer Whale	224 P-to-P	206[C]	12-80kHz	80-120µs	Focused	8
Mysticete Moans	190 rms	190	10-25Hz	10's of seconds	Omnidirectional	9
Individual Snaps of Snapping Shrimp	189 P-to-P	171[C]	Broad band inc. up to 200kHz	ms	Omnidirectional	9
Anthropogenic Sounds						
10 lbs. Of TNT	279 Peak	267[B]	Very broad band	ms	Omnidirectional	10
7900 Cubic-Inch Air-gun Array	259 Peak	247[B], 235[E]	5-500Hz	30ms	Vertically focused	11
M/V Ewing Multibeam Sonar	237 rms	237	15.5kHz	50ms	Vertically focused	12
U.S. Navy 53C Mid-Range Sonar	235 rms	235	Center freq. of 2.6 & 3.3kHz	Variable, 0.5s over 2s period	Horizonatally focused	13
Echosounders	235 Peak	223[B]	Variable 1.5-36kHz	A few ms	Strongly vertically focused	14
SURTASS LFA	235 Peak	232[B]	100-500 Hz	6-100s	Horizontally focused	5
GLORIA-type Sidescan sonar	228 Peak	225[A]	6-7kHz	Continuous	Vertically focused	15
Heard Island Test	221 rms	221	57Hz		Omnidirectional	16
Single 30 Cubic-Inch Air Gun	221 Peak	209[B]	10-600 Hz	60ms	Omnidirectional	17
Acoustic Deterence/Harassment Devices	205 rms	205	8-30kHz	Variable 15-500ms	Omnidirectional	18
M/V Ewing Sub-bottom Profiler	204 rms	204	3.5kHz	1, 2, or 4ms	Vertically focused	12
ATOC Source	195 Peak	192[A]	~55-95Hz	20 min.	Omnidirectional	19
Supertanker	190 Peak @6.8Hz	187[A]	6.8Hz	Weeks	Omnidirectional in vertical plane	11
Pile Driving	135 Peak @1km	153[BD]	30-40Hz & 100Hz	Days	Omnidirectional	11

A Calculated value based on using the standard approximate sinusoid difference between peak and rms value of 3dB for a long continuous signal.

B Calculated using the empirically derived -12dB found by Greeneridge Sciences between peak and rms values for short impulsive sounds without regard to duty cycle.

C Calculated using the empirically derived -18dB found by Greeneridge Sciences between peak-to-peak and rms values for short impulsive sounds without regard to duty cycle.

D Back-calculated assuming cylindrical spreading, and applying the empirically derived -12db found by Greeneridge Sciences between peak and rms values for short impulsive sounds.

E The second value (235dB) for the 7900 cubic-inch air-gun array is the maximum pressure actually input in the water. The first value (247) is the back-calculated value assuming the array is a point source.

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About IAGC

The International Association of Geophysical Contractors (IAGC) is the international trade association representing the industry that provides geophysical services (geophysical data acquisition, seismic data ownership and licensing, geophysical data processing and interpretation, and associated service and product providers) to the oil and gas industry.

IAGC members provides services to the oil and gas industry throughout the world; both onshore and offshore.

IAGC's mission is to optimize the business climate and commercial health of the geophysical industry, and to promote the conduct of business in a professional, safe and environmentally responsible manner.

IAGC's vision is to be a focused, efficient, and effective international trade association, adding value through commercial and government advocacy, and the development and promotion of standards and best practices.

About OGP

The International Association of Oil & Gas Producers (OGP) encompasses most of the world's leading publicly traded, private and state-owned oil & gas companies, oil & gas associations and major upstream service companies. OGP members operate in more than 80 different countries and produce more than half the world's oil and about one third of its gas.

The association was formed in 1974 to develop effective communications between the upstream industry and an increasingly complex network of international regulators.

OGP works with its members to achieve continuous improvement in safety, health and environmental performance, and in the engineering and operation of upstream ventures.

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