9.0 POTENTIAL IMPACTS AND MITIGATION – BIOPHYSICAL ENVIRONMENT

Potential sources of impacts to the biophysical environment include the following:

- Underwater noise from seismic sound sources (**Section 9.1**);
- Vessel movements (**Section 9.2**);
- Air emissions and effluent discharges (**Section 9.3**); and
- Accidental events, such as a fuel spill (**Section 9.4**).

9.1 UNDERWATER NOISE

Seismic sound sources use a burst of compressed air to create an acoustic pulse. Most of the sound energy propagates downward toward the seafloor (**Figure 9-1)**; however, some of the sound does propagate laterally.

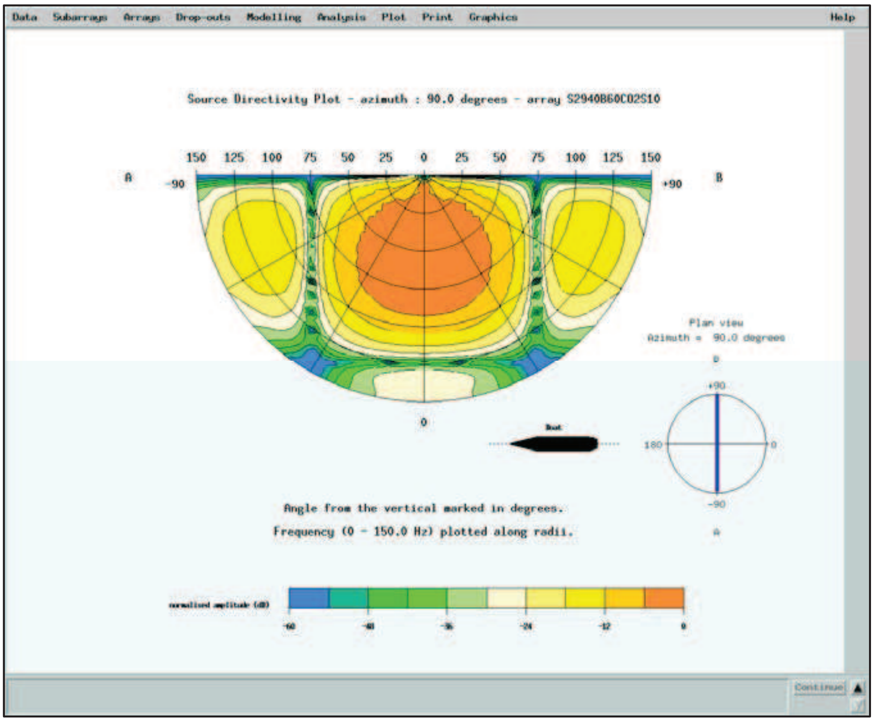

Figure 9-1. Example of a source directivity plot for sound energy released from a seismic sound source.

A detailed description of seismic source levels and propagation is provided in **Volume III**, **Part C**. The proposed source consists of a pair of arrays that will be fired in alternation, such that one array is fired while the second recharges. Each array consists of 36 sound sources (three strings of 12 sources), 6 of which are spares. The firing pressure of each sound source is 2,000 psi. Volumes of individual sound sources range from 40 to 250 in^3, for a total active volume of 3,460 in^3. The outer dimensions of the array are 16 m x 21.5 m, and the tow depth will be 5 m. The peak source level of the array in the downward direction is

243 dB re 1 µPa at 1 m. **Figure 9-2** shows predicted pressure signatures and frequency spectra. Most of the energy is concentrated in the frequency range below 200 Hz, although energy is emitted over a wide range of frequencies, from under 10 Hz to over 5 kHz.

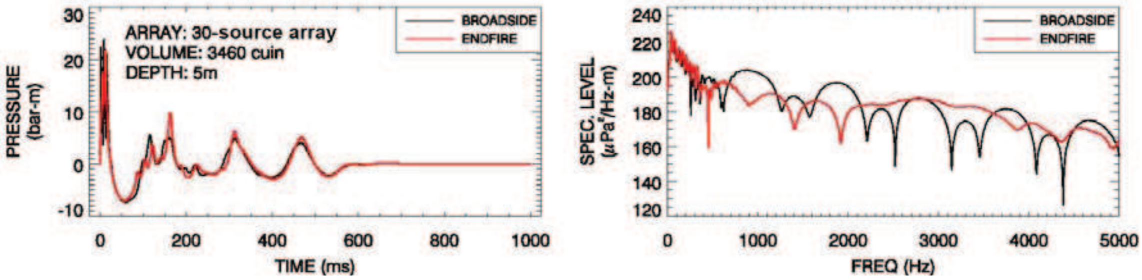

Figure 9-2. Predicted broadside and endfire (along the axis of the array) pressure signatures, with associated frequency spectra, for the seismic array planned for use in this project.

This high-energy sound has the potential to harm marine animals, particularly if they swim immediately beneath the source. While death or serious injury is unlikely, marine mammals, turtles, fishes, or other organisms may experience temporary or permanent auditory trauma if they are very close to a seismic sound source operating at full power. Beyond a few hundred meters laterally from the source, auditory trauma is unlikely, but behavioral effects (e.g., avoidance) may result. The biological importance of such behavioral responses is not well understood.

The following subsections discuss underwater noise impacts on marine mammals, turtles, fishes, plankton, and benthic invertebrates. Auditory safety issues relative to human divers also are briefly addressed; social impacts on recreational diving are discussed separately in **Section 10.0**.

Acoustic modeling was done for nine locations as described in **Volume III**, **Part C** (see **Figure 9-3**). The model results were used to estimate the areal extent of acoustic impacts and aid in the development of mitigation, including safe ranges.

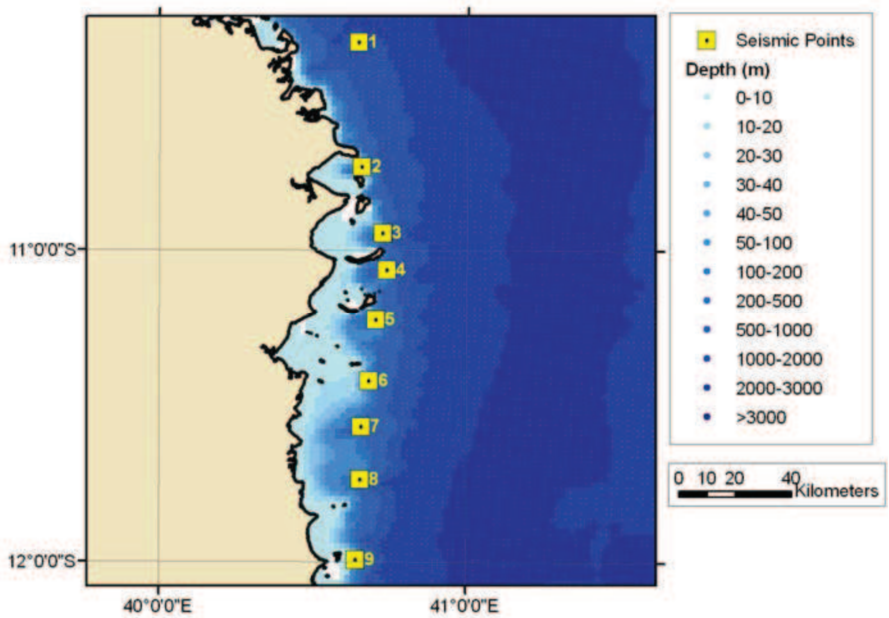

Figure 9-3. Locations selected for acoustic modeling in **Volume III**, **Part C**.

9.1.1 Impacts on Marine Mammals (Dugongs, Whales, and Dolphins)

Potential impacts of seismic surveys on marine mammals have been reviewed extensively (Richardson et al., 1995; Davis et al., 1998; Gordon et al., 1998; High Energy Seismic Survey [HESS] Team, 1999; Stone, 2003; Continental Shelf Associates, Inc., 2004). The key findings are as follows:

- There have been no documented instances of deaths or physical injuries to marine mammals from seismic surveys.
- There is a risk of temporary or permanent auditory trauma within a range of a few hundred meters of a typical seismic sound source. This range depends on a variety of factors, including the size and configuration of the array, water depth, receiver depth, seafloor characteristics, and the density structure of the water column.
- Behavioral responses have been observed in many instances, primarily in mysticetes (baleen whales, including the humpback whale). However, the biological importance of such behavioral responses to underwater noise has not been determined (Ocean Studies Board, 2003).

While the risk of auditory trauma depends on proximity to and length of time in the proximity of the sound source, behavioral responses may occur at distances of many kilometers and are not necessarily predictable from the loudness of the sound source. Also, behavioral responses may vary depending on factors such as the age and status of the animal, the type of activity it is engaged in, and the social context (McCauley et al., 2000).

Baleen whales, such as humpback whales and Bryde's whales, are believed to have good hearing in the low-frequency range produced by seismic surveying, meaning the noise would seem loud to them. Toothed whales and dolphins generally are thought to be less sensitive to low-frequency noise. However, behavioral responses to seismic survey noise have been observed in both groups.

Dugong hearing has not been studied, but some data are available for a related species, the West Indian manatee. According to Gerstein et al. (1999), hearing thresholds range from about 0.4 to 46 kHz, but the frequency range of best hearing is between 6 and 20 kHz. Similar ranges were reported by Mann et al. (2005). Therefore, most of the low-frequency noise from seismic surveys probably would be below the best hearing range of dugongs.

Auditory Trauma

In humans and terrestrial mammals, exposure to high levels of sound can cause a temporary elevation of the hearing threshold known as a temporary threshold shift (TTS) (Richardson et al., 1995). Prolonged or repeated exposure to sound levels sufficient to induce TTS without recovery time eventually leads to a permanent threshold shift (PTS), or permanent hearing loss.

Finneran et al. (2002) conducted TTS experiments with one dolphin and one white whale exposed to sounds generated from a seismic source. TTS was observed in the white whale after exposure to single impulses with a sound exposure level (SEL) of 186 dB re 1 µPa^2•s. The white whale's hearing returned to normal within 4 minutes of exposure. No TTS was observed in the dolphin at an SEL of 188 dB re 1 µPa^2•s. These experiments involved single pulses; animals exposed to multiple pulses would be expected to experience TTS at lower SELs, but this has not been quantified.

Acoustic modeling indicates that an SEL sufficient to cause TTS in marine mammals (i.e., 186 dB re 1 µPa^2•s or greater) could occur within about 128 m of the array center (**Table 9-1**). At this range, the array cannot be approximated as a point source, and the actual received sound level at any given point will depend on the proximity to larger or smaller individual seismic sources.

The U.S. National Marine Fisheries Service (NMFS) currently uses a criteria of 180 dB re 1 µPa (rms) for "Level A harassment" (essentially, onset of auditory trauma). This criterion is based on sound pressure level (SPL) rather than energy (e.g., SEL is an energy unit). The equivalent SEL is about 173 dB re 1 µPa^2•s. Based on the preceding discussion of TTS measurements, the 180 dB SPL criterion is believed to be very conservative for the onset of auditory trauma in marine mammals. Use of this criterion implicitly takes into account the risk of exposure to multiple pulses that individually might not cause TTS. Acoustic modeling indicates that an SPL of 180 dB re 1 µPa (rms) could extend 327 to 507 m from the array center. Including a 5 dB correction for uncertainty in the model predictions, the 180 dB range would extend 616 to 850 m from the array center (**Table 9-1**).

Table 9-1. Acoustic modeling results.[a]

Modeling Site	Water Depth (m)	Range (m) for Potential TTS (186 dB re 1 µPa^2•s)	Range (m) for NMFS Criterion (180 dB re 1 µPa (rms))	
			Model Prediction	With 5 dB "Uncertainty Correction"
1	950	109	347	616
2	170	112	428	849
3	150	110	441	759
4	330	110	327	662
5	180	108	424	811
6	100	112	507	672
7	220	110	418	850
8	100	114	475	672
9	50	128	379	631

[a] Ranges are based on the maximum broadside radius, which is the radius of a 60° angular sector centered on the broadside axis of the array that encompasses all points where the received level would be equal to or greater than the threshold value.

The ranges in **Table 9-1** are most applicable to mysticetes (baleen whales), which are believed to have good low-frequency hearing. Odontocetes (toothed whales and dolphins) are probably at less risk for auditory trauma because of the high hearing threshold (i.e., poor hearing) of odontocetes in the less than 200 Hz frequency range, where most of the energy from seismic pulses is concentrated (Goold, 1996). Dugongs probably also are at relatively low risk, as their frequency range of best hearing is believed to be between 6 and 20 kHz (Gerstein et al., 1999).

Auditory Masking

Auditory masking occurs when sound signals important to a marine mammal (e.g., sounds associated with echolocation, communication, and environmental sounds cues) are blocked or interfered with (Richardson et al., 1995). In the case of seismic surveys, the potential masking noise consists of a pulsed form with a low cycle rate (approximately 10% or a 1-sec disturbance in every 10 sec of ambient noise). Davis et al. (1998) considered the effect of masking resulting from marine seismic operations to be of little consequence due to the low cycle rate of seismic pulses relative to continuous sounds, such as ship noise.

Behavioral Effects

A number of studies have documented behavioral effects of marine mammals in response to seismic surveys (Richardson et al., 1995; McCauley et al., 2000; Stone, 2003; Holst et al., 2006; Miller et al., 2006). However, it is unclear how the behavioral changes may affect the mammals' long-term health (Ocean Studies Board, 2003).

Stone (2003) reported that during seismic surveys in United Kingdom waters, several dolphin species were seen less frequently when seismic sound sources were firing than when they were not firing. In addition, baleen whales, killer whales, and all of the small odontocetes were farther from large source arrays during periods of active operation than when the sources were silent. In general from these data, small odontocetes showed the strongest avoidance response to seismic activity, with baleen whales and killer whales showing some localized avoidance, pilot whales showing few effects, and sperm whales showing no observed effects. Different groups of cetaceans may adopt different strategies for responding to acoustic disturbance from seismic surveys (Stone, 2003).

Baleen whales are believed to hear well in the low frequency range and have been observed to increase their distance from the source, change their orientation, and sometimes remain nearer to the surface in response to sounds produced by seismic surveying. For example, McCauley et al. (2000) reported that humpback whales began avoidance maneuvers at 5 to 8 km from an operating sound source array and maintained a standoff range of 3 to 4 km. McCauley et al. (2000) concluded that this observation suggests localized avoidance of the operating seismic vessels. Similar results have been reported for other baleen whales (Richardson et al., 1995).

McCauley et al. (2000) reported observations of adult humpback whales engaging in percussive behavior, such as tail slapping, during seismic surveys. This behavior is typically shown by breeding males competing for females and can produce very high sound levels. It has been suggested that males may perceive the loud sounds that seismic survey pulses produce as competing males (McCauley et al., 2000).

Mother/calf behaviors, such as suckling, may be more susceptible to acoustic disturbance. McCauley et al. (2000) suggested potential avoidance ranges of 7 to 12 km by nursing animals (based on results of single trials scaled to 3-D array measurements), but noted that these might differ in different sound propagation conditions. As discussed in **Section 7.3**, humpback whales migrate along the coast of Mozambique to mate, calve, and nurse their young, primarily from July to December.

The NMFS currently uses 160 dB re 1 μPa (rms) as a criterion for behavioral harassment of marine mammals. The equivalent SEL is about 155 dB re 1 $\mu Pa^2 \cdot s$. Acoustic modeling indicates that marine mammals could be exposed to these levels within about 6.2 to 13.6 km of the source array, which is in general agreement with the ranges noted in the preceding discussion. However, behavioral responses are not necessarily predictable from the loudness of the sound source and may vary depending on factors such as the age and status of the animal, the type of activity it is engaged in, and the social context (McCauley et al., 2000).

There are no reports of dugong response to underwater noise. However, studies of a related species, the West Indian manatee, indicate that the animals responded to approaching boats by orienting towards deeper channel waters and increasing their swimming speed when boats were within approximately 25 to 50 m (Nowacek et al., 2004). Research by Mann et al. (2007) indicates that manatees are capable of localizing sounds underwater, including those produced by boats. There are no reports of responses to seismic survey noise.

Conclusion

Without mitigation, seismic surveys could produce temporary or permanent auditory trauma to marine mammals, including those species listed by the IUCN as Vulnerable or Endangered. Although humpback whales are the main concern, several other IUCN-listed whales can occur in the area (i.e., sperm whales, blue whales, fin whales, and sei whales). However, the risk is limited mainly to within a few hundred meters around the sound sources and can be minimized through mitigation measures during seismic surveys (discussed below). The dugong, a species listed as vulnerable by the IUCN, is found mostly in near-coastal waters south of the project area and is unlikely to be affected.

Behavioral responses, such as avoidance (or in some cases, approach to operating sound sources), can be expected to occur within many kilometers of an operating array. While the biological importance of behavioral changes is not well understood, the consequences probably are not significant under most circumstances (McCauley et al., 2000; Continental Shelf Associates, Inc., 2004). If surveys were conducted during the humpback whale calving/nursing season, avoidance behavior could have a greater potential for disrupting normal activities during a critical life stage.

Impact ratings are as follows:

- Confidence: Medium
- Probability: Likely (behavioral responses) to Unlikely (auditory trauma)
- Consequence: Moderate
- Significance: 3

Mitigation

The following mitigation measures are recommended to avoid and reduce impacts of underwater noise on marine mammals:

- **Scheduling** – The surveys have been planned to avoid the humpback whale season (July to December). Surveys would begin in January 2008 and are expected to be completed in 5 months. This scheduling is expected to avoid nearly all exposure of humpback whales to underwater noise from the surveys. To the extent that other mysticetes exhibit similar seasonal migration patterns, their exposure to seismic survey noise would also be avoided.
- **Soft start** – Every time the use of the seismic array is initiated, "soft-start" procedures should be used to allow time for marine mammals and turtles to move away before the array reaches full power. The process should begin with the smallest source in an array and build up slowly over 20 to 40 minutes.
- **Visual monitoring** – Beginning at least 30 minutes before startup during daylight hours, visual observers should monitor a safety (exclusion) zone of a 1-km radius around the source vessel. Startup of the array cannot begin until the safety zone is clear of marine mammals for at least 20 minutes.
- **Shutdown of the array** – Visual monitoring of the sea surface should continue while the seismic array is operating during daylight hours, and the array should be shut down if a whale or dugong enters the 1-km safety zone during visual monitoring. A whale is defined as a cetacean other than from the Family Delphinidae (i.e., including any baleen, sperm, or beaked whale species).

Mitigation measures for seismic surveys have come into common use within about the last decade, but there are many uncertainties about their effectiveness (Continental Shelf Associates, Inc., 2004; Holst et al., 2006; Miller et al., 2006; Weir et al., 2006). Factors that were considered in developing the mitigation measures are discussed below.

<u>Safety Zone</u>. The JNCC, MMS, and IFC guidelines all specify a 500-m radius safety zone, whereas the Australian guidelines specify a 3,000-m radius. The purpose of establishing a safety zone is to ensure marine mammals (and/or turtles) are not exposed to sound levels that could cause temporary or permanent auditory trauma. It is not feasible for the safety zone to be based on behavioral responses, since such responses have been noted at distances of many kilometers and are not necessarily predictable based on the received sound level (e.g., responses could depend on what the animal is doing and its previous auditory experience). The available information indicates that the 500-m safety zone specified by the JNCC, MMS, and IFC guidelines is sufficient to avoid the likelihood of most auditory trauma. SELs that have been

shown to cause TTS in cetaceans would be limited to about 130 m horizontally from the array center. However, SPLs exceeding the NMFS criterion of 180 dB re 1 μPa (rms) could occur within about 850 m horizontally from the array center. Therefore, a safety radius of 1 km is recommended as a precaution.

Shutdowns. The JNCC guidelines do not require sound sources to be shut down if a marine mammal enters the safety zone after the array is powered up. However, MMS and Australian guidelines do require a shutdown if a whale (or turtle, under the MMS guidelines) enters the safety zone. This is a reasonable precaution to reduce the likelihood of auditory trauma in the event an animal does not (or cannot) avoid the area near the seismic array. Shutdown also would be required for dugongs. The likelihood of auditory trauma for small odontocetes (e.g., dolphins) is considered low, and shutdown would not be required if they entered the safety zone during a survey.

Night-Time Operations. Ideally, if the monitoring of a safety zone for marine mammals and turtles is required during the daytime, then a similar procedure should be used at night, or surveys should be limited to daylight hours only. However, there is a trade-off between allowing continual 24-hr surveying versus restricting operations to daylight only and having a longer survey duration (Weir et al., 2006). This is especially important considering the importance of completing the surveys before the humpback whale season.

Although the JNCC guidelines “encourage” daylight operations, they do not prohibit night-time startups or operations. Both the Australian and MMS guidelines specify limits on night-time operations. The Australian guidelines allow surveying operations to continue at night with visual monitoring via infrared/night vision binoculars, despite an effective range of only around 100 m (Weir et al., 2006). MMS guidelines specify that a soft start cannot begin at night unless passive acoustic monitoring is used in place of visual observations. MMS (2007) guidelines identify passive acoustic monitoring as an “experimental” technique and clearly indicate that the requirement is intended as a means to gather data on the effectiveness of the technique. The use of passive acoustic monitoring creates significant logistical difficulties, and there are problems obtaining accurate range and bearing information on vocalizing animals (C. Weir, personal communication, 2007).

Based on the available information, no additional mitigation is recommended for night-time surveys. Visual monitoring at night (i.e., via night-vision binoculars) has a very limited range and is likely to detect only animals very near to the survey vessel (e.g., bow-riding dolphins). Use of passive acoustic monitoring would significantly complicate the logistics while providing uncertain benefits. Some protection is already in place at night because, under the recommended guidelines, a soft start is required for any shutdown longer than 5 min (day or night). The soft start offers protection from sudden exposure to damaging noise levels.

Residual Impacts (After Mitigation)

The recommended mitigation would avoid most auditory and behavioral impacts on humpback whales and reduce the probability of auditory trauma in other marine mammals. The residual impacts would be reduced in probability and consequence:

- Probability: Likely (behavioral responses) to Rare (auditory trauma)
- Consequence: Minor
- Significance: 2

9.1.2 Sea Turtles

In contrast to marine mammals, relatively little is known about sea turtle hearing ability or their dependency on sound (passive or active) for survival cues. Only two species, loggerhead and green sea turtles, have undergone any auditory investigations. The anatomy of the sea turtle ear does not lend itself to aerial conduction; rather, it is structured for sound conduction through two media: bone and water (Békésy, 1948; Lenhardt, 1982; Lenhardt and Harkins, 1983).

Auditory testing and behavioral studies show that turtles can detect low-frequency sounds (Ridgway et al., 1969; Bartol et al., 1999). Most common sound frequencies produced by seismic sources overlap with the frequency range where turtle hearing is most sensitive (100 to 700 Hz). It is likely that sea turtles would be able to hear seismic survey noise for a considerable distance from the source and possibly experience some disturbance.

Auditory Trauma

All sea turtle species are assumed to be at some risk for auditory trauma, although hearing data are only available for loggerhead and green turtles. Hatchling sea turtles are probably at minimal risk for noise impacts. These animals inhabit seaweed mats and debris floating on the sea surface. Due to the attenuation pattern of seismic arrays, seismic noise levels would be lowest in near-surface waters.

Because sea turtles remain submerged much of the time (Eckert et al., 1986, 1989; Keinath and Musick, 1993), they may be passed over by seismic arrays and, therefore, exposed to the highest sound levels, which are directed downward. Although the sound levels produced by seismic sound sources are not likely to kill a sea turtle (even at close range), they could result in auditory trauma.

Sublethal impacts of acoustic impulses on the hearing system of sea turtles have been examined in only one study (Moein et al., 1995) in which the turtles were used to test the efficacy of seismic sound sources to repel sea turtles from the path of hopper dredges. Turtles were tested for stress levels and hearing thresholds before and after the trials. A temporary alteration of blood chemistry values after exposure to the sound sources indicated that the turtles might have been affected by exposure to repeated acoustic stimuli. Values indicated both an increase in the stress level of the animal as well as damage to tissues. However, the magnitude of the changes did not indicate serious injury to the turtles' organs, and blood chemistry levels returned to normal in approximately 2 weeks. Thus, this exposure to sound stimuli did cause minor, but reversible, changes to the turtles' tissues (Moein et al., 1995). Hearing thresholds also were examined by Moein et al. (1995). Half of the turtles tested exhibited a latent shift in their auditory potential within 24 hr of exposure, indicating a change in the hearing physiology.

However, in all five cases, hearing capabilities of each turtle returned to normal by the end of 2 weeks, and the effect was always temporary.

In the absence of criteria for auditory trauma in sea turtles, the criteria for marine mammals will be assumed to apply (see **Section 9.1.1**). The criterion for TTS from a single pulse would be an SEL of 186 dB re 1 μ$Pa^2 \cdot s$; turtles could be exposed to this level within about 130 m of the array center. The more conservative NMFS criterion of 180 dB re 1 μPa (rms) takes into account exposure to multiple pulses; turtles could be exposed to this level within about 850 m of the array center.

Behavioral Effects

Two studies have examined the behavioral response of juvenile loggerheads to sound in their natural environment (O'Hara and Wilcox, 1990; Moein et al., 1995). Both studies used seismic sound sources as an acoustic repelling device for sea turtles. Trial exposures of sea turtles to seismic sounds have also been done.

O'Hara and Wilcox (1990) attempted to create a sound barrier for loggerhead turtles at the end of a canal using seismic sound sources. The test results indicated that these sources were effective as a deterrent for a distance of about 30 m. However, this study did not account for the reflection of sound by the canal walls. Consequently, the stimulus frequency and intensity levels were ambiguous (O'Hara and Wilcox, 1990). Moein et al. (1995) investigated the use of seismic sound sources to repel juvenile loggerhead sea turtles from hopper dredges, and avoidance of these sounds was observed upon first exposure. However, these animals also appeared to habituate to the sound stimuli. After three separate exposures to the seismic sound sources, the turtles no longer avoided the stimuli (Moein et al., 1995).

McCauley et al. (2000) exposed sea turtles to seismic sound pulses and found that they began to noticeably increase their swimming activity and, at higher exposure levels, began to show more erratic swimming patterns, possibly indicative of them being in an agitated state. They suggested that sea turtles displayed a general "alarm" response at an estimated 2-km distance from an operating seismic vessel, and behavior indicative of avoidance occurred at an estimated distance of 1 km.

Holst et al. (2006) reported on the results of turtle observations during seismic surveys at various locations. Sea turtles showed localized avoidance during large- and small-source surveys. The mean closest point of approach for turtles was smaller during non-seismic periods than during seismic periods (i.e., 139 m versus 228 m for large-source surveys and 120 m versus 285 m for small-source surveys).

There are no formal criteria for behavioral responses in sea turtles. The NMFS currently uses 160 dB re 1 μPa (rms) as a criterion for behavioral harassment of marine mammals. Acoustic modeling indicates that animals could be exposed to these levels within about 6.2 to 13.6 km from the source array. Based on the preceding discussion of limited turtle responses to seismic survey noise, the 160 dB criterion would appear to greatly overestimate the extent of behavioral impacts in sea turtles and is not considered applicable.

Disruption of Nesting and Hatchling Behavior

The seismic surveys will be conducted during the sea turtle nesting season and could affect the behavior of nesting females or emerging hatchlings. Both noise and lights could be a factor.

According to the discussion in **Section 7.3**, green, hawksbill, and olive ridley turtles nest on beaches of northern Mozambique, inshore of the survey area. Reported nesting seasons are from November through July for green turtles and December through March for hawksbills. Olive ridley nesting season is not reported, but is assumed to be similar to that of hawksbills. Nesting beaches for loggerhead and leatherback turtles are in southern Mozambique and not near the survey area.

The shallowest part of the survey area is along the 50-m isobath. The minimum distance to a turtle nesting beach is approximately 2.5 km at Vamizi Island. The distance would be greater for other nesting beaches, and the exposure to noise and lights would be brief as the survey vessel passed by (e.g., about 1 hr to pass a particular point). Any impacts on turtle nesting or hatchling behavior are considered minor.

Conclusion

Without mitigation, seismic surveys could produce temporary or permanent auditory trauma to sea turtles, all of which are listed by the IUCN as Endangered or Critically Endangered. However, the risk is limited mainly to within a few hundred meters around a sound source array and can be minimized through mitigation measures during seismic surveys (discussed below).

Impact ratings are as follows:

- Confidence: Medium
- Probability: Likely (behavioral responses) to Unlikely (auditory trauma)
- Consequence: Moderate
- Significance: 3

Mitigation

The following mitigation measures are recommended to protect sea turtles during the seismic surveys:

- **Soft start** – Every time the use of the seismic array is initiated, "soft-start" procedures should be used to allow time for marine mammals and turtles to move away before the array reaches full power. The process should begin with the smallest source in an array and build up slowly over 20 to 40 minutes.
- **Visual monitoring** – Beginning at least 30 minutes before startup during daylight hours, visual observers should monitor a safety (exclusion) zone of a 500-m radius around the source vessel. Startup of the array cannot begin until the safety zone is clear of turtles for at least 20 minutes.

- **Shutdown of the array** – Visual monitoring of the sea surface should continue while the seismic array is operating during daylight hours, and the array should be shut down if a sea turtle enters the 500-m safety zone during visual monitoring.

This protection for sea turtles is consistent with seismic survey guidelines issued by the MMS (2007).

Residual Impacts (After Mitigation)

The recommended mitigation would reduce the likelihood of auditory trauma in sea turtles. The residual impacts would be reduced in probability and consequence:

- Probability: Likely (behavioral responses) to Rare (auditory trauma)
- Consequence: Minor
- Significance: 2

9.1.3 Fishes

All fish species can hear with varying degrees of sensitivity within the frequency range of sound produced by seismic sound sources (Hawkins, 1973; Popper and Fay, 1973; Tavolga et al., 1981; Fay, 1988; Popper and Fay, 1993; Fay, 2000). The best hearing range for most fish is believed to be in the frequency range of 100 to 1,000 Hz (Fay, 1988). Seismic pulses may produce temporary or permanent hearing impairment in some fishes but, as in the case of marine mammals, would be unlikely to cause serious injury except at very close range. Because of wide differences in hearing capability and morphologies among fish species, behavioral responses and the susceptibility of fishes to auditory trauma varies greatly.

There is no evidence of fish mortality resulting from seismic surveys, and there are no data available on the noise intensity that would result in mortality or other pathological effects. Except at close range, the effects of seismic sound sources on fishes are thought to be transitory, mainly evoking a startle response (i.e., movement away from the source of the noise) and changes in schooling behavior. Habituation of fishes to the noise is suggested by the fact that behavioral changes are observed to cease during the exposure period, sometimes within minutes of commencement of surveying.

Noise from marine seismic surveys also may have the potential to cause masking of the sounds normally used by fishes in their usual acoustic behaviors (Popper and Clarke, 1976; Ha, 1985). These behavioral effects also may result in decreased catchability even though no direct mortality may result (Dalen and Knutsen, 1986; Pearson et al., 1992; Engås et al., 1993; Løkkeberg and Soldal, 1993). Fishes with specialized hearing abilities (such as those with swimbladders and especially those with bladders mechanically linked to the ear) will be more likely to exhibit behavioral responses to distant seismic survey operations than those fishes with relatively poor hearing (McCauley, 1994).

McCauley et al. (2000, 2003) conducted trials with captive fishes, which showed a common fish “alarm” response of swimming faster, swimming to the bottom, tightening school structure, or all three at an estimated 2 to 5 km from a seismic source. Captive fishes exposed to short-range seismic pulses were seen to have some damaged hearing structures, but showed no evidence of increased stress. Ears of fishes exposed to an operating seismic sound source sustained extensive damage to the sensory epithelia, which was apparent as ablated hair cells. The regionally severe damage showed no evidence of repair or replacement of damaged sensory cells up to 58 days after exposure. The study suggests that exposure to multiple seismic pulses of 180 dB re 1 µPa or greater can cause significant damage to the ears of fishes (McCauley et al., 2003).

In general, subtle behavioral changes in fishes may be expected to occur at received peak pressures of 160 dB re 1 µPa, and peak pressures of 180 dB or higher may cause noticeable changes in behavior (Chapman and Hawkins 1969; Pearson et al. 1992; Skalski et al. 1992) or auditory trauma (McCauley et al., 2003). For example, Pearson et al. (1992) studied the effects of seismic sounds on rockfish behavior and noted that at received levels of 180 dB re 1 µPa the animals appeared to be alarmed and either aggregated more tightly or descended or ascended in the water column. The lowest level causing any observed behavioral change was 161 dB. A return to pre-exposure behaviors was noted within 20 to 60 minutes.

The African coelacanth (*Latimeria chalumnae*) is a critically endangered species that has been reported from the region, though not specifically from the survey area. Known as the “living fossil,” this species is a nocturnal hunter, finding shelter within caves throughout the day and foraging at night on squid and other fish species. Coelacanths inhabit near-bottom waters, and received levels at the seafloor directly beneath a seismic array are likely to be about 200 dB re 1 µPa (and less in waters deeper than 100 m). However, due to movement of the survey vessel, an individual fish would likely be exposed to levels of 180 dB re 1 µPa or greater from only a few pulses. Behavioral responses (e.g., alarm response) are possible, but would be expected to be brief in duration. The survey is considered unlikely to produce any significant impacts on coelocanths if they are present in the survey area.

Conclusion

Seismic surveys may produce temporary or permanent hearing impairment in some fishes, but would be unlikely to cause serious injury except at a very close range. Most of the fishes that may be affected by the surveys are common and widely distributed, and this would be considered a minor impact.

Impact ratings are as follows:

- Confidence: Medium
- Probability: Likely (behavioral responses) to Unlikely (auditory trauma)
- Consequence: Minor
- Significance: 2

Mitigation

No mitigation measures are recommended specifically for direct impacts of seismic sound sources on fishes. The use of "soft-start" procedures under the recommended guidelines is considered sufficient to provide an opportunity for fishes to leave the area before the seismic array reaches full power.

Residual Impacts (After Mitigation)

The recommended mitigation would reduce the likelihood of auditory trauma in fishes. The residual impacts would be reduced in probability and consequence:

- Probability: Likely (behavioral responses) to Rare (auditory trauma)
- Consequence: Minor
- Significance: 1

9.1.4 Seabirds

The impact of the seismic surveys on pelagic bird species is expected to be negligible. Though some species may dive below the water surface for prey, most of their time is spent in the air and resting on the water surface. These species would be unaffected by the seismic pressure waves generated below the surface. Local distribution of some pelagic species may be indirectly affected if fish prey species are redistributed out of the area due to behavioral avoidance of the disturbance. Impacts are considered negligible, and no mitigation measures are recommended for seabirds.

Impact ratings are as follows:

- Confidence: High
- Probability: Rare
- Consequence: Negligible
- Significance: 1

9.1.5 Benthic Invertebrates

Benthic communities of environmental concern include low-relief hard bottom and seagrass/algal areas on the inner side of the islands forming the Quirimbas Archipelago and coral reefs seen on the outer side of these islands. Hard bottom (coral reef) and seagrass areas are described as "live bottom" habitats because they are characterized by high productivity and a diverse animal community.

Experimental studies have shown that benthic invertebrates, including crabs, lobsters, and bivalves, are very resistant to underwater noise pulses, including explosions (Aplin, 1947; Chesapeake Biological Laboratory, 1948; Linton et al., 1985).

Benthic organisms are unlikely to be exposed to levels of sound that could be physically harmful. Coral reefs, hard bottom, and seagrass/algal areas are well inshore of the survey area (minimum of 2.5 km). The survey will take place in waters greater than 50 m deep, and the likelihood of significant impacts to benthic organisms directly beneath the seismic array is considered negligible. No mitigation measures are recommended for invertebrates.

Impact ratings are as follows:

- Confidence: High
- Probability: Rare
- Consequence: Negligible
- Significance: 1

9.1.6 Plankton

Physical injury from underwater noise pulses occurs when a pressure wave strikes and compresses the body, and the damage is almost totally limited to the auditory system and the gas-containing structures of the organism (Department of the Navy, 2001). Zooplankton, which have an exoskeleton and no air sacs, are relatively invulnerable to such impacts. Injury to planktonic species will be limited to the very near-field of the seismic sound source energy release (5 to 10 m). This is essentially within the bubble field of the compressed air release. The effect experienced by the planktonic population will be similar to that experienced in the turbulence generated by a large ship's propellers. Potential impacts on plankton populations are considered negligible and no mitigation measures are recommended.

Impact ratings are as follows:

- Confidence: High
- Probability: Likely
- Consequence: Negligible
- Significance: 1

9.1.7 Human Divers

Auditory safety issues relative to human divers are also addressed briefly in this section. Social impacts on recreational diving (e.g., disturbance or disruption of recreational diving, apart from auditory safety concerns) are discussed separately in **Section 10.0**.

The Diving Medical Advisory Committee (DMAC), an independent committee formed in 1974 to provide advice about medical and certain safety aspects of commercial diving in Europe, considers a safe distance between seismic sound sources and divers to be 1,500 m where the compressed air sound source does not exceed 4,400 cubic inches (DMAC, 1979). In this survey, each source array will be 3,460 cubic inches. The safe distance adopted by DMAC is based on annoyance thresholds rather than physical harm and has been validated by acoustic measurements during various surveys (C. Gill, International Association of Geophysical Contractors, personal communication, 2007). At this range, acoustic modeling indicates that divers would be exposed to an SEL of 149 to 157 dB re 1 µPa^2 • s or an SPL of about 155 to 165 dB re 1 µPa (rms). The duration of exposure would be brief.

The westernmost survey line in the 3-D survey area is at least 2.5 km offshore from the nearest reef areas and, therefore, exceeds the minimum safe range for divers. As a precaution, the EMP includes measures to ensure that this minimum range is maintained.

Data from a seismic survey done in shallow water off the Yucatan Peninsula, Mexico provide some perspective on the perceived loudness of the received sound. In that survey, a diver 3.5 km from the survey vessel reported the sound in the water was barely noticeable (Barton et al., 2006). This survey was conducted over a very shallow water (< 30 m) limestone carbonate bank similar to the inshore waters of the Quirimbas Archipelago.

Conclusion

Auditory safety impacts on human divers are expected to be avoided. The risk of impact is very low due to the survey location (minimum of approximately 2.5 km from the reef line). Impact ratings are as follows:

- Confidence: High
- Probability: Rare
- Consequence: Severe
- Significance: 3

Mitigation

- **2,500-m buffer** – The final survey plan should be reviewed to verify all survey lines are a minimum of 2,500 m from reefs, shorelines, and known dive sites. This provides an additional buffer in addition to the DMAC-recommended safe range of 1,500 m.
- **Coordination with dive operators** – Through the Stakeholder Communications Plan (SPC), AMA1 should coordinate with dive operators to ensure they are aware of survey locations and timing. Diving should only be permitted when specific arrangements are made between AMA1 and the dive operator on the day concerned in order to ascertain the exact position of the seismic vessel in relation to the dive site. Diving should not be permitted under any circumstances when the seismic vessel will be operating within 2,500 m of the intended dive site.

Further mitigation for divers is discussed in **Section 10.0**.

Residual Impacts (After Mitigation)

The recommended mitigation will reduce further the already low probability and consequence of auditory impacts to divers. Impact ratings are as follows:

- Probability: Remote
- Consequence: Moderate
- Significance: 1

9.2 VESSEL MOVEMENTS

Vessel movements are a source of potential impacts on marine mammals and sea turtles. Vessel strikes on large whales are among the factors leading to the decline of several of these species. Although all sizes and types of vessels can collide with whales, the most lethal or severe injuries are caused by ships 80 m or longer and traveling 13 to 15 kts or faster (Laist et al., 2001; Jensen and Silber, 2003). The seismic survey vessel normally travels at about 5 kts and would have a much lower risk of striking a whale. The chance of a vessel striking a whale is considered negligible because of the vessel's slow speed, the use of trained observers monitoring for marine mammals before and during surveys, and the whales' likely avoidance of the waters near the survey vessel due to seismic noise.

Although there have occasionally been reports of dolphins being struck by recreational and commercial vessels (Wells and Scott, 1997), dolphins, in general, are at comparatively low risk because of their speed and agility. The chance of a vessel striking a dolphin is considered negligible for the same reasons stated above (slow speed of the vessel and visual monitoring during surveys).

Dugongs are very slow-moving and generally more susceptible to vessel strikes than whales or dolphins. However, dugongs are typically scarce within Mozambique, with their distribution limited mainly to the coast well south of the survey area (see **Section 7.3**). During the 2007 aerial surveys in the project area, no dugongs were sighted. Because of their nearshore distribution and the factors cited above for whales and dolphins (slow speed of the vessel and visual monitoring during surveys), the chance of the survey vessel striking a dugong would be remote. The chance for a support vessel traveling to Pemba for supplies striking a dugong would be somewhat greater, but similar to the risk from other vessel traffic in the region.

Conclusion

A vessel strike on an IUCN-listed marine mammal would not be expected to occur during the project. Impact ratings are as follows:

- Confidence: High
- Probability: Rare
- Consequence: Moderate
- Significance: 2

Mitigation

- **Visual monitoring** – The visual monitoring that will be conducted for marine mammals (see **Section 9.1.1**) will ensure there are no dugongs near the seismic survey vessel before and during operations.
- **Support vessel operations** – Support vessel(s) traveling to Pemba for supplies will maintain a watch for dugongs and travel at slow speeds while operating in coastal areas.

Residual Impacts (After Mitigation)

The recommended mitigation will reduce the likelihood of vessel striking a dugong from rare to remote, reducing the overall significance as well:

- Probability: Remote
- Consequence: Moderate
- Significance: 1

9.3 AIR EMISSIONS AND EFFLUENT DISCHARGES

9.3.1 Air Quality

Air pollutant emissions from seismic survey vessels will have a minor impact on air quality due to the release of combustion gases. Onshore air quality is not expected to be significantly affected.

In **Section 5.6**, air pollutant emissions from survey vessels were estimated using a worksheet developed by the MMS for offshore oil and gas operations. The worksheet uses standard U.S. EPA emission factors. The source vessel is powered by two Ulstein Bergen BMV-12 engines rated at 5,300 Kw each, for a total of 10,600 kW (14,400 BHP). The two escort vessels are assumed to have engines rated at 2,650 kW (3,600 HP) each. All vessels are assumed to operate 24 hr/day, 7 days/week for the duration of the survey (5 months). Estimated emissions are presented in **Table 5-3**.

The main survey vessel will be operating several kilometers offshore (portions of the survey area are up to 46 km offshore). It is unlikely that vessel emissions will have detectable effects on coastal/onshore air quality.

Conclusion

Based on the criteria in **Table 8-1**, impacts of air pollutant emissions are considered minor. All air pollutant emissions will comply with Mozambican laws and international guidelines, and no further mitigation is recommended. Impact ratings are as follows:

- Confidence: High
- Probability: Certain
- Consequence: Negligible
- Significance: 1

9.3.2 Water Quality

Effluent discharges from vessels, including treated sanitary waste, domestic waste, deck drainage, and bilge and ballast water, will have minor, transient impacts on water quality.

The survey vessel will have treatment equivalent to a U.S. Coast Guard-approved Type II marine sanitation system in accordance with international standards and CGG Service's Operational Discharges Management Plan.

Domestic wastewater, including kitchen waste, will contain detergents and fats. Fats are among the more stable organic compounds and not easily decomposed by bacteria. Discharge of domestic waste will increase the BOD in the receiving environment. Domestic waste does not normally contain fecal coliform; thus, chlorination is not needed. Domestic waste water (and sewage) is positively buoyant in the receiving marine water, keeping the waste stream at the surface where aeration and oxygenation takes place and minimizing its impact on dissolved oxygen.

In the case of rain/deck water, international standards specify that oil removal is required so that discharges do not contain free oil. The survey vessels will be required to meet this standard.

In accordance with international maritime standards, AMA1 and CGG Services prohibit the discharge of ballast water containing oil. Ballast water discharges will be continuously monitored for oil sheen at the moorings. Any visibly contaminated ballast water discharges will be terminated on detection, and the oily water will be retained on board the vessel.

Conclusion

Impacts of effluent discharges on water quality are considered negligible. All effluent discharges will comply with Mozambican laws and international standards (e.g., MARPOL), and no further mitigation is recommended. Impact ratings are as follows:

- Confidence: High
- Probability: Certain
- Consequence: Negligible
- Significance: 1

9.4 ACCIDENTAL EVENTS

Potential accidents during the project could include a small volume spill due to collision or fueling operation accident associated with all types of vessel traffic (fuel oil). The vessel will be initially fueled from the point of mobilization; further refueling will be by offshore vessel-to-vessel transfer ("bunkering"). Fuel and cable oils (used to provide neutral buoyancy in hydrophone cables) are the only significant hazardous materials in terms of potential environmental impact.

Spills, if they occurred, would most likely be small, and potential negative impacts would have a short duration. Impact ratings are as follows:

- Confidence: High
- Probability: Rare
- Consequence: Minor to Moderate
- Significance: 1 to 2

Mitigation

The following management measures are included in the project to prevent and/or respond to oil spills:

- The survey vessel has an SOPEP and maintains an Oil Record Book as required under MARPOL 73/78.
- Oils, greases, and streamer fluids will be stored in designated containment areas on board the survey vessel.
- Sorbent materials will be used to clean up any minor spill on board the survey vessel. Stocks of absorbent materials will be checked and replenished as needed prior to the survey.
- Strict fuel transfer procedures will be implemented to prevent spills during loading of fuel at the port of Pemba and during transfers between supply vessels and the survey vessel.
- In the event of a spill of oil or other products, the incident will be promptly reported through the contractor chain-of-command to AMA1.

Residual Impacts (After Mitigation)

Spill prevention and the SOPEP will reduce the probability of a spill and lessen potential impacts by cleaning up the oil or preventing it from reaching sensitive habitats. The residual impacts would be reduced in probability and consequence:

- Probability: Remote
- Consequence: Minor
- Significance: 1