Review of potential impacts to sea turtles from underwater explosive removal of offshore structures

Article *in* Environmental Impact Assessment Review · May 2008

DOI: 10.1016/j.eiar.2007.05.010

7 authors, including:

Stephen Viada
CSA Ocean Sciences Inc.
6 PUBLICATIONS **125** CITATIONS
SEE PROFILE

Roberto Racca
JASCO Research Ltd
52 PUBLICATIONS **234** CITATIONS
SEE PROFILE

David Hannay
JASCO Research Ltd
54 PUBLICATIONS **232** CITATIONS
SEE PROFILE

Brian Balcom
CSA Ocean Sciences Inc.
6 PUBLICATIONS **38** CITATIONS
SEE PROFILE

Available online at www.sciencedirect.com

ScienceDirect

Environmental Impact Assessment Review 28 (2008) 267 – 285

Environmental Impact Assessment Review

www.elsevier.com/locate/eiar

Review of potential impacts to sea turtles from underwater explosive removal of offshore structures

Stephen T. Viada [a,*], Richard M. Hammer [a], Roberto Racca [b], David Hannay [b], M. John Thompson [a], Brian J. Balcom [a], Neal W. Phillips [a]

[a] *CSA International, Inc., 759 Parkway Street, Jupiter, FL 33477, USA*

[b] *JASCO Research Ltd., Vancouver Island Technology Park, Suite 2101, 4464 Markham Street, Victoria, British Columbia, Canada, V8Z 7X8*

Received 13 December 2006; received in revised form 23 May 2007; accepted 25 May 2007

Abstract

The purpose of this study was to collect and synthesize existing information relevant to the explosive removal of offshore structures (EROS) in aquatic environments. Data sources were organized and summarized by topic — explosive removal methods, physics of underwater explosions, sea turtle resources, documented impacts to sea turtles, and mitigation of effects. Information was gathered via electronic database searches and literature source review. Bulk explosive charges are the most commonly used technique in EROS. While the physical principles of underwater detonations and the propagation of pressure and acoustic waves are well understood, there are significant gaps in the application of this knowledge. Impacts to sea turtles from explosive removal operations may range from non-injurious effects (e.g. acoustic annoyance; mild tactile detection or physical discomfort) to varying levels of injury (i.e. non-lethal and lethal injuries). Very little information exists regarding the impacts of underwater explosions on sea turtles. Effects of explosions on turtles often must be inferred from documented effects to other vertebrates with lungs or other gas-containing organs, such as mammals and most fishes. However, a cautious approach should be used when determining impacts to sea turtles based on extrapolations from other vertebrates. The discovery of beached sea turtles and bottlenose dolphins following an explosive platform removal event in 1986 prompted the initiation of formal consultation between the U.S. Department of the Interior, Minerals Management Service (MMS) and the National Marine Fisheries Service (NMFS), authorized through the Endangered Species Act Section 7, to determine a mechanism to minimize potential impacts to listed species. The initial consultation resulted in a requirement for oil and gas companies to obtain a permit (through separate consultations on a case-by-case basis) prior to using explosives in Federal waters. Because many offshore structure removal operations are similar, a "generic" Incidental Take Statement was established by the NMFS that describes requirements to protect sea turtles when an operator's individual charge weights did not exceed 50 lb (23 kg). Requirements associated with the Incidental Take Permit were revised in 2003 and 2006 to accommodate advances in explosive charge technologies, removals of structures in deeper waters, and adequate protection of deep water marine mammal species in Gulf of Mexico waters. Generally, these requirements include pre- and post-detonation visual monitoring using standard surface and aerial survey methods for sea turtles and marine mammals, and, in some scenarios, passive acoustic survey methods for marine mammals within a specified radius from an offshore structure. The survey program has been successful in mitigating impacts to sea turtles associated with EROS. However, even with these protective measures in place, there have been observations of sea turtles affected by explosive platform removals.

Keywords: Sea turtle; Marine mammal; Impact; Explosive removal (severance); Acoustic; Offshore structures

---

* Corresponding author. Tel.: +1 561 746 7946.
E-mail addresses: sviada@conshelf.com (S.T. Viada), rhammer@conshelf.com (R.M. Hammer), rob@jasco.com (R. Racca), dave@jasco.com (D. Hannay), jthompson@conshelf.com (M.J. Thompson), bbalcom@conshelf.com (B.J. Balcom), nphillips@conshelf.com (N.W. Phillips).

0195-9255/$ - see front matter © 2007 Elsevier Inc. All rights reserved.
doi:10.1016/j.eiar.2007.05.010

1. Introduction

This paper focuses on a review of existing information pertaining to the potential impacts to sea turtles from the underwater explosive removal of offshore structures (EROS). The introduction is followed by background sections that briefly summarize the current regulatory environment, available explosive removal methods, and the physics of underwater explosions. Review sections summarize the potential biological impacts of explosive removal to sea turtles and highlight current mitigation techniques. The discussion section summarizes existing data gaps and identifies a series of recommendations to expand our current knowledge of explosive removal impacts on sea turtles.

The U.S. Department of the Interior, Minerals Management Service (MMS) is responsible for management of mineral resource leases and activities on submerged Federal lands of the U.S. Outer Continental Shelf (OCS) seaward of State boundaries. Nearly 4000 oil and gas structures currently exist in Federal waters, with most located in the Gulf of Mexico. These offshore structures are used by offshore operators to develop and produce oil, natural gas, and/or gas condensates from offshore hydrocarbon reservoirs. When offshore production from producing fields becomes uneconomic, leases may be terminated at the request of the offshore operator. MMS decommissioning requirements specify that offshore oil and gas structures be removed within 1 year of lease termination. Offshore structure removal typically involves the use of explosives to sever platform legs and other components. During the 10-year period between 1994 and 2003, an average of 156 platform decommissionings occurred per year, with more than 60% involving explosive severance activity. Based on forecast modeling and assessment of historical trends and industry projections, MMS (2005) estimated that 170 to 273 explosive removal operations will occur annually during the next several years. EROS has the potential to cause environmental impact.

The MMS has a strong directive to develop approaches for managing the Nation's OCS mineral resources in an environmentally sound and safe manner. The MMS has funded numerous projects under its Environmental Studies Program to obtain information useful for decisions related to potential impacts associated with mineral activities. This paper presents the results of an MMS-funded project that reviewed explosive removal methods and the physics of underwater explosions, the potential impacts to marine mammals, sea turtles, and fishes from underwater EROS (Continental Shelf Associates, Inc., 2004), and available mitigation measures. This analysis addresses those elements pertinent to potential impacts to and feasible mitigation efforts for sea turtles.

2. Regulatory environment

The MMS is mandated by the OCS Lands Act, as amended, to manage the development of OCS oil, gas, and mineral resources, while protecting the human, marine, and coastal environments. Regulations relevant to OCS oil and gas operations are codified in 30 Code of Federal Regulations (CFR) Part 250. Specifically, 30 CFR 250 Subpart Q was implemented to (1) determine that decommissioning activities comply with regulatory requirements and approvals and (2) ensure that offshore structure removal and site clearance are properly performed to protect marine life and the environment, and do not conflict with other users of the OCS. MMS oversees EROS activities through existing Notices to Lessees and Operators (NTLs) and permit requirements. A recent history of these requirements is as follows:

- MMS implemented restrictions on explosive removal activities in NTL 2001-G08.
- MMS issued a final rule amending its regulations governing oil and gas operations on the OCS to update decommissioning requirements on 17 May 2002 (67 Federal Register [FR] 35398). MMS decommissioning rules were restructured and regulations updated to make requirements more user-friendly and reflect changes in technology.
- Corrections to the final rule were made 1 July 2002 (67 FR 44265) and 30 October 2002 (67 FR 66046) to ensure that lessees and pipeline right-of-way holders conduct their decommissioning operations safely and effectively.
- MMS issued NTL 2004-G06 on 5 April 2004 to provide further guidance and clarification on structure removal operations requirements in the Gulf of Mexico OCS. This NTL superseded and replaced NTL 2001-G08 and provided additional information on Federal requirements for protecting endangered and threatened species, including sea turtles and select marine mammals.

The MMS also completed two Programmatic Environmental Assessments (PEAs) and Findings of No Significant Impact, the first in 1987 (Minerals Management Service, 1987) and most recently in 2005 (Minerals Management Service, 2005), satisfying regulatory requirements of the National Environmental Policy Act. One of the alternatives considered in the 2005 PEA evaluated all potential removal scenarios (e.g. shelf vs. slope environments; multiple charge sizes; above and below seafloor surface [mudline] detonations) and appropriate mitigation measures. Currently, all structure removal operations within all water depths of the Western and Central Planning Areas and the currently available lease sale area of the Eastern Planning Area of the Gulf of Mexico require mitigation measures to reduce or eliminate potential impacts to sea turtles from EROS.

MMS also coordinates with the National Oceanic and Atmospheric Administration (NOAA), National Marine Fisheries Service (NMFS) regarding EROS activities. Coordination is in compliance with applicable environmental laws (i.e. Endangered Species Act [ESA]), as amended, for sea turtles). Endangered and threatened species listed or proposed for listing are protected under the ESA, and include all sea turtle species.

The MMS complies with ESA Section 7 provisions through consultation to minimize potential impacts to listed species. Historical milestones relevant to MMS and NMFS consultation include the following:

- In 1988, the NMFS issued a "generic consultation" covering structure removal activities on the Gulf of Mexico continental shelf (National Marine Fisheries Service, 1988), following completion of the 1987 MMS PEA evaluating structure removal activities (MMS, 1987) (Section 6.1.).
- Incidental take authorization regulations were promulgated by NMFS in October 1995 (60 FR 53139, 12 October 1995).
- On 10 April 1996 (61 FR 15884), the regulations were moved to Subpart M (50 CFR 216.141 et seq.). Effective for 5 years, the take regulations detailed conditions, reporting requirements, and mitigative measures similar to those listed in the 1988 ESA Biological Opinion requirements for sea turtles.
- After Subpart M expired in November 2000, the NMFS and MMS advised operators to continue following the guidelines and mitigative measures of the expired subpart pending a new petition and subsequent regulations.
- The NMFS released interim regulations (Subpart M) in August 2002, which expired on 2 February 2004 (67 FR 49869, 1 August 2002).
- In 2003, the NMFS issued a de minimus consultation covering structure removal activities that use smaller explosive charges (U.S. Department of Commerce, 2003) (Section 6.2.).

Issuance of the 2005 MMS programmatic document also provided updated information for new formal ESA Section 7 consultation. The MMS prepared a biological assessment for the ESA consultation to address the explosive removal of oil and gas structures at all water depths. The 1988 "generic" and 2003 de minimus consultations (both effective as of 2005 issuance of the PEA) were replaced with a single/new Biological Opinion, which was prepared by the NMFS and MMS in 2006. The revised Biological Opinion introduced a revised mitigation program to protect marine protected species, including five species of sea turtles and diverse marine mammal species such as the endangered sperm whale potentially present in the U.S. Gulf of Mexico (U.S. Department of Commerce, 2006) (Section 6.3).

3. Explosive removal methods

To remove a fixed offshore platform, the installation steps are essentially reversed. Topside equipment such as living quarters, generators, and processing equipment is taken off by crane and returned to shore for scrap or to be reused. Deck sections are then lifted from the platform and placed on cargo barges for transportation to their disposal site. Platform legs, wellheads, flare piles, conductors, submerged wells, caissons, and other offshore structures are subject to explosive removal. MMS regulations require that structures be severed at least 15 ft (5 m) below the surface of the seafloor and removed.

Offshore structures can be cut away by mechanical means using divers and remotely operated vehicles (ROVs) equipped with tungsten-carbide blade cutters, diamond wire and hydraulic shear cutters, and other mechanical means or abrasive cutting techniques. However, the safest, easiest, and most reliable cutting procedure is to place an explosive charge inside a structure at the desired depth and sever it explosively. Presently employed explosive cutting (severance) techniques include bulk explosive charges, configured bulk charges, and cutting charges. Potential future explosive cutting techniques include contact plaster charges, shock wave focusing charges, and radial hollow charges.

3.1. Bulk explosive charges

Bulk explosive charges are the most commonly used technique for explosive cutting. These C-4 or Comp B explosives are castable and moldable, have high velocity on detonation and high shattering power, and are not as dangerous to handle as some other types of high explosives. Bulk explosives have a 95% success rate when sized properly. Increased water depth has no adverse impact on the success rate of bulk explosive cuts.

3.2. Configured bulk charges

Configured bulk charges such as “ring charges” and “focusing” charges are designed to collide or focus the detonation front to concentrate more energy along the fracture line, and thus reduce the size of the charge needed to cut. Both types have the advantage of reductions in explosive weight, but both have the drawback of needing prefabrication and sizing to fit each application.

3.3. Cutting charges

Cutting charges include linear-shaped charges and “cutting tape.” Linear-shaped charges use high velocity explosive energy to accelerate a v-shaped band of cutting material, usually copper, in a high velocity jet that penetrates through the steel of the piling. Explosive cutting tape is a flexible version of the linear-shaped charge, but is not as efficient, especially at depths greater than 300 ft (91 m) (National Research Council, 1996).

4. Physics of underwater explosions

This section outlines the fundamental physical processes involved in the underwater detonation of a charge and the resulting injection and propagation of blast and acoustic energy into the surrounding medium. It begins with an overview of the properties of underwater explosions and how they are affected by the charge designs and deployment configurations used in the offshore explosive removal practice; it then moves on to the manner in which shock and acoustic waves propagate from the source into the ocean, and ends with a discussion of the principal metrics commonly used in quantifying the acoustic levels and expressing impact criteria.

4.1. The explosive process

When an explosive detonates, a physical shock front rapidly compresses the explosive material and advances significantly faster than the sonic velocity of the material. As this front passes through the explosive, it triggers the release of chemical energy and thus realizes a self-sustaining wave that builds up to a stable limiting rate of propagation that is characteristic of the detonating material. This process is only sustained within the limits of the explosive material, and ceases at the boundary with the medium containing the explosive. A conventional shock wave then passes into the surrounding medium.

Beyond a short distance from the blast (generally 3 to 10 diameters of the explosive charge), thermal and direct detonation effects from the explosion can be ignored. The main sources of impact outside this distance are the shock wave and expanding gaseous reaction products. The original shock wave is the primary cause of harm to aquatic life at great distances from the shot point. The expanding gases, if they do break into the water column from the substrate where the explosion occurs, can set up a pulsating bubble whose recurring pressure waves also may contribute significantly to damage.

4.2. Shaped charges and directionality

In offshore explosive removal operations, most structural members to be severed are cylindrical metal structures protruding from the bottom sediment, including support legs, piles, and well conductors. As outlined in the previous section, the use of shaped charges is a well established method for applying maximum cutting power to the surface of an object while minimizing the dispersion of explosive energy in ineffectual directions. The related technique of simultaneously igniting a charge at selected initiation points also takes advantage of detonation front dynamics to focus energy release toward a smaller target area. While a discussion of these complex explosive processes is outside the scope of this article, it is important to note that their result is to create directionality in the release of blast energy. This must be taken into account when using acoustic pressure estimation formulas based on the size (mass) of the explosive charge, as directionality will affect the energy that is propagated into the overlying mud and water column and may result in a very significant reduction in comparison to a uniformly distributed detonation.

4.3. Media considerations

Location of the explosive in the surrounding media plays a key role in determining the acoustic levels generated in the water column by an underwater detonation. Open-water shots, in which an unconfined explosive is detonated within the water column itself, are not part of the current practice for EROS, because regulations specify a minimum depth of 15 ft (5 m) below the mud line for any charge used to sever a structural component. The acoustic impact of the buried charge explosion, however, can vary significantly depending on the geological composition and compactness (water content) of the sediment and could range in principle from an essentially waterborne detonation to a completely confined shot with no venting of explosion gases into the water column. The presence of the metal structure being severed, which may act as containment and will absorb a portion of the explosive energy, further complicates the scenario compared to the detonation of a free charge in the sediment. Generally it is safe to assume that ignoring the effects of the structure will yield a conservative "worst case" assessment of the impact from the detonation. There is in fact evidence that the extremely high detonation forces in close proximity of the charge so far exceed the strength of the metal structure as to make its influence negligible.

4.4. Multiple charges

The practice of cutting several supporting piles of a platform by detonating multiple charges at once was adopted in the past as an efficient removal procedure. This procedure was prohibited by operational restrictions introduced in 1988 that include a minimum delay of 900 milliseconds (ms) between detonations as well as a limit of eight detonations in a group. With the regulatory prescription of nearly a 1 s minimum interval between detonations, the sound level pattern from a single charge would not be affected by interaction with others.

4.5. Shock wave and acoustic propagation

The manner in which shock and acoustic waves propagate from the source into the ocean is strongly influenced by the ocean environment. Noise propagating in shallow water areas (i.e. depths less than a few hundred meters) can reflect many times from the sea surface and bottom. In shallow waters, sea surface state (roughness) and sea bottom geoacoustic characteristics (density, compressional and shear sound velocity and attenuation) often are very important to noise propagation. Fewer sea surface and bottom interactions occur in deep waters. Refractive effects due to differential temperature and salinity profiles can cause sound to be trapped in small depth channels and can lead to sound focusing. This subsection discusses very briefly how sound produced by underwater explosive removal operations propagates away from the operation site and ensonifies the surrounding water volume.

The pressure waveform from underwater explosive detonations is composed of a shock or primary pulse followed by a series of bubble pulses. The shock pulse has rapid rise time and exponential decay due to rapid conversion of the solid explosive to gaseous form. In the region close to the detonation, known as the near field, the pressure wave has sufficiently high amplitude that particle displacements are not always proportional to pressure. In this region the shock pressure front preconditions the medium by heating and compression, so that acoustic waves behind it travel more quickly. The acoustic waves catch up to and reinforce the shock front, thereby sustaining its high pressure. As the shock front travels away from the source, it weakens and eventually reaches pressure levels at which it behaves like a normal sound wave. The bubble pulses arise from the rapid expansion and subsequent collapse of the bubble of gases produced by the explosive in a rapidly decaying oscillatory pattern in which each collapse generates a positive pressure pulse.

As previously mentioned, propagation of underwater sound away from the explosion site can be strongly influenced by reflections off the water surface and the bottom. The smooth sea surface is a strong reflector of acoustic energy at nearly all frequencies. The reflection coefficient is close to -1, indicating that 180-degree phase reversal occurs upon reflection. A rough sea surface, on the other hand, causes scattering of sound on reflection; furthermore, entrapped bubbles near the surface due to breaking waves can absorb acoustic energy and add to the scattering of reflected energy. Surface roughness, therefore, tends to reduce the amplitude of the reflected sound, but primarily at higher frequencies where the wavelength of the sound is equal or smaller than the roughness scale. The sea bottom, or seafloor, is also a reflector of underwater sound but through a more complex mechanism. A large fraction of acoustic energy incident on the seafloor is transmitted into the bottom, where it may reflect from subbottom layers. Rough ocean bottoms tend to scatter energy, similar to rough sea surfaces, thereby reducing the reflection efficiency for higher frequency sounds.

Sound levels received at significant distance from underwater explosions can vary considerably depending on the charge burial depth, explosion depth relative to the surface, and ocean environment characteristics. A simplified equation divides the problem into three primary components: Source Level, SL; Transmission Loss, TL; and Received Level, RL. They are related through the equation:

$$\mathrm{RL} = \mathrm{SL} - \mathrm{TL}.$$

Source level indicates the strength of the source in decibels (dB). Transmission loss is the parameter that quantifies how the medium reduces the sound level as the signal propagates from the source to the receiver. This parameter includes the effects of sea surface and bottom reflections, as well as any refractive effects occurring in the water itself. Prediction of transmission loss can be a very complex problem because it is dependent on the combined properties of the sea surface, water column, and sea bottom, as well as the source and receiver locations relative to bottom topography.

Several different theories and associated modeling approaches exist that describe and characterize wave propagation and loss characteristics, including ray theory, normal mode, wavenumber integral, and finite difference methods (e.g. parabolic equations). Each approach has inherent advantages and disadvantages for different environments and frequency ranges, though techniques such as parabolic equations have good versatility and are used routinely under many conditions. Rule-of-thumb methods have also been devised to obtain rough estimates of transmission loss on the basis of semi-empirical relations; their use is becoming less and less justifiable with the increasing availability of fast computers capable of performing detailed numerical modeling.

4.6. Sound metrics and impact criteria

4.6.1. Metrics

Sound level metrics are parameters that quantitatively describe sound pressure wave characteristics at a given spatial location. Commonly used metrics for impulsive sounds variously emphasize the amplitude, energy, and time-related characteristics of the pressure wave. Values of specific metrics are used to gauge the degree of impact that underwater sound signals have on marine wildlife. Standard thresholds based on certain metrics have been established in reference to the minimum levels at which specific impacts have been observed to occur for a given species.

Metrics that need to be considered for gauging one impact type may differ from metrics used for another impact type. The most common metrics for impulsive sounds are as follows:

- Peak pressure: The highest pressure attained by a sound pressure signal. This pressure is measured with respect to ambient pressure, and also is referred to as zero-to-peak pressure.
- Peak-to-peak pressure: The difference between the highest pressure and lowest pressure over the duration of a waveform. For impulsive sounds produced by blasting, the lowest pressure is generally negative with respect to ambient pressure and occurs soon after the largest positive peak due to expansion imparted to the water by its positive impulse.
- Impulse: The time integral of pressure through the largest positive phase of a pressure waveform. It has units of Pascal seconds. The impulse for exponentially decaying shock pulses from underwater explosives (assuming no interference with surface or bottom reflections) is given by a simple expression. However, for shallow sources or receivers, the arrival of the surface reflection has the effect of canceling later parts of the pressure pulse. Consequently, impulse calculations are often performed by integrating the direct path pressure only up to the arrival time of the surface reflection.
- Root-mean-square (rms): The square root of the mean square pressure divided by the duration of the impulsive waveform. The value of this metric is strongly dependent on the duration parameter, whose definition can be ambiguous for certain types of impulsive events. Methods have been proposed for determining the duration consistently on the basis of the cumulative energy flux density function (see below), by considering the portion of the event that holds a specified percentage of the total. The rms metric has gained popularity because it gives the most representative measure of the average effective amplitude over a transient signal's duration, and is especially well suited to characterize sonar pings and signals such as windowed sine pulses. It also is quite widely applied for estimating impacts of impulsive airgun noise on species such as sea turtles and marine mammals.
- Energy flux density (EFD): The total acoustic energy propagated through a unit area normal to the direction of propagation. The EFD of plane waves can be computed as the time integral of squared pressure divided by the acoustic impedance of the medium. The EFD is not a suitable metric for continuous-wave sounds because the integral is not normalized in time.
- Sound exposure level (SEL): The time integral of square pressure divided by the product of sound speed and water density. SEL may be the most appropriate metric to be used in the analysis of potential impacts from explosive sources, in preference over rms, in that it avoids the uncertainty in the determination of a suitable duration scale in complex propagation environments.

4.6.2. Decibels

All of the above metrics, except for impulse, are normally expressed in decibels. The decibel in its fundamental use in acoustics presents sound pressure level on a logarithmic scale relative to a pre-defined reference. The EFD and SEL metrics are converted to decibels in a slightly different way, which relates the SEL of the signal to that of a standard plane sine wave. It is noteworthy that these two metrics often are used equivalently to refer to the time integral of square pressure divided by the product of sound speed and density. This, however, is not a strictly correct definition for EFD in the case of complex pressure fields.

4.6.3. Frequency content

None of the above metrics directly provide information about the spectral energy content of the sound signal. Spectral content is important for some types of impact criteria; for example, one of the accepted threshold levels for temporary threshold shift (TTS) is based on exceeding EFD levels of 182 dB re μPa^2 s in any 1/3-octave frequency band. The standard approach in this case is to apply frequency domain filtering to the pressure waveform prior to computation of the threshold. This approach is recommended only for the EFD (or SEL) and rms metrics. Modified versions of the peak pressure metric have also been developed to account for the frequency-dependent hearing sensitivities of specific species; two recent frequency weighting approaches are the dB_{ht}(Species) and M-weighting methods.

4.6.4. dB_{ht}(species)

As a means of assessing potential injury from acoustic sources, the dB_{ht}(Species) metric expresses sound pressure levels relative to species-specific hearing thresholds. It is used most commonly for gauging impacts of continuous sounds, although it also may be applicable for impulsive noise. This metric is based on the same principle as frequency weighting schemes used for determining impacts of noise on humans. It is computed by first filtering the pressure function according to the frequency sensitivity of the species of interest. The resulting time series is analyzed to determine the peak or rms sound pressure level. A level of 0 dB_{ht} should be just audible, i.e. at the hearing threshold of the species. Measurements of hearing sensitivity versus frequency for individual species, known as audiograms, have been made for many fish species and a limited number of marine mammals. To date, no sea turtle data have been compiled. Confidence in the accuracy of audiograms for most marine species is limited at the present time due to the small number of individuals on which these measurements have been performed.

4.6.5. M-weighting

When applying the hearing threshold audiogram measures to a potentially injurious sound or shock wave, one should be cautious about injury caused by mechanisms other than those having to do with perceived loudness. Consider an animal with poor hearing at low frequencies being exposed to an extraordinarily high sound pressure at low frequencies. The audiogram-based dB_{ht} measure will be much lower than the absolute pressures and could be misleading in terms of the amount of injury incurred. A recent frequency weighting scheme, referred to as M-weighting, has been devised to address this problem for marine mammals (NMFS Noise Exposure Criteria Group, 2005). The M-weighting approach considers both audible and inaudible acoustic frequencies. It is similar to the C-weighting approach used to assess impulsive noise impacts on humans. The approach most strongly weights the audible frequencies but also provides lower weight values to frequencies above and below the audible frequency range. Five M-weight sets have been defined for use with the different marine mammal species groups: low-frequency cetaceans (whales and dolphins), mid-frequency cetaceans, high-frequency cetaceans, pinnipeds (seals and sea lions) in water, and pinnipeds in air.

5. Potential impacts to sea turtles

This section focuses on potential impacts to sea turtles from underwater EROS and does not address other impact-producing factors such as water quality degradation, vessel collisions, and site clearance trawling associated with decommissioning or other OCS activities. Effects of underwater explosions on pelagic marine vertebrates such as sea turtles are dependent on several factors, including the size, type, and depth of the explosive charge; overall water column depth; size and depth of the animal in the water column; and standoff distance from the explosive charge to the organism (Department of the Navy, 2001, 2007). Impacts to marine vertebrates are a result of physiological responses (generally the destruction of tissues at air–fluid interfaces) to both the type and strength of acoustic signature and shock wave generated by an underwater explosion.

Very little information exists regarding the impacts of underwater explosions on sea turtles. These effects of explosions on turtles often must be inferred from documented effects to other vertebrates, including humans, marine mammals, and fishes with lungs or other gas-containing organs. However, impacts to these other vertebrates may not be reliably extrapolated to sea turtles.

In the following subsections, potential impacts to sea turtles are categorized as non-injurious and injurious effects. Non-injurious effects are further subdivided into acoustic annoyance and tactile detection or physical discomfort. Injurious effects are further subdivided into non-lethal and lethal injuries. Quantitative data concerning effects of underwater explosions on sea turtles are discussed in the last subsection titled documented injuries.

5.1. Non-injurious effects

Non-injurious effects of underwater explosions to sea turtles include acoustic annoyance and mild tactile detection or physical discomfort.

5.1.1. Acoustic annoyance

The ear anatomy of sea turtles has been discussed by Wever (1978); Lenhardt et al. (1985); Moein (1994); Bartol et al. (1999), and Bartol and Musick (2003). Ear anatomy serves as the basis for an analysis of sound reception processes in sea turtles. As with mammals, most reptiles demonstrate three principal divisions of the ear: the outer, middle, and inner ear. In turtles, an external ear is entirely absent (Wever, 1978). The outer ear of turtles receives sound waves from the external environment. The sound-receptive and sound-conductive mechanism of the middle ear is well developed (Hadiselimoviæ and Andeliæ, 1967 and Wever, 1978) and most important to evaluating potential impacts because of the air filled chamber referred to as the tympanic cavity.

Electrophysiological studies on the acoustic sensitivity of the green turtle (*Chelonia mydas*) and loggerhead turtle (*Caretta caretta*) using auditory brainstem response (ABR) techniques determined that the effective range of hearing of these species is within low frequencies (100 to 500 Hz) (Ridgway et al., 1969, 1970; Lenhardt et al., 1994; Moein, 1994; Moein et al., 1994; Bartol et al., 1999 and Bartol and Ketten, 2003). Bone-conducted hearing appears to be an effective reception mechanism for sea turtles (i.e. loggerhead and Kemp's ridley [*Lepidochelys kempii*]), with both the skull and shell acting as receiving surfaces for waterborne sound at frequencies encompassing the 250 to 1000 Hz range (Lenhardt et al., 1983 and Moein et al., 1993, 1994). As high sound frequencies are attenuated by bone, the range of bone-conducted sounds detected by sea turtles are limited to only low frequencies (Tonndorf, 1972).

These data suggest that sea turtle auditory perception occurs through a combination of both bone and water conduction rather than air conduction (Lenhardt, 1982 and Lenhardt and Harkins, 1983). From these studies, it is reasonable to assume that the sea turtle auditory apparatus is sensitive to sounds produced by underwater explosions, and the air-filled middle ear (tympanic cavity) is sensitive to associated pressure effects. It may be presumed that a momentary startle response or perhaps temporary disorientation of a sea turtle could result from detonations of low intensity or of sufficient distance to be detected but not injurious.

5.1.2. Tactile detection or physical discomfort

Data pertaining to the tactile perception of sea turtles from an explosive shock wave are not available. It is reasonable to assume that sea turtle skin in soft tissue areas, particularly areas around the eyes, mouth, external nares, and vent, are sensitive to tactile stimulation. Based on studies conducted on human subjects, reports of tactile perception associated with low level or distant underwater detonations range from the sensation of pressure, to "stings" of varying degrees (moderate or strong) when exposed to shock waves (Department of the Navy, 2001, 2007). It is expected that sea turtles also may experience similar sensations when exposed to low intensity or distant explosive shock waves. However, the tactile perception of sea turtles to explosive shock waves within this range of intensity would be of such brevity that it would be expected to cause at most a momentary startle response. If exposed to stronger shock waves, strong tactile responses (moderate to strong stings) would likely occur along with injuries to the auditory system and other internal organs.

5.2. Injurious effects

Generally, blast injury, defined as biophysical and pathophysiological events and clinical syndromes that occur when a living body is exposed to a blast of any origin, comprises two categories: primary blast injury (PBI) and cavitation (Costanzo and Gordon, 1989; Office of the Surgeon General, 1991 and Department of the Navy, 2001, 2007). PBI occurs when the blast wave strikes and compresses the body, and energy from the blast is transferred directly from the transmitting medium (air or water) to the body surface. Cavitation occurs when compression waves generated by an underwater explosion propagate to the surface and are reflected back through the water column as rarefaction waves. Subsequently, rarefaction waves create a state of tension within the water column, causing cavitation (defined as the formation of partial vacuums in a liquid by high intensity sound waves) within a bounded area called the cavitation region.

Injury resulting from PBI is almost totally limited to gas-containing organs. For sea turtles, this would be primarily the auditory system and lungs (Geraci and St. Aubin, 1985). The direct effects of cavitation on marine turtles are unknown, though (as with marine mammals) it is assumed that cavitation created by detonation of a small charge could directly annoy or injure (primarily the auditory system or lungs) or increase the severity of PBI injuries to turtles in the cavitation region (Department of the Navy, 2001, 2007).

5.2.1. Non-lethal injuries

Non-lethal injuries include minor injuries to the turtle's auditory system and certain internal organs. However, delayed complications arising from individual or cumulative non-lethal injuries may ultimately result in death of a sea turtle.

The organ most sensitive to the primary effects of a blast wave is the auditory apparatus (Office of the Surgeon General, 1991). Rupture of the tympanic membrane, or the tympanum in the case of sea turtles, while not necessarily a serious or life-threatening injury, may lead to permanent hearing loss (Ketten, 1995, 1998). No data exist that correlate the sensitivity of the sea turtle tympanum and middle and inner ear to trauma associated with shock waves associated with underwater explosions.

Other slight injuries include those to internal organs. These include slight lung hemorrhage and contusions (defined as injury to tissue, usually without laceration [such as bruising]) and hemorrhage of the gastrointestinal tract caused by excitation of radial oscillations of small gas bubbles normally present in the intestine (Richmond et al., 1973 and Yelverton et al., 1973). Goertner (1982) developed a conservative model for calculating the ranges for occurrence of these two types of internal organ injuries to marine mammals when exposed to underwater explosion shock waves. This model by itself is not directly applicable to sea turtles, as it is not known what degree of protection to internal organs from shock waves is provided to sea turtles by their shell. The general principles of the model, however, may be applicable. For lung hemorrhage, the Goertner model considered lung volume and its shock wave impulse tolerance as a function of animal body mass and depth. Injuries to the gastrointestinal tract, however, could be related to the magnitude of the peak shock wave pressure over the hydrostatic pressure, which, according to the Goertner model, is independent of animal size and weight. Overall, non-lethal injuries associated with underwater explosions, such as the onset of lung hemorrhage and gastrointestinal tract contusion, are injuries from which a sea turtle would be expected to recover on its own and would not be debilitating (Department of the Navy, 2001, 2007).

5.2.2. Lethal injuries

5.2.2.1. Lethal injuries to internal organs. Lethal injuries may result from massive trauma or combined trauma to internal organs as a direct result of proximity of the affected turtle to the point(s) of detonation. Extensive lung hemorrhage is an injury that sea turtles would not be expected to survive (Department of the Navy, 2001, 2007). This discussion draws from observations made on mammals subjected to underwater explosions. Gastrointestinal tract injuries associated with the onset of extensive lung hemorrhage are shown to include contusions with no ulcerations (defined as a break or disintegration of the surface tissue; Richmond et al., 1973). As severity of lung hemorrhage increases, gastrointestinal tract injuries would be expected to include contusions with ulcerations throughout the tract, ultimately including tract ruptures. Mortality associated with these combined severe injuries is expected to be almost certain. As described in the Department of the Navy (2001, 2007) analysis of impacts of underwater explosions on marine mammals, the onset of extensive lung hemorrhage also may be used as a conservative index for the onset of mortality of sea turtles of any size class.

5.2.2.2. Lethal injuries from shock waves with high peak pressure. Exposure of animals to high peak pressure shock waves may result in concussive brain damage; cranial, skeletal, or shell fractures; hemorrhage; or massive inner ear trauma (Ketten, 1995). Depending on the size of the animal (with small animals being more susceptible), extremely high shock wave pressure impulse levels may or may not be lethally injurious to internal organs. However, overall system shock and significant external tissue damage as well as severe localized damage to the skeletal system would be expected. These injuries, if not themselves fatal, would probably put the animal at increased risk of predation, secondary infection, or disease (Department of the Navy, 2001, 2007).

5.2.3. Documented injuries

In 1981, three unidentified sea turtles were unintentionally exposed to three underwater detonation tests carried out by the Naval Coastal Systems Center off Panama City, Florida (O'Keeffe and Young, 1984). Each test detonated a mid-water charge equivalent of 1200 lb (545 kg) of trinitrotoluene (TNT) in water of about 120-ft (37-m) depth. Three unidentified sea turtles were noted subsequent to the detonations. The first, a 400-lb (182-kg) animal, was killed at a distance of 500 to 700 ft (153 to 214 m) from the charge. The second, a 200- to 300-lb (91- to 136-kg) animal, received non-lethal, minor injuries at a range of 1200 ft (366 m) from the charge. The third, another 200- to 300-lb (91- to 136-kg) animal, was apparently unaffected at a range of 2000 ft (610 m) from the charge. Turtle depths at the time of detonation are unknown. Assuming these animals were at a mid-water depth of 60 ft (18 m) at the time of the detonation, calculated shock wave pressures are 258 to 178, 99, and 57 psi (1758 to 1213, 675, and 388 kPa) at ranges of 500, 700, 1200, and 2000 ft (152, 213, 366, and 610 m), respectively (Department of the Navy, 2001). A summary of the effects of underwater explosions on sea turtles, as reported by O'Keeffe and Young (1984) and Klima et al. (1988), is presented in Table 1.

In March and April 1986, the first evidence of potential impacts of EROS to protected species became apparent when 51 sea turtles, primarily Kemp's ridley, and 41 bottlenose dolphin (*Tursiops truncatus*) were found dead on Texas beaches shortly after the explosive removal of oil and gas structures in Texas State waters of the Gulf of Mexico that involved 22 underwater explosions (Klima et al., 1988 and National Research Council, 1996). Because commercial shrimp trawling operations (a major cause of sea turtle mortality) were at a very low level in the area, these mortalities were attributed to (but never directly correlated with) explosions associated with the structure removals (Klima et al., 1988).

In July 1986, an unidentified dead or injured turtle was found drifting in an inverted position about 10 ft (3 m) below the water surface in the Gulf of Mexico. This turtle was sighted 1.5 h after an explosive removal of an offshore platform off Sabine Pass, Texas (Gitschlag and Renaud, 1989).

After a 1987 explosive platform removal in the Gulf of Mexico, two loggerhead turtles were found stranded on nearby beaches and autopsied. One turtle showed no characteristics consistent with explosive impacts. External inspection of the second turtle revealed a bloated carcass with green-colored flesh and evidence of gas bubbles below the shell scutes. Necropsy results showed lung hemorrhage, four ruptures of the right atrium, and bloody fluid in the pericardial sac. Though lung hemorrhage is consistent with impacts resulting from underwater explosions, this condition, along with ruptures in the heart, also may have been the result of postmortem decomposition (Klima et al., 1988).

In 1991, a loggerhead was found with a fracture down the length of its carapace. This turtle surfaced within 1 min of detonation at a removal site of a caisson in the Gulf of Mexico (National Research Council, 1996).

Two immature green turtles were killed when 20 lb (9.1 kg) of plastic explosives (C-4) were detonated in open water in the eastern Gulf of Mexico (at distances of 100 to 150 ft [30.5 to 45.7 m] from the charge) by a U.S. Navy Ordnance Disposal Team. Necropsy examinations revealed extensive internal damages, particularly to the lungs (National Research Council, 1996). Overall water depth, charge depth, and turtle depths were not reported. Turtle body mass also was not provided, although it is assumed to be small, considering the turtles were reported as of "immature" size class. In an open water environment, 20 lb (9.1 kg) of C-4 explosive would be expected to generate nominal peak pressures of 347 and 244 psi (2392 and 1682 kPa) at ranges of 100 and 150 ft (30.5 and 45.7 m), respectively (Department of the Navy, 2001).

Klima et al. (1988) placed four Kemp's ridley and four loggerhead turtles in cages at four distances (750 ft [213 m], 1200 ft [366 m], 1800 ft [549 m] and 3000 ft [915 m]) from an offshore platform scheduled for removal using explosive charges. Cages were suspended at a depth of 15 ft (4.5 m) over a seafloor of 30 ft (9 m) depth prior to the simultaneous detonation of four, 50.75-lb (23-kg) charges of nitromethane, placed inside the platform's support pilings at a depth of 16 ft (5 m) below the seafloor surface ("mudline"). Sea turtles exposed at 750 and 1200 ft, as well as one loggerhead exposed at 3000 ft, were rendered unconscious. The Kemp's ridley turtle exposed at 750 ft also sustained slight physical injury, showing an eversion of cloacal lining through its vent. Remaining Kemp's ridley turtles at more distant ranges were apparently unharmed. All loggerheads displayed abnormal pink coloration of soft tissues around the eyes and external nares, and at the base of the throat and flippers, reportedly caused by a dilation of blood vessels. This condition persisted in these individuals for a period of 2 to 3 weeks.

Unfortunately, data collected by Klima et al. (1988) did not include concurrent pressure measurements to estimate the magnitude and duration of the shock wave received by the caged turtles. Peak shock wave pressures for buried charges such as those used in this platform removal may be as low as 10% of expected free-field values for non-buried charges (Connor, 1990). Ranges and estimated pressures for this data set were used to calculate an equivalent "non-buried" charge weight, using standard similitude equations and weak shock theory (Gaspin, 1983). From these data, a 2-lb (0.92-kg) TNT charge detonated free-field would produce the shock wave pressures at the ranges shown in Table 1. Because the water depth of this platform

Table 1
Underwater explosion effects on sea turtles reported by O'Keeffe and Young (1984) and Klima et al. (1988) (from: Department of the Navy, 2001)

Charge weight lb (kg)	Charge depth ft (m)	Water depth ft (m)	Turtle weight lb (kg)	Turtle depth ft (m)	Range ft (m)	Peak pressure psi (kPa)	Injuries	
							Immediate	1 h after blast
O'Keeffe and Young (1984)								
1200[a] (544)	60 (18.3)	120 (36.6)	400 (181)	Unknown	500–700 (152–213)	258–178 (1758–1213)[b]	Mortal injury	–
1200[a] (544)	60 (18.3)	120 (36.6)	200–300 (91–136)	Unknown	1200 (366)	99 (675)[b]	Minor injury	–
1200[a] (544)	60 (18.3)	120 (36.6)	200–300 (91–136)	Unknown	2000 (610)	57 (388)[b]	None	–
Klima et al. (1988)								
203[b] (92)	14.8 (4.5)[c]	29.5 (9.5)	14.8 (6.7)	14.8 (4.5)	750 (229)	16.3 (111)[c]	Unconscious	Vasodilation around throat and flippers (lasted 2–3 wks); 2 cm of cloacal lining everted
203[b] (92)	14.8 (4.5)[c]	29.5 (9.5)	9.3 (4.2)	14.8 (4.5)	750 (229)	16.3 (111)[c]	Unconscious	As above and including redness around eyes and nose
203[b] (92)	14.8 (4.5)[c]	29.5 (9.5)	1.3 (0.6)	14.8 (4.5)	1200 (366)	10.3 (70)[c]	Unconscious	Appeared normal
203[b] (92)	14.8 (4.5)[c]	29.5 (9.5)	12.1 (5.5)	14.8 (4.5)	1200 (366)	10.3 (70)[c]	Unconscious	Normal behavior, but vasodilation around base of flippers (lasted 2–3 wks)
203[b] (92)	14.8 (4.5)[c]	29.5 (9.5)	2.9 (1.3)	14.8 (4.5)	1800 (549)	6.5 (44)[c]	None visible	Appeared normal
203[b] (92)	14.8 (4.5)[c]	29.5 (9.5)	8.8 (4.0)	14.8 (4.5)	1800 (549)	6.5 (44)[c]	None visible	Appeared normal except for vasodilation around throat and flippers (lasted 2–3 wks)
203[b] (92)	14.8 (4.5)[c]	29.5 (9.5)	3.3 (1.5)	14.8 (4.5)	3000 (915)	4.1 (28)[c]	None visible	Appeared normal
203[b] (92)	14.8 (4.5)[c]	29.5 (9.5)	15.0 (6.8)	14.8 (4.5)	3000 (915)	4.1 (28)[c]	Unconscious	Appeared normal except for vasodilation around throat and flippers (lasted 2–3 wks)

[a] TNT equivalent.

[b] Four 50.75-lb (23-kg) nitromethane charges buried 16.4 ft (5 m) below the mudline.

[c] Calculations for buried charges assumed a 2-lb (0.92-kg) TNT charge detonated "free-field" at mid-depth in the water column.

removal was extremely shallow (30 ft [9 m]), multiple shock wave pulses and bulk cavitation resulting from bottom- and surface-reflected shock waves could have affected the turtles.

6. Mitigation

Discovery of beached sea turtles and bottlenose dolphins following the 1986 explosive platform removal event prompted initiation of formal consultation between the MMS and NMFS authorized through ESA Section 7 (Henwood, 1988). The purpose of this consultation was to determine a mechanism to minimize potential impacts to listed species. On 25 July 1988, the NMFS issued a Biological Opinion describing potential impacts to sea turtles from explosive removals of offshore structures in the Gulf of Mexico. This resulted in a requirement for oil and gas companies to obtain a permit (through separate consultations on a case-by-case basis) from the MMS prior to using explosives in Federal waters. Because many offshore structure removal operations are similar, a “generic” Incidental Take Statement was included in the 25 July 1988 Biological Opinion that describes requirements to protect sea turtles. Regulations, including those designed to protect marine mammals, such as the endangered sperm whale (*Physeter macrocephalus*), have evolved from the initial guidelines specified in the 1988 Biological Opinion. A brief discussion of these regulations is presented in following sections.

Table 2
Summary of the National Marine Fisheries Service “Generic” incidental take statement requirements regarding protection of sea turtles prior to and during the explosive removal of offshore structures (from: Richardson, 1989 and Gitschlag et al., 1997)

1) Qualified observers must monitor the area around the site for sea turtles beginning 48 h prior to detonations;
2) A 30-minute aerial survey must be conducted within 1 h prior to and after detonation;
3) If sea turtles are observed within 1000 yards of the structure prior to detonation, detonations must be delayed until the animals have moved beyond 1000 yards. The aerial survey also must be repeated;
4) Detonations must occur no sooner than 1 h after sunrise and no later than 1 h before sunset;
5) During salvage-related diving, divers must report turtle and mammal sightings. If turtles are thought to be resident, pre- and post-detonation diver surveys must be conducted;
6) Explosive charges must be staggered to minimize cumulative effects of explosions;
7) Avoid use of “scare” charges to frighten away turtles that may be attracted to the point of detonation to feed on dead marine life and be subsequently exposed to explosions; and
8) The structure removal company must file a report summarizing the results.

6.1. 25 July 1988 NMFS Biological Opinion

A summary of requirements specified in the 25 July 1988 Biological Opinion, as described in Richardson (1989) and Gitschlag et al. (1997), are listed in Table 2. To be considered under the “generic consultation,” a proposal for an explosive structure removal had to meet the following limitations, with individual charge weights that could not exceed 50 lb (23 kg), as established by the NMFS (from Richardson, 1989):

1) High velocity explosives with a detonation rate of 25,000 ft/s (7600 m/s) or greater must be used;
2) Each explosive charge cannot exceed 50 lb (23 kg) (with a maximum 50-lb [23-kg] backup charge);
3) Charges must be placed a minimum of 15 ft (5 m) below the seafloor (mudline); and
4) Detonations must be limited to groups of eight or less, with a minimum of 900 ms (0.9 s) between each detonation.

Similar procedures were adopted for explosive structure removals in State waters, where permits were managed and obtained by the U.S. Army Corps of Engineers.

In 1987, the NMFS initiated a sea turtle observer program that followed the guidelines specified in the NMFS Incidental Take Statement (Table 2) at all oil and gas structure explosive removal sites in both State and Federal waters of the Gulf of Mexico (Gitschlag, 1990). Aerial survey techniques were found to be approximately 10 times more effective in observing sea turtles than day or night surface surveys (i.e. from vessels and from oil and gas platforms). During these surveys, turtles were primarily sighted near structures positioned in water depths of approximately 50 to 200 ft (15 to 60 m) (Gitschlag et al., 1997). From 1987 through 1988, surveys sighted turtles at 13% of the structures removed (Gitschlag and Renaud, 1989). Surveys conducted during 1992 and 1993 sighted sea turtles at 20% and 13% of the structures monitored, respectively (Gitschlag and Herczeg, 1994 and Gitschlag et al., 1997). The sea turtle observer program has been successful in mitigating impacts to sea turtles associated with EROS. However, even with these protective measures in place, there have been observations of sea turtles impacted by explosive platform removals (Table 3).

Subsequent to the sea turtle mortalities associated with underwater detonations in 1981, O’Keeffe and Young (1984) proposed that a safe range for sea turtles from a free-field underwater explosion could be expressed by the equation $R=200\ w^{1/3}$, where R is the safe distance, or range, in feet and w is the charge

Table 3
Sea turtles affected by explosive structure removals from 1987 to May 2003 (From: G.R. Gitschlag, 2003, personal communication, NMFS, Galveston, TX)

Month	Year	Species	Observed condition
October	1990	Loggerhead turtle (*Caretta caretta*)	Cracked shell
November	1997	Loggerhead turtle (*Caretta caretta*)	Cracked shell
July	1998	Loggerhead turtle (*Caretta caretta*)	Dead from blast
August	2001	Loggerhead turtle (*Caretta caretta*)	Stunned from blast

weight in pounds. This equation was later modified by Young (1991) to $R = 560\ w^{1/3}$, based on estimates of safe ranges as established by the NMFS for explosive platform removals. The metric form of this equation is R (m) $= 222\ W$ (in kg)$^{1/3}$. Young (1991), however, suggested that calculated sea turtle safe ranges should be used for preliminary planning purposes only. For example, applying the Young (1991) equation for safe distances to observations recorded in Klima et al. (1988), this equation predicts a safe range of 3291 ft (1003 m), which is slightly greater than the greatest distance at which an effect was observed (i.e. a turtle was rendered unconscious at a distance of 3000 ft [915 m], the greatest distance tested) (Department of the Navy, 2001). These results suggest that explosive impacts might be realized at distances greater than 3000 ft (915 m).

Using the O'Keeffe and Young (1984) data for sea turtles, a model developed by Goertner (1982) for calculating the ranges for occurrence of two types of internal organ injury to marine mammals exposed to shock waves associated with an underwater explosion was run for the test conditions for the onset of lung hemorrhage, onset of extensive lung hemorrhage, and extensive lung hemorrhage (Department of the Navy, 2001). Prediction results from this test were consistent with the mortal injury suffered by the 400-lb (181-kg) turtle located 500 to 700 ft (153 to 214 m) from the detonation, the minor injuries suffered by the 200- to 300-lb (91- to 136-kg) turtle 1200 ft (366 m) from the detonation, and the uninjured 200- to 300-lb (91- to 136-kg) turtle 2000 ft (610 m) from the detonation. These results suggest that lung injury predictions for sea turtles are not inconsistent with predictions for small mammals, as developed for the impact analysis of the Final Environmental Impact Statement for the shock trial of the guided missile destroyer WINSTON S. CHURCHILL, also known as DDG 81 (Department of the Navy, 2001).

Keevin and Hempen (1997) suggest that it may be possible to protect sea turtles from underwater explosions by either avoiding periods when they are in the project area or by removing the turtles from the project area. Depending on location and species, there may be time periods when certain sea turtle species are not in the project area due to life history, migratory, or seasonal patterns. These periods may be determined by coordination with the State natural resource agency or the NMFS. Theoretically, detonations may be planned during time periods of low turtle abundance. However, in areas such as the Gulf of Mexico, sea turtles are ubiquitous during all seasons except perhaps during mid-winter months when seawater temperatures are depressed. Explosive removal activities during these months rarely occur because of inclement weather conditions. As a last resort, turtles have been physically captured and removed from the project area; however, this method is considered inefficient and unreliable.

6.2. 10 October 2003 NMFS Biological Opinion

Increasing interest in the use of engineered explosives (i.e. explosives of reduced charge weight whose shape or placement has been engineered for a particular application) potentially reduces the amount of explosive required and the potential zone of impact (e.g. see Saint-Arnaud et al., 2004). In June 2003, the MMS requested that the NMFS establish a de minimus explosive weight limit of 5 lb (2.3 kg) to reflect a decreased impact zone and limited mitigation needed to ensure adequate protection of sea turtles. The MMS believed that a de minimus limit would also provide an incentive to design and use smaller, but more efficiently shaped, explosive charges. The NMFS entered into an informal Section 7 consultation with the MMS and then issued a new Biological Opinion on 10 October 2003, allowing offshore operators the option of reducing required mitigation and allowing them to conduct their own pre-detonation monitoring.

If offshore operators used explosive charges with a weight greater than 5 lb (2.3 kg) and less than or equal to 50 lb (23 kg), the "generic consultation" requirements applied (see Table 2). If offshore operators used explosive charges with a weight of 5 lb (2.3 kg) or less (under the de minimus limits), the NMFS established the following specific mitigations in place of using NMFS staff observers and conducting aerial surveys:

1) Observers may be operator or removal contractor employees; observers must have attended observer

Table 4

Blasting categories, mitigation scenarios, and monitoring survey and time requirements for all explosive removal scenarios (from: U.S. Department of Commerce, 2006)

Blasting category	Placement configuration [a] (Charge wt [lb])	Species delineation zone [b]	Impact zone radius [c]	Mitigation scenario [d]	Pre-detonation [e] surface survey [f] (min)	Pre-detonation [e] aerial survey [g] (min)	Pre-detonation [e] acoustic survey [h] (min)	Post-detonation [e] surface survey [f] (min)	Post-detonation [e] aerial survey [g] (min)	Post–Post-detonation [i] aerial survey [g] (Yes/No)
Very-Small	BML (0–10 lb)	OCS shelf	856 ft (261 m)	A1	60	N/A	N/A	30	N/A	No
		OCS slope		A2	90	N/A	N/A	30	N/A	No
	AML (0–5 lb)	OCS shelf	961 ft (293 m)	A3	60	N/A	N/A	30	N/A	No
		OCS shelf		A4	90	N/A	N/A	30	N/A	No
Small	BML (> 10–20 lb)	OCS shelf	1224 ft (373 m)	B1	90	30	N/A	N/A	30	No
		OCS slope		B2	90	30	N/A	N/A	30	No
	AML (> 5–20 lb)	OCS shelf	1714 ft (522 m)	B3	90	30	N/A	N/A	30	No
		OCS slope		B4	90	30	N/A	N/A	30	No
Standard	BML (> 20–80 lb)	OCS shelf	2069 ft (631 m)	C1	90	30	N/A	N/A	30	No
		OCS slope		C2	90	30	120	N/A	30	No
	AML (> 20–80 lb)	OCS shelf	2721 ft (829 m)	C3	90	45	N/A	N/A	30	No
		OCS slope		C4	90	60	150	N/A	30	Yes
Large	BML (> 80–200 lb)	OCS shelf	3086 ft (941 m)	D1	120	45	N/A	N/A	30	No
		OCS slope		D2	120	60	180	N/A	30	Yes
	AML (> 80–200 lb)	OCS shelf	3693 ft (1126 m)	D3	120	60	N/A	N/A	30	No
		OCS slope		D4	150	60	210	N/A	30	Yes
Specialty	BML (> 200–500 lb)	OCS shelf	4916 ft (1500 m)	E1	150	90	N/A	N/A	45	No
		OCS slope		E2	180	90	270	N/A	45	Yes
	AML (> 200–500 lb)	OCS shelf	5012 ft (1528 m)	E3	150	90	N/A	N/A	45	No
		OCS slope		E4	180	90	270	N/A	45	Yes

N/A = Not applicable.

[a] BML = Below Mudline; AML = Above Mudline.

[b] OCS Shelf = MMS OCS Continental Shelf (< 656 ft [200 m]); OCS Slope = MMS OCS Continental Slope (> 656 ft [200 m]).

[c] Horizontal radius around a decommissioning target in which a marine protected species could be affected during detonation of an explosive removal charge.

[d] Twenty, specific mitigation scenarios (A1–4, B1–4, C1–4, D1–4, and E1–4) were developed to address explosive removal activities conducted under the five blasting categories (very small, small, standard, large, and specialty), considering both charge placement configuration and species delineation zone (OCS shelf/slope).

[e] Any marine protected species survey (surface, aerial, or acoustic) conducted prior to/after the detonation of any explosive cutting (severance) tool. Survey time requisites (expressed in minutes before/after detonation) take into consideration the marine protected species and their surfacing rates.

[f] Marine protected species monitoring surveys conducted during daylight hours from the highest vantage point available on the structure being removed or proximal surface vessels. Surface surveys will be restricted to daylight hours only and monitoring will cease upon inclement weather or when marine conditions are not adequate for visual observations.

[g] Marine protected species monitoring surveys conducted during daylight hours from helicopters running low-altitude search patterns over the impact zone. Aerial surveys will be conducted after requisite surface survey has been completed, will be restricted to daylight hours, and will cease upon inclement weather, when marine conditions are not adequate for visual observations, or when the pilot/removal supervisor determines that helicopter operations must be suspended.

[h] Marine protected species (marine mammals only) monitoring surveys conducted on C2, C4, D2, D4, E2, and E4 scenarios in the OCS slope (> 656 ft [200 m]) Species Delineation Zone. Acoustic surveys will use NOAA-approved passive acoustic monitoring devices and technicians will be run concurrent with requisite pre-detonation surface and aerial surveys.

[i] Aerial surveys that are conducted on C4, D2, D4, E2, and E4 mitigation scenarios. These aerial surveys will be conducted within 2 to 7 days after detonation activities conclude. Observations start at the removal site and proceed to leeward and outward of wind and current movement.

training courses offered by private or government entities;

2) Observers must be stationed in a small watercraft and/or on an elevated platform on a derrick barge;
3) Observers must survey for sea turtles and marine mammals in the impact zone — an area with a 700-ft (213-m) radius centered on the detonation site in Beaufort sea states 0 through 3. Adequate environmental conditions must exist to allow for observations of the animals in the impact zone;
4) In all water depths, observations must begin at least 30 min before each detonation;
5) Observations must not commence earlier than 20 min after sunrise. Therefore, no detonation in water depths 656 ft (200 m) or less can occur until at least 50 min following sunrise, and no detonation in water depths greater than 656 ft (200 m) can occur until at least 80 min following sunrise; and
6) All pre-detonation survey requirements for sea turtles and marine mammals must be fully completed at least 1 h before sunset. Therefore, all detonations must be completed at least 1 h before sunset.

6.3. 28 August 2006 NMFS Biological Opinion

Changes in structure removal methods and concerns regarding explosive structure removals in deeper waters of the Gulf of Mexico OCS slope (greater than 656 ft [200 m] depth), where there are legitimate concerns for diverse marine mammal species such as the endangered sperm whale, were addressed by the MMS and NMFS during the Explosive-Severance Workshop held in May 2004. A revised mitigation program was proposed by the MMS in 2005 (MMS, 2005). Formal consultation between the MMS and NMFS (13 May 2005) resulted in the preparation of an updated Biological Opinion, which was approved on 28 August 2006 (U.S. Department of Commerce, 2006). Various mitigation scenarios were developed for specific ranges of explosive charge weights, the placement of explosives above or below the mudline, and ambient water depth. Five “blasting categories” were developed based on specific ranges of charge weights needed to conduct future OCS structure removals. These categories may be used within two species-specific delineation zones: the OCS shelf (< 656 ft [200 m] water depth) and the OCS slope (> 656 ft [200 m] water depth). Within these charge configurations and delineation zones, the MMS developed 20 mitigation scenarios to address severance activities (Table 4). Monitoring requirements and methodologies associated with each mitigation scenario were developed, taking into consideration the characteristics and surfacing rates of marine protected species (sea turtles and marine mammals), calculated impact parameters, and current mitigation requirements. Monitoring surveys and associated time periods were designed to allow for adequate detection of protected marine species that may be present within each impact zone based on the potential presence of these species and overall size of the impact area. Details of each mitigation scenario are discussed in the Biological Opinion (U.S. Department of Commerce, 2006).

7. Discussion

There have been no laboratory studies and only limited field observations and experiments of explosive impacts on sea turtles. In several instances, turtle injuries and mortalities (and in some cases, strandings) have been noted following underwater detonations. In one case where turtles were recovered after an open-water detonation, both charge weight and the approximate distances of the turtles from the detonation were known (O’Keeffe and Young, 1984). Only one field experiment has been conducted in which sea turtles were exposed at known distances from a structure removal detonation; however, that study did not include concurrent pressure measurements to estimate the magnitude and duration of the shock wave received by caged turtles (Klima et al., 1988). There have been several reports of turtle impacts and injury following structure removal detonations, including a few in the 15 years since the current mitigation requirements (monitoring) were instituted (G.R. Gitschlag, 2003, personal communication, NMFS, Galveston, Texas).

There have been no mechanistic models developed specifically to estimate impacts on sea turtles. Rather, it has been assumed that models developed for other vertebrates are reasonable approximations. O’Keeffe and Young (1984) developed an equation for a turtle “safety range” (the distance beyond which turtles would not likely be killed or seriously injured) based on field observations of three turtles following an open-water detonation. The equation is based on cube-root scaling of the charge weight and the distance at which one turtle apparently was not affected. Young (1991) provided a more conservative version of the same equation but states that it is based on the criteria for platform removal established by the NMFS (i.e. it was not independently derived from observations or experimental data). The Department of the Navy (2001) also modeled effect ranges using the turtle death/injury observations from O’Keeffe and Young (1984) and a lung injury model developed by Goertner (1982) for small mammals. Results suggest that lung injury predictions for sea turtles are not inconsistent with predictions for small mammals.

An important goal with respect to sea turtles is calculating the areal extent of the mortality/injury zone so that this area can be monitored for turtles prior to detonations. In the 1988 "generic consultation" for structure removals in the Gulf of Mexico, the NMFS specified that the area within 3000 ft (915 m) of the platform must be clear of visible sea turtles prior to detonation. The NMFS document does not specify the source of this number, but it apparently is based on the turtle death/injury observations to date (Klima et al., 1988) rather than any modeling. Klima et al. (1988) reported that of two turtles at this distance from platform removal detonations, one was normal and the other was rendered unconscious but appeared normal other than vasodilation around the throat and flippers.

Years of experience using the 3000-ft (915-m) range monitored under the "generic consultation" suggests it was effective in preventing most deaths or serious injuries of sea turtles (Gitschlag and Herczeg, 1994 and Gitschlag et al., 1997). In addition, the modeling analyses done by the Department of the Navy (2001, 2007), while not directly addressing the "safety range" for structure removals, suggest that the monitoring range specified in the "generic consultation" was likely to prevent death and lung injury to sea turtles. However, the empirical and theoretical basis for this specific number was weak. Knowledge gained from marine mammal studies in recent years was instrumental in the major revision of mitigation methods, including safety range (or impact zone radius), based on charge weight and placement and ambient water depth (U.S. Department of Commerce, 2006).

It may be possible to collect supportive data concerning explosion parameters that may result in non-lethal injuries to the sea turtle auditory mechanism or other gas-filled organs by conducting tests on non-listed aquatic turtle species. Studies designed to ascertain damaging effects (non-lethal or lethal) of underwater explosions on sea turtle organs and other tissues may utilize dead sea turtles, similar to ongoing and successful studies conducted on dead marine mammals by Ketten et al. (2003).

Visual census methods (i.e. shipboard and aerial surveys) provide the most reliable means available to determine the presence of sea turtles around offshore oil and gas structures prior to explosive removals. Active underwater acoustic methods are untested, and data may be confounded by subsurface structures as well as the presence of large fishes or fish aggregations associated with offshore structures.

8. Conclusions

For sea turtles, there have been no laboratory studies of blast injury, only limited field observations and experiments. No mechanistic models have been developed specifically to estimate impacts to sea turtles.

Years of experience using the 3000-ft (915-m) "safety range" monitored under the "generic consultation" suggest it has been effective in preventing most sea turtle deaths and serious injuries. However, the empirical and theoretical basis for this specific number was considered weak, and did not take into consideration the potential effects to marine mammal species, especially deep water species such as the sperm whale. Mortality/injury zones were revised for sea turtles and marine mammals using standard sound level metrics and incorporating detonation characteristics appropriate for offshore structure removals. In addition, a suite of mitigation scenarios was developed, based on explosive charge weight and placement and ambient water depth. These regulations ultimately provide a firmer foundation for the protection of sea turtles and marine mammals.

There is relatively little information about sublethal impacts to sea turtles exposed to explosive removal activities, particularly on the auditory system. While mitigation measures appear to be effective in preventing death or injury of turtles, it is uncertain to what extent sublethal effects may be occurring beyond the safety range. While recent and ongoing studies may provide the basis for estimating auditory impacts in marine mammals, which are particularly important in the regulatory context of "harassment," there is almost no information to estimate auditory impacts on sea turtles.

Acknowledgments

The U.S. Department of the Interior, Minerals Management Service funded this project under Contract No. 85237, with S.L. Tsoflias and M. Boatman as the Contracting Officer's Technical Representatives and S.L. Benik as the Contracting Officer. Authors are grateful for the assistance and expertise provided by other individuals who participated in the original project but were not authors of this paper, including David Snyder, Denis Thomson, William Richardson, William Poe, Charles Green, and Gregg Gitschlag. The manuscript was substantially improved by technical comments from anonymous referees.

References

Bartol SM, Ketten D. Auditory brainstem responses of multiple species of sea turtles. In: Gisiner R, editor. Environmental consequences of underwater sound (ECOUS) abstracts, 12–16 May 2003, San Antonio. Arlington, VA: Office of Naval Research; 2003. p. 29.

Bartol SM, Musick JA. Sensory biology of sea turtles. In: Lutz PL, Musick JA, Wyneken J, editors. The biology of sea turtles, volume II. Boca Raton, FL: CRC Press; 2003. p. 79–102.

Bartol SM, Musick JA, Lenhardt ML. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*). Copeia 1999;3:836–40.

Connor Jr JG. Underwater blast effects from explosive severence of offshore platform legs and well conductors. Naval Surface Warfare Center, Silver Spring, NAVSWC TR 90-532; 1990. http://www.mms.gov/tarprojects/118/118AA.PDF.

Continental Shelf Associates, Inc., Explosive removal of offshore structures — information synthesis report, U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA, OCS Study MMS 2003-070, (2004), http://www.gomr.mms.gov/PI/PDFImages/ESPIS/2/3042.pdf.

Costanzo FA, Gordon JD. A procedure to calculate the axisymmetric bulk cavitation boundaries and closure parameters. SSPD-89-177-78. Bethesda, MD: David Taylor Research Center; 1989.

Department of the Navy. Shock trial of the WINSTON S. CHURCHILL (DDG 81): final environmental impact statement; 2001.

Department of the Navy. Shock trial of the MESA VERDE (LPD 19): draft environmental impact statement; 2007.

Gaspin JB. Safe swimmer ranges from bottom explosions. Naval Surface Weapon Center, White Oak Laboratory, Defense Technical Information Center, Silver Spring, NSWC/WOL TR-83-84; 1983.

Geraci JR, St. Aubin DJ. Effects of offshore oil and gas development on marine mammals and turtles. In: Boesch DF, Rabalais NN, editors. The long-term effects of offshore oil and gas development: an assessment and a research strategy. Rockville, MD: National Marine Pollution Office, National Oceanic and Atmospheric Administration; 1985. p. 12−1–12−34.

Gitschlag GR. Sea turtle monitoring at offshore oil and gas platforms. In: Richardson TH, Richardson JI, Donnelly M, Compilers, editors. Proceedings of the tenth annual workshop on sea turtle biology and conservation, 20–24 February 1990, Hilton Head, SC, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS SEFSC-278; 1990. p. 233. http://www.nmfs.noaa.gov/pr/pdfs/species/turtlesymposium1990.pdf.

Gitschlag GR, Herczeg BA. Sea turtle observations at explosive removals of energy structures. Mar Fish Rev 1994;56(2):1–8.

Gitschlag GR, Renaud M. Sea turtles and the explosive removal of offshore oil and gas structures. In: Eckert SA, Eckert KL, Richardson TH, Compilers, editors. Proceedings of the ninth annual workshop on sea turtle conservation and biology, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-SEFSC-232; 1989. p. 67–8. http://www.nmfs.noaa.gov/pr/pdfs/species/turtlesymposium1989.pdf.

Gitschlag GR, Herczeg BA, Barcak TR. Observations of sea turtles and other marine life at the explosive removal of offshore oil and gas structures in the Gulf of Mexico. Gulf Res Rep 1997;9(4):1–16.

Goertner JF. Prediction of underwater explosion safe ranges for sea mammals, Naval Surface Weapons Center, Silver Spring, NSWC TR 82-188, NTIS ADA139823; 1982. http://stinet.dtic.mil/cgi-bin/GeTRDoc?AD=ADA139823&Location=U2&doc=GeTRDoc.pdf.

Hadiselimoviæ H, Andeliæ M. Contribution to the knowledge of the ear in the sea turtle. Acta Anat 1967;66:460–77.

Henwood T. National Marine Fisheries Service perspective on structure removals. Minerals Management Service, proceedings: eighth annual Gulf of Mexico information transfer meeting, December 1987, U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico Region, New Orleans, OCS Study MMS 88-0035; 1988. p. 300–3. http://www.gomr.mms.gov/PI/PDFImages/ESPIS/3/3691.pdf.

Keevin TM, Hempen GL. The environmental effects of underwater explosions. St. Louis District, St. Louis: U.S. Army Corps of Engineers; 1997.

Ketten DR. Estimates of blast injury and acoustic trauma zones for marine mammals from underwater explosions. In: Kastelein RA, Thomas JA, Nachtigall PE, editors. Sensory systems of marine mammals. Woerden, The Netherlands: De Spil Publishers; 1995. p. 391–407.

Ketten DR. Marine mammal auditory systems: a study of audiometric and anatomical data and its implications for underwater acoustic impacts. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center, La Jolla, NOAA-TM-NMFS-SWFSC SWFSC-256; 1998.

Ketten DR, Arruda J, Cramer S, O'Malley JO, Reidenberg J, McCall S. Experimental measures of blast trauma in marine mammals. In: Gisner R, editor. Environmental consequences of underwater sound, 12–16 May 2003. Bethesda, MD: Office of Naval Research, Life Sciences Research Office; 2003. p. 30.

Klima EF, Gitschlag GR, Renaud ML. Impacts of the explosive removal of offshore petroleum platforms on sea turtles and dolphins. Mar Fish Rev 1988;50(3):33–42.

Lenhardt ML. Bone conduction hearing in turtles. J Aud Res 1982;22:153–60.

Lenhardt ML, Harkins SW. Turtle shell as an auditory receptor. J Aud Res 1983;23:251–60.

Lenhardt ML, Bellmund S, Byles RA, Harkins SW, Musick JA. Marine turtle reception of bone-conducted sound. J Aud Res 1983;23:119–25.

Lenhardt ML, Klinger RC, Musick JA. Marine turtle middle-ear anatomy. J Aud Res 1985;25:66–72.

Lenhardt ML, Moein SE, Musick JA, Barnard D. Evaluation of the response of loggerhead sea turtles (*Caretta caretta*) to a fixed sound source. Waterways Experiment Station: U.S. Army Corps of Engineers; 1994 [15 pp.].

Minerals Management Service. Structural removal activities, Central and Western Gulf of Mexico Planning Areas, programmatic environmental assessment, U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans OCS EIS/EA MMS 87-0002; 1987.

Minerals Management Service. Structure-removal operations on the Gulf of Mexico continental shelf, programmatic environmental assessment. Gulf of Mexico Region, New Orleans: U.S. Department of the Interior, Minerals Management Service; 2005. OCS EIS/EA MMS, http://www.gomr.mms.gov/PDFs/2005/2005-013.pdf.

Moein S, Lenhardt M, Barnard D, Keinath J, Musick J. Marine turtle auditory behavior. J Acoust Soc Am 1993;93(4, Pt.2):2–378.

Moein SE, Musick JA, Lenhardt ML. Auditory behavior of the loggerhead sea turtle (*Caretta caretta*). In: Bjorndahl KA, Bolten AB, Johnson DA, Eliazar PJ, Compilers, editors. Proceedings of the fourteenth annual symposium on sea turtle biology and conservation, National Oceanic and Atmospheric Administration, NOAA Technical Memo. NMFS-SEFSC-351; 1994. p. 89. http://www.nmfs.noaa.gov/pr/pdfs/species/turtlesymposium1994.pdf.

Moein SM. Auditory evoked potentials of the loggerhead sea turtle (*Caretta caretta*), MS thesis, College of William and Mary; 1994.

National Marine Fisheries Service. Biological opinion, consultation for removal of certain outer continental shelf oil and gas structures in the Gulf of Mexico. Silver Spring: National Marine Fisheries Service; 1988.

National Marine Fisheries Service Noise Exposure Criteria Group. Strategies for weighting exposure in the development of acoustic criteria for marine mammals. Presentation at Acoustical Society of America conference October 2005, Minneapolis, MN; 2005. http://www.oce.uri.edu/faculty_pages/miller/Noise_Weighting_10_18_2005.ppt.

National Research Council. An assessment of techniques for removing offshore structures. Washington, DC.: National Academy Press; 1996. http://books.nap.edu/catalog/9072.html.

Office of the Surgeon General. USA textbook of military medicine; part 1, volume 5, conventional warfare; ballistic, blast, and burn injuries; 1991. http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=ADA278723&Location=U2&doc=GetTRDoc.pdf.

O'Keeffe DJ, Young GA. Handbook on the environmental effects of underwater explosions. Naval Surface Weapons Center, Dahlgren and Silver Spring, NSWC TR 83-240; 1984.

Richardson GE. Sea turtles and structure removals in the Gulf of Mexico. In: Eckert SA, Eckert KL, Richardson TH, Compilers, editors. Proceedings of the ninth annual workshop on sea turtle conservation and biology, 7–11 February 1989, Jekyll Island, Georgia, National Oceanic and Atmospheric Administration, NOAA Technical Memorandum NMFS-SEFC-232; 1989. p. 145–6. http://www.nmfs.noaa.gov/pr/pdfs/species/turtlesymposium1989.pdf.

Richmond DR, Yelverton JT, Fletcher ER. Far-field underwater blast injuries produced by small charges. Lovelace Foundation, Albuquerque, DNA 3081T; 1973.

Ridgway SH, Wever EG, McCormick JG, Palin J, Anderson JH. Hearing in the giant sea turtle, *Chelonia mydas*. Proc Natl Acad Sci 1969;64:884–90 http://www.pnas.org/cgi/reprint/64/3/884.

Ridgway SH, Wever EG, McCormick JG, Palin J, Anderson J. Sensitivity of the green sea turtle's ear as shown by its electrical potentials. J Acoust Soc Am 1970;47:67.

Saint-Arnaud D, Pelletier P, Poe W, Fowler J. Oil platform removal using engineered explosive charges: in situ comparison of engineered and bulk explosive charges, final report. Gulf of Mexico OCS Region, New Orleans, LA: U.S. Department of the Interior, Minerals Management Service; 2004. http://www.mms.gov/tarprojects/429/Oil%20Platform%20Removal%20Using%20Engineered%20Explosive%20Charges%20_M%E2%80%A6.pdf.

Tonndorf J. Bone conduction. In: Tobias JV, editor. Foundations of modern auditory theory, volume II. New York: Academic Press; 1972. p. 197–237.

U.S. Department of Commerce. National Oceanic and Atmospheric Administration, Endangered Species Act Section 7 consultation — Biological Opinion; "de minimus" Explosive Severing Activities. St. Petersburg, FL: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southeast Regional Office; 2003.

U.S. Department of Commerce. National Oceanic and Atmospheric Administration, Endangered Species Act Section 7 consultation — biological opinion; permitting structure removal operations on the Gulf of Mexico outer continental shelf. Silver Spring, MD: U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Permits, Conservation, and Education Division; 2006.

Wever EG. The reptile ear: its structure and function. Princeton: Princeton University Press; 1978.

Yelverton JT, Richmond DR, Fletcher ER, Jones RK. Safe distances from underwater explosions for mammals and birds. Lovellace Foundation, Albuquerque, DNA 3114T; 1973. http://stinet.dtic.mil/cgi-bin/GetTRDoc?AD=AD766952&Location=U2&doc=GetTRDoc.pdf.

Young GA. Concise methods of predicting the effects of underwater explosions on marine life. White Oak, Silver Spring: Naval Surface Weapons Center; 1991. NTIS AD A241310.

Stephen T. Viada. CSA International, Inc. Mr. Viada received his M.S. degree in Biological Oceanography from Texas A&M University. As a Senior Scientist with CSA International, Inc. since 1993, he has managed and participated in numerous baseline habitat characterization and population assessment studies, long-term environmental monitoring studies, and environmental impact assessment studies. His areas of related expertise include the effects of offshore oil and gas operations on marine mammals, turtles, and birds.

Richard M. Hammer. CSA International, Inc. Dr. Hammer received his Ph.D. degree in Marine Biology from the University of Southern California and his M.S. degree in Biological Oceanography from Texas A&M University. He has served as Senior Scientist, Oceanographer, and Editor for CSA International, Inc. since 1980, managing the design, analyses, and manuscript preparation for numerous offshore and coastal programs. His programs have included multidisciplinary literature and data search and synthesis projects, ecological baseline and long-term monitoring field studies, and applications of the results to environmental impact documents. Dr. Hammer has assessed potential environmental impacts associated with beach nourishment, borrow areas, dredging, ocean dredged material disposal sites, oil and gas activities, naval operations, power plants, ocean incineration, and other controversial topics.

Roberto Racca. JASCO Research Ltd. Dr. Racca received his Ph.D. degree in Coherent Optics and his M.S. degree in Applied Fluid Dynamics from the University of Victoria, Canada. He has served as Senior Acoustics Scientist at JASCO Research Ltd. since 1986 and has been President of the company since 2000. His work in underwater acoustics has included managing and participating in a large number of defense research and environmental projects, ranging from the development of highly efficient parallel algorithms for source localization to the field study of acoustic deterrents for fishes in arctic lakes. In recent years he has been involved in numerous environmental impact assessment and mitigation programs involving both numerical forecasting and field monitoring of noise levels.

David Hannay. JASCO Research Ltd. Mr. Hannay received his M.S. degree in Physics and Underwater Acoustics from the University of Victoria, Canada. He has worked in the field of underwater acoustics for JASCO Research Ltd. since 1988 and has been Vice President of JASCO since 2000. His work has concentrated on measurement and computer modeling of sound propagation underwater and in air. His work has included quantifying sound levels produced by underwater explosives, shipping noise, and seismic exploration. Much of his work has been dedicated to quantifying noise levels for use at estimating environmental impacts. He has developed several numerical models for this purpose, utilizing ray trace, parabolic equation, wavenumber integral and normal model approaches, and has designed and carried out field verification studies to ensure the accuracies of model predictions. The models are used extensively for environmental impact assessments.

M. John Thompson. CSA International, Inc. Mr. Thompson received his M.S. degree in Marine Biology from Florida Atlantic University in 1972. Prior to joining CSA International, Inc., he was a field station manager and research scientist working with the Harbor Branch Oceanographic Institution and Smithsonian Institution in the Florida Keys and in Fort Pierce, Florida. Since joining CSA International, Inc. in 1980 as Senior Staff Scientist, he has been a senior project manager for domestic and international marine impact assessment projects.

Brian J. Balcom. CSA International, Inc. Mr. Balcom received his M.S. and B.S. degrees in Biological Sciences from the University of Southern California and has completed graduate courses in environmental engineering, environmental law, and environmental impact assessment. As a Senior Scientist with CSA International, Inc. since 1981, Mr. Balcom has provided marine biological technical expertise, environmental impact assessment capabilities, and management oversight on numerous multidisciplinary assessments of proposed activities in domestic and international marine and coastal waters. His areas of expertise include assessments of noise effects on marine mammals, sea turtles, and fishes, with an emphasis on endangered, threatened, and protected species. His project managerial responsibilities have typically been coupled with senior editorial and technical author duties.

Neal W. Phillips. CSA International, Inc. Dr. Phillips received his Ph.D. degree in Ecology from the University of Georgia in 1983. As a Senior Scientist for CSA International, Inc., he has been involved in preparing environmental impact assessments, analyzing and interpreting data from marine environmental studies, and writing and editing synthesis reports for government and industry clients. His area of expertise is marine benthic ecology.