

(humpback, gray and bowhead whales; ringed seals). However, information is lacking for many other species. These potential impacts are discussed further in the LDEO application.

Hearing Impairment and Other Physical Effects

Temporary or permanent hearing impairment is a possibility when marine mammals are exposed to very strong sounds. The minimum sound level necessary to cause permanent hearing impairment is higher, by a variable and generally unknown amount, than the level that induces barely detectable temporary threshold shift (TTS). The level associated with the onset of TTS is considered to be a level below which there is no danger of damage and current NMFS policy regarding exposure of marine mammals to high-level sounds is that cetaceans and pinnipeds should not be exposed to impulsive sounds exceeding 180 and 190 dB re 1 micro Pa (rms), respectively.

Several aspects of the planned monitoring and mitigation measures for this project are designed to detect marine mammals occurring near the airgun array (and multi-beam sonar) and to avoid exposing them to sound pulses that might cause hearing impairment. In addition, many cetaceans are likely to show some avoidance of the area with ongoing seismic operations. In these cases, the avoidance responses of the animals themselves will reduce or avoid the possibility of hearing impairment.

Non-auditory physical effects may also occur in marine mammals exposed to strong underwater pulsed sound. Possible types of non-auditory physiological effects or injuries that might (in theory) occur include stress, neurological effects, bubble formation, resonance effects, and other types of organ or tissue damage. It is possible that some marine mammal species (i.e., beaked whales) may be especially susceptible to injury and/or stranding when exposed to strong pulsed sounds.

TTS

TTS is the mildest form of hearing impairment that can occur during exposure to a strong sound (Kryter, 1985). When an animal experiences TTS, its hearing threshold rises and a sound must be stronger in order to be heard. TTS can last from minutes or hours to (in cases of strong TTS) days. The magnitude of TTS depends on the level and duration of noise exposure, among other considerations (Richardson *et al.*, 1995). For sound exposures at or somewhat above the TTS threshold, hearing sensitivity recovers rapidly after exposure to the noise ends. Only a few

data on sound levels and durations necessary to elicit mild TTS have been obtained for marine mammals.

The predicted 180- and 190-dB distances for the airgun arrays operated by LDEO during this activity were summarized previously in this document. These sound levels are not considered to be the levels at or above which TTS would occur. Rather, they are the received levels above which, in the view of a panel of bioacoustics specialists convened by NMFS, one cannot be certain that there will be no injurious effects, auditory or otherwise, to marine mammals. It has been shown that most whales tend to avoid ships and associated seismic operations. Thus, whales will likely not be exposed to such high levels of airgun sounds. Any whales close to the trackline could move away before the sounds become sufficiently strong for there to be any potential for hearing impairment. Therefore, there is little potential for whales being close enough to an array to experience TTS. In addition, ramping up airgun arrays, which has become standard operational protocol for many seismic operators, including LDEO, should allow cetaceans to move away from the seismic source and to avoid being exposed to the full acoustic output of the airgun array.

Permanent Threshold Shift (PTS)

When PTS occurs, there is physical damage to the sound receptors in the ear. In some cases, there can be total or partial deafness, and in other cases, the animal has an impaired ability to hear sounds in specific frequency ranges. Physical damage to a mammal's hearing apparatus can occur if it is exposed to sound impulses that have very high peak pressures, especially if they have very short rise times (time required for sound pulse to reach peak pressure from the baseline pressure). Such damage can result in a permanent decrease in functional sensitivity of the hearing system at some or all frequencies.

Single or occasional occurrences of mild TTS do not cause permanent auditory damage in terrestrial mammals, and presumably do not do so in marine mammals. However, very prolonged exposure to sound strong enough to elicit TTS, or shorter-term exposure to sound levels well above the TTS threshold, can cause PTS, at least in terrestrial mammals (Kryter, 1985). In terrestrial mammals, the received sound level from a single sound exposure must be far above the TTS threshold for any risk of permanent hearing damage (Kryter, 1994; Richardson *et al.*, 1995). Relationships between TTS and PTS thresholds have not been studied in

marine mammals but are assumed to be similar to those in humans and other terrestrial mammals.

Some factors that contribute to onset of PTS are as follows:

(1) exposure to single very intense noises, (2) repetitive exposure to intense sounds that individually cause TTS but not PTS, and (3) recurrent ear infections or (in captive animals) exposure to certain drugs.

Cavanagh (2000) has reviewed the thresholds used to define TTS and PTS. Based on his review and SACLANT (1998), it is reasonable to assume that PTS might occur at a received sound level 20 dB or more above that which induces mild TTS. However, for PTS to occur at a received level only 20 dB above the TTS threshold, it is probable that the animal would have to be exposed to the strong sound for an extended period.

Sound impulse duration, peak amplitude, rise time, and number of pulses are the main factors thought to determine the onset and extent of PTS. Based on existing data, Ketten (1994) has noted that the criteria for differentiating the sound pressure levels that result in PTS (or TTS) are location and species-specific. PTS effects may also be influenced strongly by the health of the receiver's ear.

Given that marine mammals are unlikely to be exposed to received levels of seismic pulses that could cause TTS, it is highly unlikely that they would sustain permanent hearing impairment. If we assume that the TTS threshold for exposure to a series of seismic pulses may be on the order of 220 dB re 1 μ Pa (P-P) in odontocetes, then the PTS threshold might be about 240 dB re 1 μ Pa (P-P). In the units used by geophysicists, this is 10 bar-m. Such levels are found only in the immediate vicinity of the largest airguns (Richardson *et al.*, 1995; Caldwell and Dragoset, 2000). It is very unlikely that an odontocete would remain within a few meters of a large airgun for sufficiently long to incur PTS. The TTS (and thus PTS) thresholds of baleen whales and pinnipeds may be lower, and thus may extend to a somewhat greater distance. However, baleen whales generally avoid the immediate area around operating seismic vessels, so it is unlikely that a baleen whale could incur PTS from exposure to airgun pulses and pinnipeds are not found in the GOM. Therefore, although it is unlikely that the planned seismic surveys could cause PTS in any marine mammals, caution is warranted given the limited knowledge about noise-induced hearing damage in marine mammals, particularly baleen whales.