

components of the airgun pulses would be further reduced.

Pulses of underwater sound from open-water seismic exploration are often detected 50 to 100 km (30 to 54 nm) from the source location, even during operations in nearshore waters (Greene and Richardson, 1988; Burgess

and Greene, 1999). At those distances, the received levels on an approximate rms basis are low (below 120 dB re 1 mPa). However, faint seismic pulses are sometimes detectable at even greater ranges (e.g., Bowles *et al.*, 1994; Fox *et al.*, 2002). Considerably higher levels can occur at distances out to several

kilometers from an operating airgun array.

The distances at which seismic pulses from the Ewing's airguns are expected to diminish to various received levels of 190, 180, 170 dB and 160 dB re 1 mPa, on an rms basis) are as follows:

Airgun Array	RMS Radii (m/ft)			
	190 dB	180 dB	170 dB	160 dB
2 GI airguns*	15/49	50/164	155/508	520/1706
6 airguns**	50/164	220/722	700/2296	2700/8858
10 airguns**	250/820	830/2723	2330/7644	6500/21325
12 airguns**	300/984	880/2887	2680/8793	7250/23786
20 airguns**	400/1312	950/3117	3420/11220	9000/29527

* Airgun depth 6 m (20 ft)

**airgun depth 7.5 m (24.6 ft)

The primary objective of LDEO's planned study is to verify or improve these estimated distances. Additional details concerning the expected levels at various distances and angles relative to each of these airgun arrays can be found in the LDEO application.

Effects of Seismic Surveys on Marine Mammals

The LDEO application provides the following information on what is known about the effects on marine mammals of the types of seismic operations planned by LDEO. The types of effects considered here are (1) masking, (2) disturbance, and (3) potential hearing impairment and other physical effects. Additional discussion on species specific effects can be found in the LDEO application.

Masking

Masking effects on marine mammal calls and other natural sounds are expected to be limited. Seismic sounds are short pulses occurring for less than 1 sec every 20 or 60–90 sec in this project. Sounds from the multi-beam sonar are very short pulses, occurring for 1–10 msec once every 1 to 15 sec, depending on water depth. (During operations in deep water, the duration of each pulse from the multi-beam sonar as received at any one location would actually be only 1/5th or at most 2/5th of 1–10 msec, given the segmented nature of the pulses.) Some whales are known to continue calling in the presence of seismic pulses. Their calls can be heard between the seismic pulses (e.g., Richardson *et al.*, 1986; McDonald *et al.*, 1995; Greene *et al.*, 1999). Although there has been one report that sperm whales cease calling when exposed to pulses from a very distant seismic ship (Bowles *et al.*, 1994), a recent study reports that sperm whales

continued calling in the presence of seismic pulses (Madsen *et al.*, 2002). Masking effects of seismic pulses are expected to be negligible in the case of the smaller odontocete cetaceans, given the intermittent nature of seismic pulses plus the fact that sounds important to them are predominantly at much higher frequencies than are airgun sounds.

Most of the energy in the sound pulses emitted by airgun arrays is at low frequencies, with strongest spectrum levels below 200 Hz and considerably lower spectrum levels above 1000 Hz. These frequencies are mainly used by mysticetes, but not by odontocetes or pinnipeds. An industrial sound source will reduce the effective communication or echolocation distance only if its frequency is close to that of the cetacean signal. If little or no overlap occurs between the industrial noise and the frequencies used, as in the case of many marine mammals vs. airgun sounds, communication and echolocation are not expected to be disrupted. Furthermore, the discontinuous nature of seismic pulses makes significant masking effects unlikely, even for mysticetes.

A few cetaceans are known to increase the source levels of their calls in the presence of elevated sound levels, or possibly to shift their peak frequencies in response to strong sound signals (Dahlheim, 1987; Au, 1993; Lesage *et al.*, 1999; Terhune, 1999; reviewed in Richardson *et al.*, 1995). These studies involved exposure to other types of anthropogenic sounds, not seismic pulses, and it is not known whether these types of responses ever occur upon exposure to seismic sounds. If so, these adaptations, along with directional hearing and preadaptation to tolerate some masking by natural sounds (Richardson *et al.*, 1995), would all reduce the importance of masking.

Disturbance by Seismic Surveys

Disturbance includes a variety of effects, including subtle changes in behavior, more conspicuous dramatic changes in activities, and displacement. Disturbance is the primary concern for this project. However, there are difficulties in defining which marine mammals should be counted as "taken by harassment". For many species and situations, scientists do not have detailed information about their reactions to noise, including reactions to seismic (and sonar) pulses. Behavioral reactions of marine mammals to sound are difficult to predict. Reactions to sound, if any, depend on species, state of maturity, experience, current activity, reproductive state, time of day, and many other factors. If a marine mammal does react to an underwater sound by changing its behavior or moving a small distance, the impacts of the change may not be significant to the individual let alone the stock or the species as a whole. However, if a sound source displaces marine mammals from an important feeding or breeding area for a prolonged period, impacts on the animals could be significant. Given the many uncertainties in predicting the quantity and types of impacts of noise on marine mammals, scientists often resort to estimating how many mammals were present within a particular distance of industrial activities, or exposed to a particular level of industrial sound. This likely overestimates the numbers of marine mammals that are affected in some biologically important manner.

The sound criteria used to estimate how many marine mammals might be disturbed to some biologically important degree by a seismic program are based on behavioral observations during studies of several species