Poster prepared for:

Marine Mammal Monitoring and Mitigation during Recent Seismic Surveys for Geophysical Research

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ABSTRACT: The R/V *Maurice Ewing*, operated by Lamont-Doherty Earth Observatory of Columbia University, conducts academic marine seismic surveys sponsored by the U.S. National Science Foundation. In autumn 2002, a beaked whale stranding occurred in Baja California when the *Ewing* was operating its largest airgun configuration (20 guns; 8600 in^3) nearby. No causal link was confirmed. However, subsequent *Ewing* seismic surveys have included progressively more stringent monitoring and mitigation measures under provisions of Incidental Harassment Authorizations issued by the U.S. National Marine Fisheries Service (NMFS). ***Monitoring*** includes visual observations by trained marine mammal observers during all daytime airgun operations and during nighttime ramp-ups, when allowed. Starting in 2004, a towed hydrophone array is monitored day and night for cetacean calls when the larger airgun configurations are used. ***Pre-cruise mitigation*** includes selecting the smallest airgun array consistent with the geophysics objectives and, where possible, adjusting plans to avoid seasons and/or locations of special concern for marine mammals, sea turtles, and most recently fisheries. ***Mitigation during cruises*** includes ramp-ups, plus power-downs (to one small airgun) or shut-downs when mammals and (recently) sea turtles are detected within a "safety radius": the 180 dB re 1 µPa (rms) distance for cetaceans and sea turtles, and the 190 dB radius for pinnipeds. Specific rules determine when airgun operations can resume after a shut-down or power-down. ***Acoustic measurements*** showed that the safety radii are greater in shallow than deep water. Recently, depth-dependent safety radii have been applied, and other mitigation measures have been more stringent in shallow waters. ***Conclusions:*** No one monitoring or mitigation measure is entirely effective in detecting marine mammals or avoiding their exposure to strong airgun sounds. However, different monitoring and mitigation techniques can be complementary. In judiciously-chosen combinations, they can substantially reduce the likelihood of biologically-significant effects. These benefits have costs to the seismic operator.

PURPOSE and APPROACH: We summarize the progressive development of coordinated monitoring and mitigation measures for use during "academic" marine seismic operations (geophysical research). No one monitoring or mitigation measure is sufficient, and a combination of measures was needed. Following U.S. requirements, the primary objective is to minimize exposure of mammals to very strong sound pulses: >180 and >190 dB re 1 µPa (rms) for cetaceans and pinnipeds, respectively (NMFS 2004). Disturbance in response to lower received levels is accepted provided the numbers of animals involved are "small" and effects are predicted to be "negligible". The procedures rely on avoidance responses by some mammals as one means of reducing risk of exposure to high sound levels.

RESULTS and **DISCUSSION**: The evolution of monitoring and mitigation measures during six cruises is shown in Tables 1, 2 and 3. The airgun sources are classified as small (2 GI guns), medium (6-12 airguns), and large (20 airguns). (Source level is more directly influenced by number of guns than by total gun volume.)

The most restrictive conditions were applied in the SE Caribbean cruise (Table 3), where encounter rates were expected (and proved) to be relatively high, a large airgun array was used, and part of the area was shallow. (Received levels diminish more slowly with increased distance in shallow water—Tolstoy et al. 2004.) Requirements for a subsequent cruise (SE Alaska) are less restrictive (Table 3) because the sound source is smaller, but still relatively restrictive because of the anticipated abundance of mammals, shallow waters, etc.

Monitoring results from the SE Caribbean confirmed expectations that some cetaceans would avoid the operating airguns, and that visual and acoustic monitoring would each detect some mammals missed by the other method. Even with the most restrictive provisions, some mammals are within the safety radius when detected, and some of those present are presumably missed altogether. There remains an urgent need for specific information about the effects of exposure to varying levels of airgun sounds.

NMFS. 2004. Small takes of marine mammals incidental to specified activities; oceanographic surveys in the southeast Caribbean Sea and adjacent Atlantic Ocean. *Fed. Regist.* 69(86, 4 May):24571-24585.

Tolstoy, M. et al. 2004. Broadband calibration of R/V Ewing seismic sources. *Geophys. Res. Let.* 31. L14310, doi: 10.1029/2004GL020234.

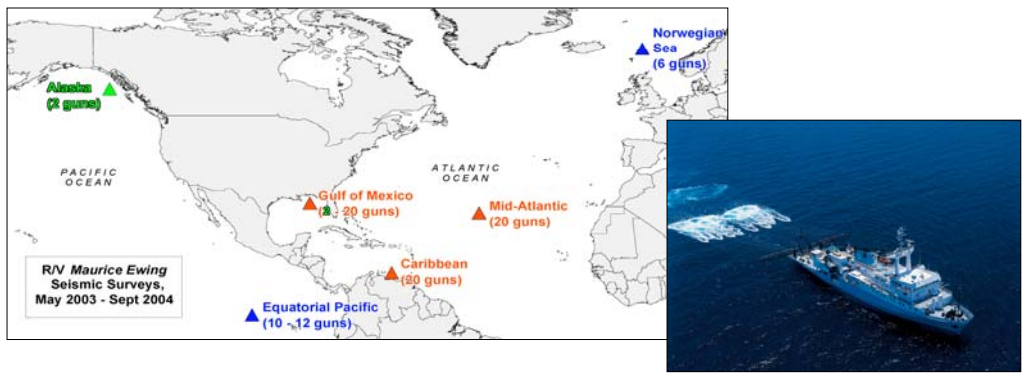

Table 1. CRUISES

	Gulf of Mexico	Equatorial Pacific	Norwegian Sea	Mid-Atlantic Ridge	SE Caribbean Sea	SE Alaska **
Dates	28 May - 2 Jun 2003	12 - 23 July 2003	30 Aug - 26 Sep 2003	30 Oct - 5 Nov 2003	20 Apr - 1 Jun 2004	1 Sep - ~ 23 Sep 2004
Depths	30 & 3200 m	2000 - 3400 m	700 - 4000 m	1500 - 4500 m	15 - 6000 m	30 - 3000 m
# Airguns or GI guns	2 - 20	10 - 12	6	20	20	2
Volume	210 - 8600 in^3	3050 - 3660 in^3	1350 in^3	8760 in^3	6947 in^3	210 in^3
Source Level: bar-m dB*	14 - 123/ 243 - 262	55 - 68/ 255 - 257	31/ 250	124/ 262	124/ 262	14/ 243
km shot	322	1580 km	3700 km	169 km	6605 km	~ 1800 km
hours shot	17 h	192 h	398 h	20 h	755 h	~ 240 h
Shot spacing	30 - 120 s	11 or 60 - 90s	20 s	150 s	20 or 60 s	~ 6 - 10 s
Night shooting	No	✓	✓	✓	✓	✓

* Nominal, downward only, in bar-m / dB re 1µPa (p-p).
** Provisional information; project in progress.

Table 2. MONITORING

	Gulf of Mexico	Equatorial Pacific	Norwegian Sea	Mid-Atlantic Ridge	SE Caribbean Sea	SE Alaska **
Visual (Day + Night)	61 + 0 h	211 + 4 h	331 + 6 h	125 + 1 h	504 + 6 h	**
- airguns on	17 h	99 h	266 h	20 h	425 h	**
- 2nd observer	Four obs.	97%	Usually	Usually	222 h	Usually
- incl. Big Eyes	✓	-	-	-	(✓)	(✓)
Visual (Night) during						
- Ramp ups	-	✓	✓	✓	✓	✓
- All shooting	-	-	-	-	-	✓
Acoustic Monitoring (Towed Hydrophones)	32 h	-	-	-	24 h / day; 846 h	-
Sound Measurements	✓	-	-	-	-	-
# Visual Sightings						
-Airguns On	2	1	17	0	18	**
-Airguns Off	5	22*	0	0	3	**
Acoustic Encounters	0	-	-	-	34D + 44N	-
2nd Vessel						
- Visual obs.	-	-	-	-	394 h	-
- Sightings	-	-	-	-	26	-

* In transit to/from study area.
** Project in progress.

Table 3. MITIGATION

	Gulf of Mexico	Equatorial Pacific	Norwegian Sea	Mid-Atlantic Ridge	SE Caribbean Sea	SE Alaska **
Pre-Cruise						
- Smaller Source	-	-	-	-	✓	-
- Change Dates	-	-	-	-	✓	-
Ramp-up	✓	✓	✓	✓	✓	✓
Restrictions if						
- At night	No night ops.	(✓)	(✓)	(✓)	✓	✓
- Poor Sightability	-	✓	✓	✓	✓	✓
- Shallow Water	-	-	-	-	✓	✓
- no PAM	-	-	-	-	✓	-
Power Downs	-	✓ (0)	✓ (4)	✓ (0)	✓ (9)	-
Shut Downs	✓ (0)	✓ (0)	✓ (0)	✓ (0)	✓ (2)	✓ (**)
Safety Radius	1.5 x 180 dB (m)	1.5 x 180 dB (m)	1.5 x 180 dB (m)	1.5 x 180 dB (m)	Deep: 900 m	Deep: 54 m
for Cetaceans	2 guns: 75 m	10 guns: 1245 m	6 guns: 330 m	20 guns: 1350 m	Inter.: 1350 m	Inter.: 81 m
	6-20: 1425 m	12 guns: 1320 m			Shallow: 3500 m	Shallow: 750 m*
Omit Some Lines	✓	-	-	-	-	✓

* Safety radius based on 170 dB criterion for shallow water (<100 m deep) off SE Alaska.
** Project in progress.