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Short-Finned Pilot Whales (*Globicephala macrorhynchus*) Respond to an Airgun Ramp-up Procedure off Gabon

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Abstract

The *ramp-up* is a standard procedure within the offshore geophysical industry for mitigating the potential impacts of seismic airgun sound on marine mammals. However, the efficiency of the ramp-up as a mitigating procedure is poorly documented. In March 2008, a pod of 15 short-finned pilot whales (*Globicephala macrorhynchus*) was monitored before, throughout, and following a 30-min ramp-up procedure during a 2-D seismic survey off Gabon. No change in behaviour was apparent during the initial period of the ramp-up. However, 10 min into the ramp-up procedure (at airgun volume of 940 cu^3), the nearest whale subgroup turned sharply away from the airguns. Subsequent behaviour included milling, tail-slapping, and a 180° change of course to travel in the opposite direction from the seismic vessel. The observation described here suggests that pilot whales did initially demonstrate an avoidance response to the ramp-up. However, the movement away from the source was limited in time and space. Recommendations are made for further research into the efficiency of the ramp-up procedure for marine mammal mitigation.

Key Words: Short-finned pilot whale, *Globicephala macrorhynchus*, airguns, ramp-up, Gabon, seismic survey, geophysical survey

Introduction

The *ramp-up* is a standard procedure within the geophysical industry operating offshore to mitigate the potential impacts of seismic airgun sound on marine mammals (see Gordon et al., 2004). A ramp-up is a gradual build-up of airgun sound level over time (usually 20 to 40 min), aimed at warning marine mammals and allowing them to depart from the vicinity of an airgun source before the full operating level is projected (International Whaling Commission [IWC], 2006; Weir & Dolman, 2007). Ramp-ups are also commonly used to mitigate other anthropogenic sound sources such as military sonar and pile-driving (David, 2006; Evans & Miller, 2004). Although the ramp-up procedure is the most widely used seismic mitigation measure worldwide, it is currently implemented as a *common sense* procedure, and there is little information on its efficiency in evoking an appropriate response from marine mammals (i.e., that it causes them to move away from the airgun source). The International Whaling Commission (IWC) (2006) recently recommended research to evaluate and quantify the effectiveness of existing mitigation procedures used by offshore industry, highlighting ramp-up as one procedure requiring validation.

While the overt responses of cetaceans to airgun sound are being increasingly documented, there are only limited published studies in which responses to a ramp-up procedure have been described. Stone & Tasker (2006) found no difference between the distance of cetaceans from airguns during ramp-up compared with either full volume or guns-off operations. Weir (2008) observed Atlantic spotted dolphins (*Stenella frontalis*) veering away from a ship during the early stages of a ramp-up procedure off Angola.

Two cetacean species particularly well-suited to behavioural observations at sea are the short-finned (*Globicephala macrorhynchus*) and long-finned (*G. melas*) pilot whales, which are relatively straightforward to detect, identify, and track in the field. Various responses of pilot whales to airgun sounds have been described in the literature. Off Nova Scotia, long-finned pilot whales approached within 300 m (and sometimes within 150 m) of active airguns and may have been exposed to sound levels exceeding 190 dB re: 1 μPa rms (Moulton & Miller, 2005). There was no difference in the sighting rate or the closest point of approach of long-finned pilot whales according to airgun activity in UK waters (Stone & Tasker, 2006), although there was one instance of a pod that changed course when it was 290 m from an airgun array in what those authors considered to be a "startle response" to a ramp-up. While Bowles et al. (1994) observed that pilot whales ceased sound production in response to broadcasts of low frequency (57 Hz) sound during the Heard Island Feasibility Study, this species is often soniferous during airgun activity in UK waters (pers. obs.).

The responses of pilot whales to airgun sounds clearly depend on the animals being able to detect the sound. Airgun arrays typically have source levels in the region of 220 to 248 dB re: 1 μPa with the highest energy produced in the 10 to 200 Hz bandwidth (Richardson et al., 1995). However, significant energy may be produced up to at least 22 kHz within a 2-km radius of an airgun source (Goold & Fish, 1998), and energy in the 0.3 to 3.0 kHz frequency range may dominate airgun sound received in surface waters (DeRuiter et al., 2006; Madsen et al., 2006). Pilot whales produce tonal sounds with dominant frequencies in the 2 to 9 kHz bandwidth (Rendell et al., 1999) and echolocation clicks at peak frequencies of 30 to 60 kHz (Evans, 1973). While their hearing range is poorly known, the auditory sensitivity of pilot whales may reasonably be expected to occur between that of the killer whale (*Orcinus orca*) and false killer whale (*Pseudorca crassidens*), given both their taxonomic relationship and similar body size (Matthews et al., 1999). Pilot whales may therefore be expected to have their highest auditory sensitivity at frequencies of between 15 and 70 kHz, probably peaking between 20 and 40 kHz.

This paper reports on an observation of pilot whales off Gabon during an airgun ramp-up procedure. The response of the animals is described and discussed in relation to the effectiveness of the ramp-up procedure during seismic surveys.

Materials and Methods

The observation occurred during a geophysical seismic survey carried out by the 90-m *CGG Venturer* off Gabon during March 2008. The survey used a single airgun source consisting of six airgun strings, each comprising 36 Bolt 1500/1900 guns of individual volume between 40 and 290 in^3. The total production volume of the array was 6,650 in^3 and the pressure was 2,000 psi. The array was towed at a depth of 8.5 m and a speed of 4 to 5 kts. Shots were fired at a 37.5-m shotpoint interval, resulting in one shot approximately every 16 s.

In compliance with the marine mammal mitigation guidelines of the Joint Nature Conservation Committee (2004), a ramp-up procedure was implemented prior to every new airgun operation. The ramp-up procedure on the *CGG Venturer* was fully automated. However, in contrast to the automated procedures used on some other seismic vessels which are programmed by shotpoint and may consequently vary according to vessel speed, the ramp-up procedure on the *CGG Venturer* was programmed by time and was therefore precisely controlled. Signals from extra guns were added in every 51 s over the course of a 30-min period (Figure 1). A cumulative volume of 7,200 in^3 was reached after 30 min, and three spare guns were then removed to produce the production volume of 6,650 in^3 (Figure 1).

A dedicated marine mammal observer (MMO) located at a 9.8-m eye height on the roof of the ship's bridge maintained a watch for cetaceans throughout the survey, scanning 360° around the vessel with 10x binoculars and the naked eye. Effort logs (comprising position, water depth, vessel activity, and environmental data, including

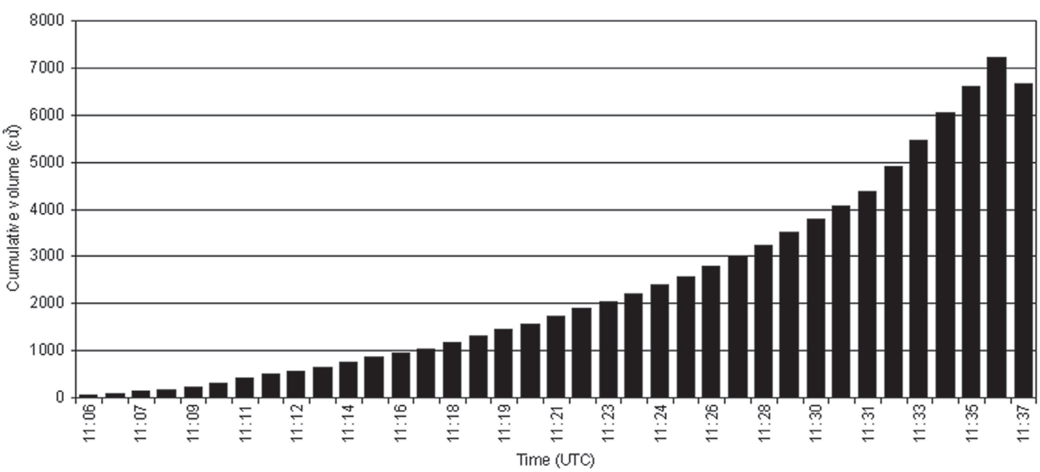

Figure 1. Build-up of airgun volume during the *CGG Venturer* ramp-up procedure as used by the geophysical industry to mitigate the potential impacts on marine mammals during seismic surveys

Beaufort sea state) and sighting data (comprising species, number [and age class where possible] of marine mammals, behaviour, position, and water depth) were completed. The vessel position was logged at 1-min intervals using a Garmin 76CSx GPS. The distance between the ship and the animal(s) was calculated using a simple range-estimation stick based upon the Heinemann (1981) equation. The bearing of the animals relative to the source was recorded using a compass angle board.

Sighting positions were recalculated based on vessel position, bearing, and distance to the animals using the *GeoFunc* function (downloaded from the National Marine Mammal Laboratory on 21 March 2008 at www.afsc.noaa.gov/nmml/software/excelgeo.php), and sightings were mapped in *ArcView* GIS software.

Results

On 10 March 2008 at 1042 h, a group of short-finned pilot whales was sighted during the pre-shoot watch prior to a ramp-up procedure off Gabon. The initial sighting was located 4.5 km ahead of the ship which was at position 03° 20.52' S, 09° 07.08' E in 1,759-m water depth. The animals were travelling in two subgroups separated by approximately 700 m. The nearest subgroup contained six animals, including two adult males and a juvenile, and is the group described in the remainder of this paper. The farthest subgroup included nine animals. The animals were travelling steadily NE throughout the 24 min for which they were monitored prior to the ramp-up procedure on a trajectory that interjected with that of the seismic vessel. Since it was possible that the nearest whale group would be relatively close to the seismic vessel when the airguns were due for activation, the MMO requested that the ramp-up commence 7 min earlier than planned to allow the whales the greatest opportunity to move away.

The ramp-up procedure began at 1106 h, by which time the whales were located 900 m ahead of the airgun array (Figure 2) and could be observed with the naked eye. The animals continued to travel slowly NE. At 1116 h, when 750 m from the airgun array, the whales turned sharply away 90° relative to the ship's course and moved off to the SE. Airgun volume at this time had reached 940 cu^3. The whales stopped moving at 1119 h (900 m abeam of the airguns which had reached 1,430 cu^3) and spent 3 min logging and milling at the surface with individuals orientated in different directions. At 1122 h, the whales turned eastwards towards the farthest subgroup which were still travelling slowly to the NE. At 1125 h and when 1.3 km from the airguns (2,580 cu^3), the whales stopped and logged with all animals orientated towards the airguns. They swam alongside the airgun array for 1 min, and then from 1127 h spent 6 min logging at the surface and orientated towards the array as the source volume increased from 2,980 to 5,460 cu^3 and the airguns moved from beam-on to pass the whale group (Figure 2).

At 1134 h, the individuals began to orientate in different directions, and by 1136 h (when the airgun array reached maximum volume of 7,200 cu^3), the group had recoordinated and turned away from the airgun array towards the farthest whale subgroup. The whales were now located 2.1 km away on a relative bearing SE of the airgun source (Figure 2). At 1137 h, the airgun source decreased to a production volume of 6,650 cu^3. At 1138 h, an adult male was observed to tail-slap vigorously seven times. The whale group changed heading and assumed a SE course away from the survey footprint. At 1140 h, when 2.5 km from the airguns, the group changed heading again and assumed a course of 210° to move in the exact opposite direction from the seismic survey and their original heading (Figure 2). At this time, it was noted that the farthest whale subgroup had turned and was also travelling SW to follow the course of the nearest group. All pilot whales continued on a SW course until tracking ceased at 1150 h when the animals were almost 4.5 km from the source.

Discussion

The observations described here are noteworthy due to (1) the paucity of available information on cetacean responses to ramp-up procedure, (2) accurate knowledge of the onset and build-up of the ramp-up procedure during the sighting, (3) the 24-min period of observations of undisturbed behaviour of the animals prior to the onset of ramp-up, (4) the detailed monitoring of the behaviour of the animals relative to the source during the ramp-up, and (5) the presence of the same whale group within visual monitoring range for over an hour permitting pre-, during, and post-observations relative to the ramp-up procedure.

Ramp-up is intended as an acoustic warning to marine mammals based on the unproven assumption that animals will move away from sound levels that cause them disturbance (potentially ranging from annoyance to physical damage). The observations described here suggest that pilot whales did respond to the early stages of a ramp-up procedure, showing a marked alteration in direction to move away from the approaching source at 1116 h when the airgun ramp-up procedure had been in progress for 9 min and reached 940 cu^3 volume. The causal factor for this response may

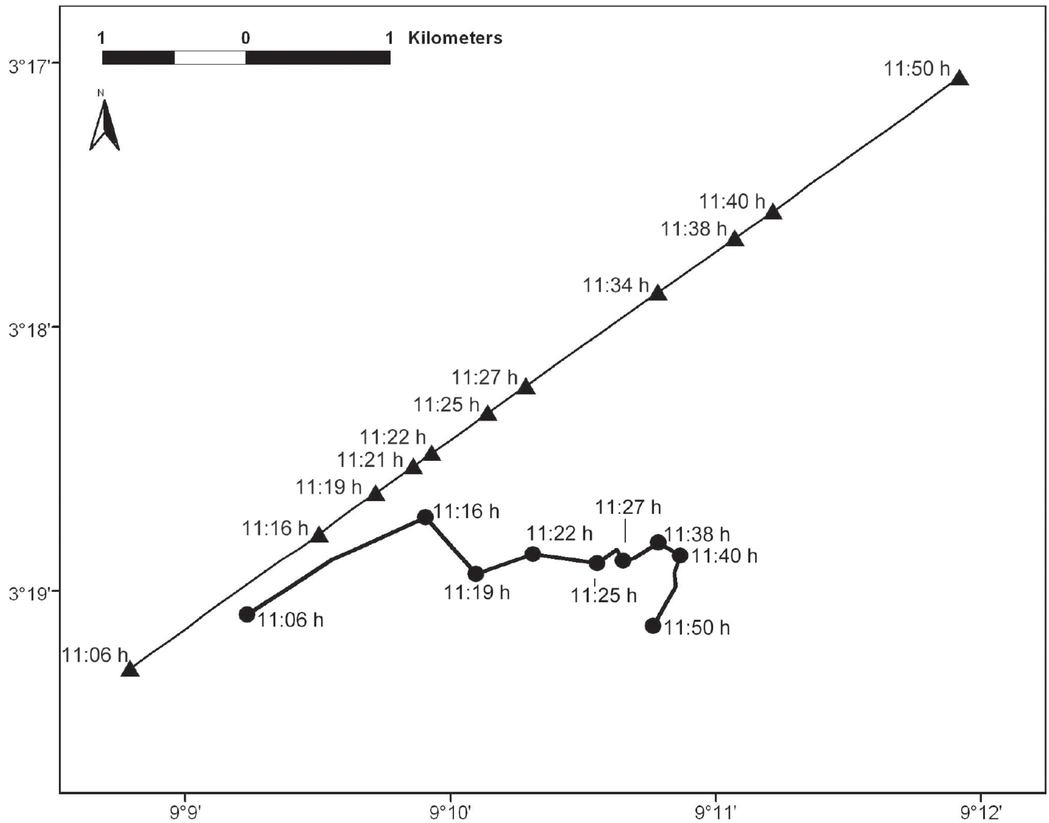

Figure 2. Movement of the pilot whale group (circles) in relation to the seismic survey vessel (triangles) during the ramp-up procedure observed in March 2008 on the *CGG Venturer*

have been either the increase in source volume or the sudden detection by the animals of a novel sound stimulus in the environment. A response of the animals to the presence of the seismic vessel itself cannot be eliminated although this seems unlikely given that the same group of animals had passed within 300 m of the 37-m escort vessel during the 24-min observation prior to the ramp-up without showing any noticeable reaction and that short-finned pilot whales encountered in nonfiring periods during the survey behaved indifferently towards the seismic vessel.

It is not possible to determine which of the two proposed causal factors may have been responsible for the change in pilot whale behaviour since calculating the airgun sound levels received by cetaceans in the field is inherently problematic. In addition to the numerous environmental and oceanographic variables that affect the propagation of sound through water (e.g., water temperature, turbidity, depth, seabed type), the energy released into the water column is determined by source parameters (DeRuiter et al., 2006). The sound levels emitted from an airgun array are not simply a function of airgun volume but depend on the number, size, and spatial geometry of individual guns within the array; the position of the receiver (horizontally and vertically) relative to the array; and the frequency range being examined. Estimating the sound levels potentially received by cetaceans around an airgun array becomes especially complex during a ramp-up procedure when signals from individual guns of varying volume and spatial geometry are added one at a time resulting in a continuous variation in source configuration. The sound levels received by the animals at the time of the behavioural change are therefore unknown, but it is possible that they had increased to amplitudes that became uncomfortable to the animals.

A *startle response* to a novel acoustic stimulus is also plausible since although the ramp-up had commenced at 1106 h, it is possible, given the relative bearing from and the amplitude of the source, that the whales may only have become fully aware of the airguns at 1116 h and reacted purely to the sudden onset of a new sound stimulus within their environment.

It was notable that although the animals initially showed an avoidance response to the ramp-up signal, the movement away from the source was limited in time and space. Despite a four-fold increase in source volume between 1119 and 1134 h, the whales exhibited several bouts of logging at the surface often orientated towards the airguns. Therefore, the whales did not continue to exhibit a directed movement away as the volume increased but, instead, exhibited behaviour best described as *milling*. Ascertaining the response of cetaceans to anthropogenic sound in the field is fraught with difficulty. For example, the continued logging of pilot whales at the surface during a ramp-up procedure could be interpreted as a lack of marked avoidance response to increasing airgun volume. Alternatively, the same observation could be explained by animals spending more time at the surface in a *vertical avoidance* response to higher levels of received sound in the lower water column (Richardson et al., 1995). Furthermore, cetaceans may show both interspecific and intraspecific variation in their response to airgun sound as has been documented for responses to vessel disturbance during whale-watching operations (IWC, 2008). For example, 4 d following the sighting described here during the same survey off Gabon, a pod of 12 short-finned pilot whales approached to within 300 m of the airgun array while it was firing at full volume and spent several minutes logging as the source passed by. Large sample sizes are therefore required before conclusions on a species' response to airgun sound can be reached.

The observation reported here has several implications for future studies of the response of cetaceans to ramp-up procedures as recommended by the IWC (2006). First, it is clear that extensive observations are required to determine the behaviour and movement of animals in relation to the ramp-up procedure, particularly having sufficient time prior to the onset of airgun use to accurately gauge the undisturbed behaviour of the animals and, therefore, be able to detect a change when it occurs. Many MMOs working on seismic vessels have little field experience with free-ranging cetaceans or with scientific data collection and may not be able to appropriately assess and record behavioural and directional changes by animals. Furthermore, the data recording forms currently used worldwide are oversimplified and do not allow the detailed recording of behavioural data and circumstances of airgun use that are required to assess the response of animals to a ramp-up procedure. Consequently, such data permit only very broad scale analyses, which may be too insensitive to detect behavioural changes. For example, Stone & Tasker (2006) reported that cetaceans detected during a ramp-up procedure tended to be heading away from the vessel. However, this finding is based on simple sketches (often by inexperienced observers) of animal movement relative to a ship and uses combined datasets from many different airgun configurations, species, and water depths. Furthermore, given increasing evidence for species-specific variation in response to airgun sound (Moulton & Miller, 2005; Stone & Tasker, 2006; Weir, 2008), combined multispecies analyses are of limited relevance. Equally important in analysing cetacean responses is the accurate monitoring and description of the ramp-up procedure. The procedure described here was unusual in being (1) automated and (2) programmed by time rather than by shotpoint so that the gun volume was accurately known throughout the cetacean observation. This is different from the ramp-up procedure on the majority of seismic vessels, which are operated manually (with each gun(s) added in by switch at an appropriate time), wherein the precision of both the procedure and the logging of times relies entirely on the experience and interest of individual seismic crews (Weir & Dolman, 2007).

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