Acoustic surveying for beaked whales in the Coral Sea as a mitigation measure for naval exercises.

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Abstract- **Beaked whales have been over-represented in whale strandings that have occurred at similar times and places of some naval exercises in the northern hemisphere. Although whale strandings are common, it is unusual to find beaked whales stranded in such large numbers. Consequently, the environmental management of naval exercises requires mitigation measures to avoid potential impact on beaked whales. This requires some knowledge of beaked whale distributions and behavior, but little is known about beaked whales, less than for all other whales. Beaked whales are small whales that inhabit deep water. They are particularly elusive and rarely seen at sea. Much of what little is known about them results from the few that have been washed ashore. Visual surveying has proved to be generally ineffective. Beaked whale vocalizations are, however, sufficiently distinctive to allow passive acoustic detection and classification [1]. The sounds are sufficiently distinctive to distinguish them from those of other toothed whales, though these distinctions are subtle. All toothed whales produce echo-location clicks or pulses with a small number of cycles and most energy at ultrasonic frequencies. Beaked whale clicks can be distinguished by the frequency range, duration and number of cycles but other species have clicks that are close in one or other of the characteristics.**

In 2008 and 2009 we conducted two passive acoustic surveys of a naval exercise area in deep water in the Coral Sea (north east of Fraser Is.) in an attempt to determine the distributions of beaked whales in the area of about 18,900 square km. Each survey was three weeks duration and involved acoustic and visual observations. A towed array of two hydrophones with frequency response to 150 kHz, and two drifting systems with hydrophones at 400 m depth and response to 96 kHz were used (beaked whale sounds have an upper limit of about 80 kHz). The drifting systems were tracked using a radio link suspended from a buoy that transmitted the GPS position of the buoy at regular intervals. Nothing was known about the presence of beaked whales in the area, but there are records of stranding of four species on the nearest part of the Queensland coast. Two of these species were the same as those recorded with the DTAGs.

Almost 400 h of recordings were obtained using the towed array and almost 200 h from the drifting systems. Thousands of toothed whale clicks were recorded. Some of the clicks recorded were remarkably similar to those published for beaked whales [1, 2] and so were identified as beaked whales. Only a small proportion of clicks were typical of beaked whale sounds and these were recorded mainly over the steep slopes of two coral islands. The analysis is continuing

I. INTRODUCTION

Beaked whales are small toothed whales that generally inhabit deep waters offshore. There are many species (about a dozen in Australian waters). They are very elusive and because of this and their offshore habitat, they are rarely seen. Consequently, little is known about their biology and distributions. Most of what is known has come from occasional stranded animals and rare sightings. Beaked whales have been predominant in whale strandings that have occurred at times of a number of naval exercises in the Northern Hemisphere and this has led to a need for improved knowledge of their distributions for management of impacts.

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The effectiveness of visual surveying for beaked whales is, however, too limited to be useful because they are so difficult to detect visually. A few years ago data the sounds produced by two species of beaked whale, *Ziphius cavirostris* (Cuvier's beaked whale) and *Mesoplodon densirostris* (Blainville's beaked whale), were recorded in the northern hemisphere by placing sound recording tags with suction caps on individual animals with suction caps[1]. Known as DTAGs, these also record the three dimensional motion of the animal. The recordings showed that the two species produced similar sounds and that these were sufficiently different in several acoustical characteristics from those of other toothed whales, providing a reliable means of detection and identification. The sounds, usually referred to as clicks, were modulated tone bursts of seven to 10 cycles over a duration of typically 200 to 300 µs with a frequency sweep starting between 20 and 30 kHz and ending above 50 kHz [1]. There was also evidence that the clicks were used as echolocation and that clicking was mainly confined to depths greater than several hundred meters. The interval between clicks became more rapid as prey were approached, leading to a rapid sequence of buzz clicks [2]. Recently recordings of Gervais' beaked whales *Mesoplodon europaeus* have been published and their vocalizations are generally similar to those of the other two species discussed above [3]. Other species of toothed whales such as dolphins, pilot whales, killer whales and sperm whales also produce echolocation clicks [4], many in a broader frequency band with shorter number of cycles.

In July 2010, a combined US/Australian naval exercise, Talisman Saber, took place in the Coral Sea off Queensland. Two combined visual and acoustic survey for beaked whales was conducted in the area to determine the distribution of beaked whales there, to provide data needed to for environmental management of the exercise. The first survey was conducted in August, September 2009 and was intended both as a trial of the equipment and techniques and to provide useful data. The second survey commenced just before the exercise, and continued through the exercise.

II. THE SURVEY AREA

The survey covered a box extending about 92 n mi (171 km) E-W and 60 n mi (111 km) km N-S (Fig. 1), the coordinates of the NW corner of the box being 22°20′ S and 54°00′ E. While nothing was known about the presence of beaked whales in the area, there have been strandings of four species of beaked whales on the beaches along the coast in the same general area. These included the two of the species for which acoustic signals have been recorded (Cuvier's and Blainville's), the strap toothed beaked whale (*Mesoplodon layardii*) and Longman's beaked whale (*Indopacetus pacificus*). Water depths in the area sloped down the western edge from 300 m on the continental slope to over 3,500 m towards the centre, and included steep sided coral islands edges to the east. What is known about beaked whale habitat preferences indicates that they forage in deep water near the continental slope or steep sided islands [5]. Currents in the region show large scale eddies. Forecasts by the Australian Government ocean forecasting system BLUElink showed significant eddies with cold core intrusions in the area during the surveys (http://www.bom.gov.au/oceanography/forecasts/).

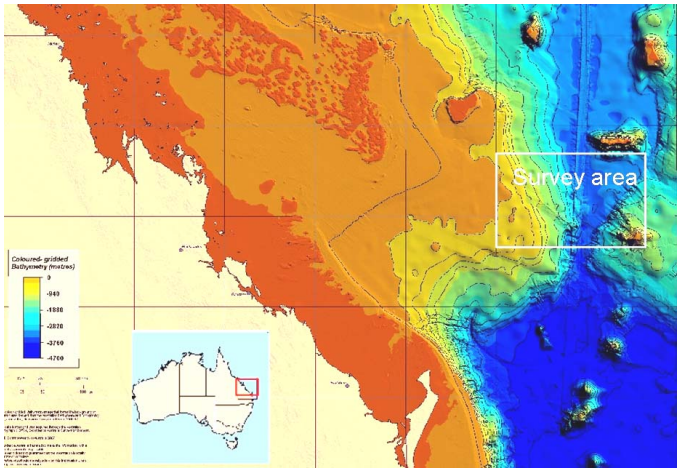

Figure 1. Map showing the location of the survey area and the bathymetry. Water depth varies from 300 m to over 3,500 m. The NW corner of the survey area is 22°20′ S, and 154°00′ E. Fraser Is. is evident to the south west of the area.

III. METHODS

A Royal Australian Navy landing craft, HMAS Labuan was used for the surveys which involved both visual and acoustic monitoring to compare both approaches. It was not expected that visual and acoustic detections could be correlated, since the whales vocalize only while at depths below several hundred meters and there is likely to be significant distance between whales when sighted and when they vocalized during a deep foraging dive. It is reasonable to assume however, that if beaked whales were sighted then sounds of other individuals might be detected in the same general area, given that visual or acoustic detection would indicate that the area was a suitable habitat for the whales.

Although beaked whale sounds have relatively high source levels, acoustic detection ranges of beaked whale clicks are limited because of the higher absorption of sound at the high frequencies of the vocalizations, and because of their narrow beam pattern. Zimmer et al. [6] estimate that the range for 50% probability of detection using a receiver depth of 100 m would be between 1.5 and 3.8 km, and detection beyond 4 km would be very unlikely. These estimates are for low background noise and shorter ranges are to be expected for higher noise levels as conditions (e.g. wind speed) changes. Hence we needed to cover the area with a grid of transects to provide an adequate sample of the distribution. DTAG recordings have shown that while beaked whales change their orientation frequently as they move in search of prey, the variation of beam directions is highest horizontally and lowest vertically. This suggests that detection would be more likely

with deep receivers (at depths approaching those of the whales while vocalizing) than with shallow ones, because a whale would need to point the beam towards the surface to be detected on a shallow receiver.

Two acoustic sensing systems were used on the surveys. One was a towed array supplied by Ecologic UK Ltd., and consisted of two mid frequency channels (500 Hz – 30 kHz) and two high frequency channels (500 Hz – 150 kHz) and a depth sensor. Data were recorded on hard disk via a data acquisition card sampling at 300 kHz. Recording was continuous and saved in wav files of 30 min duration. The hydrophones were closely spaced at the end of the 400 m cable and their depths were about 10 m.

The other system was set to drift with a hydrophone suspended to a depth of 400 m to be closer to the depth of the whales. The depth chosen was a compromise to avoid the hydrophone scraping on the bottom if it drifted into shallower water. Two of these drifting systems ("acoustic loggers") were deployed. The system was developed by the Centre for Marine Science and Technology at Curtin University for the purpose and each comprised a computer controlled recording system in a container suspended below surface buoy near the hydrophone. The data were sampled at 192 kHz and recorded onto a Sound Devices type 722 digital recorder, with 300 s of recording made every 900 s. A suspension system was used to minimize transfer of surface motion to the hydrophone. A radio beacon transmitted the GPS position of each buoy allowing the survey team on the ship to keep track of their position. The logger systems were deployed for a period of a few days at a time, and then recovered, the data downloaded and the systems redeployed. While the towed array provided continuous monitoring, the much deeper hydrophones of the drifting systems were considered to provide an advantage in the detection of clicks from beaked whales foraging at depth.

The hydrophones on the towed array were too close to be useful in localizing the source of sounds. However, because of the short acoustic detection range, a detection would be localized to a small area compared to the size of the survey area. Hence the position of the vocalizing whale could be determined with sufficient accuracy for the purpose, without attempting to use acoustic localization such as with a line array.

Data have been analyzed using MATLAB and the following acoustic software packages: Adobe Audition (Adobe Systems), and Ishmael [7]. Click detections were compared with those published [1, 2]. Some attempts have been made to use automated detection systems, but the first priority has been to manual search for sounds characteristic of those of beaked whales.

IV. RESULTS

There were 210 h of visual survey in 2009 and 200 h in 2010, with two observers throughout. More than 700 individual whales from about 12 species (a small number of individuals were not identified to species), mainly toothed whales from dolphins to sperm whales were seen. There were six sightings of 12 individual beaked whales in 2009, possibly Cuviers based on coloring, and only one sighting in 2010 (possibly Longman's).

The towed array provided 185 h of recording in 2009 and a similar amount in 2010. The drifting acoustic loggers provided 130 h in 2009 and 95 in 2010. The drifting systems were first used on these surveys and proved quite successful. They moved between 30 and 50 km over the few days of each deployment and remained within radio detection range throughout.

Thousands of clicks from various species of toothed whale were detected during both years. Some clicks were found to be remarkably similar to those reported for Cuvier's and Blainville's beaked whales [1, 2] in their duration, frequency range, frequency sweep and number of cycles, and were therefore identified as beaked whale sounds. They consisted of tone bursts sweeping up in frequency over the range from about 25 kHz to 50 to 60 kHz with durations of 200 to 300 μs. The envelopes of the tone bursts showed varying shapes, but generally within the range shown in [1]. Inter-click intervals were also similar. Individual beaked whales are known to produce large numbers of clicks while foraging, so the actual numbers of individual numbers of beaked whales detected will be much fewer than the number of clicks recorded.

Beaked whale clicks were only a small proportion of the total toothed whale clicks recorded and this increases the difficulty of finding beaked whale sounds. It also compromises the effectiveness of automated detection methods. The priority has been given to detecting beaked whale sound manually, and this is proving a long process and analysis is still continuing.

The highest density of clicks in the area surveyed was over the steep slopes of Cato Is., the coral island in the south east corner of the area and over the slopes of Wreck Reef on the northern edge of the area near the north east corner (Fig.1). These are topographically similar to the typical environments where beaked whales have been observed elsewhere.

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