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The first recordings from free-ranging Gervais' beaked whale (*Mesoplodon europaeus*) are presented. Nine Gervais' beaked whales were observed visually for over 6 h. Clicks were only detected over a 15 min period during the encounter, which coincided with an 88 min period during which no whales were observed at the surface. Click lengths were typically around 200 μS and their dominant energy was in the frequency range 30–50 kHz. While these clicks were broadly similar to those of Cuvier's and Blainville's beaked whales, the Gervais' beaked whale clicks were at a slightly higher frequency than those of the other species.
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I. INTRODUCTION

Beaked whales are a group of medium sized, deep diving toothed whales. They inhabit oceanic waters and make extremely deep and long foraging dives (Tyack *et al.*, 2006). These elusive and poorly known animals have been the focus of particular interest in recent years as a result of repeated incidents during which the use of mid-frequency military sonar has resulted in mass stranding and multiple mortalities of beaked whales. A number of well investigated incidents over the past decade, as well as an analysis of historical stranding databases, have now firmly established the link between military sonar exercises and beaked whale mortality events (Frantzis, 1998; Evans *et al.*, 2001; Jepson *et al.*, 2003; Fernandez *et al.*, 2005; Cox *et al.*, 2006). The mechanism by which these stranding occur and the reasons for beaked whale's unusual sensitivity remains unresolved, although it is now felt likely that the process is the secondary result of altered behavior rather than a direct acoustic impact (Cox *et al.*, 2006). Incidents so far have involved Blainville's beaked whale (*Mesoplodon densirostris*), Cuvier's beaked whale (*Ziphius cavirostris*), and Gervais' beaked whale (*Mesoplodon europaeus*), but this may reflect densities and distributions of beaked whales in sonar exercise areas as much as the susceptibility of different species to sonar.

Beaked whales are difficult animals to observe at sea (Barlow and Gisiner, 2006) and an ability to detect them acoustically using passive acoustic monitoring (PAM) could assist in attempts to mitigate sonar impacts. PAM could provide better information on the animals' distribution, it could allow real time monitoring before and during exercises, and it may have a role in facilitating research aimed at understanding the mechanisms behind stranding events (Cox *et al.*, 2006). Effective PAM requires a better understanding of the signal type and the animals' acoustic behavior.

Beaked whales are an unusually diverse group with 21 genetically confirmed species (Dalebout *et al.*, 2004). Wide bandwidth recordings have been made and reported from only a handful of species, however. Recent work, using Digital recording TAGS (DTAG—Johnson and Tyack, 2003) attached to individual whales using suction cups, has provided extremely detailed information on the acoustic characteristics of the sounds produced by two species: Cuvier's and Blainville's beaked whales (Johnson *et al.*, 2004; Madsen *et al.*, 2005; Zimmer *et al.*, 2005; Johnson *et al.*, 2006).

The dominant energy in Cuvier's beaked whale clicks was shown to be between 30 and 45 kHz and click lengths

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were around 200 μs. The clicks of Blainville's beaked whales were broadly similar to those of the Cuvier's. The recording bandwidth of the tag used in some of the earlier studies was 48 kHz, leading to speculation that there may be energy at even higher frequencies. However, later work using DTAGs with sampling rates of 192 kHz and a cabled hydrophone system with sensitivity up to 180 kHz (Zimmer *et al.*, 2005) have confirmed that the dominant frequency for Cuvier's beaked whales is indeed in the 30–40 kHz region.

By combining tracking data and recordings from DTAGs on two Cuvier's beaked whales tagged concurrently, Zimmer *et al.* (2005) were able to calculate a peak to peak source level for clicks of 214 dB re 1 μPa at 1 m and a directionality index of 25dB.

Clicks of similar frequency have also been recorded from other beaked whale species including Baird's beaked whale (*Berardius bairdii*), which had frequency peaks between 23 and 42 kHz (Dawson *et al.*, 1998) and northern bottlenose whales (*Hyperoodon ampullatus*) which had frequency peaks at a mean frequency of 24 kHz while foraging (Hooker and Whitehead, 2002).

Whistles or tonal vocalizations have rarely been recorded from beaked whales. Rogers and Brown (1999) reported on recordings made from Arnoux's beaked whales (*Berardius arnuxii*) made using audiocassette tape with an upper frequency response of ~16 kHz. As well as clicks, these authors reported whistles with a mean length of 0.65 s which were highly frequency modulated with multiple harmonics in the 2–6 kHz range. They also recorded amplitude modulated pulsed tones of similar duration and dominant frequencies in the 1–8.5 kHz range.

DTAG recordings have provided detailed information on the acoustic behavior of Blainville's and Cuvier's beaked whales (Madsen *et al.*, 2005; Tyack *et al.*, 2006; Zimmer *et al.*, 2005; Johnson *et al.*, 2006). In both species clicks have only been detected during deep foraging dives at depths between 222 and 1885 m. There is strong evidence that clicks are used for echolocation (Madsen *et al.*, 2005). Search clicks are produced in regular trains, with typical inter-click intervals (ICIs) of around 0.3–0.4 s and these are interspersed with buzz clicks, rapid bursts of higher frequency clicks produced as whales approach their prey (Johnson *et al.*, 2006).

Caldwell and Caldwell (1991) described clicks and a tonal sound recorded from a male Gervais beaked whale held in captivity following a live stranding. Sounds from the animal were recorded using a Uher 4400-Report tape recorder with an upper frequency limit of 20 kHz. During recording sessions over several days, clicks described as having a "high amplitude" as well as a tonal sound at 6 kHz were recorded. ICIs evident in the spectrograms in the article are consistent with those of other beaked whale species. Click energy is, however, at a much lower frequency than has been reported from other species, the dominant energy being generally below 3 kHz. The tonal sound is approximately 0.1 s long and is modulated in frequency, first sweeping down from 6 to 5 kHz, and then back up to slightly over 6 kHz.

Gervais' beaked whales have rarely been sighted in the wild, and as such very little is known about their ecology. They have been described as widely distributed in deep-water habitats in warm temperate and tropical waters of the North and South Atlantic (Jefferson *et al.*, 2008). Most knowledge about their distribution comes from strandings, most of which have been reported between Cape Cod Bay and Florida on the eastern sea board of the United States, and it is the most frequently stranded *Mesoplodon* in this region (Norman and Mead, 2001; MacLeod *et al.*, 2006; Waring *et al.*, 2007). The species is also found in the Gulf of Mexico and through the Caribbean. South of the equator, strandings have been reported along the Atlantic coast of South America as far south as Brazil and Ascension Island (MacLeod *et al.*, 2006). Strandings have been less frequently reported on the eastern side of the Atlantic and Mediterranean (Podesta *et al.*, 2005) but seem to occur over roughly the same range of latitudes.

Gervais' beaked whales are known from the Bahamas from six single stranding events and one confirmed sighting at sea in March 2001 (Balcomb, 1981; Balcomb and Claridge, 2001; BMMRO unpublished data). A second sighting of Gervais' beaked whales occurred off Andros Island in the Bahamas in October 2007, during which the first recordings of free-ranging Gervais beaked whales, reported here, were collected.

II. METHODS

A. Visual

Recordings were made during a visual line transect and photo-identification survey for beaked whales in the northern Bahamas conducted in October 2007 from a 26 m converted shrimp trawler. While surveying, the research vessel followed a pre-determined transect at a speed of approximately 8 kn. Survey effort was restricted to Beaufort sea state 4 or less and most tracks were completed in Beaufort sea state 3 or less. During visual surveys three observers searched for cetaceans from an observation platform at a height of 7 m. Two observers scanned from 90° to ahead on each side of the vessel using 25×150 Big-Eye binoculars while a third searched with naked eye and 7×50 binoculars. Ranges to sightings were measured using reticules in the binocular eye pieces to measure angle of dip from the horizon. Information on vessel track, survey effort, and environmental conditions (sea state, swell, visibility, wind speed, etc.) were collected using the IFAW LOGGER software (www.ifaw.org/sotw). Effort and environment data were entered every 30 min or when conditions changed.

Once a beaked whale was sighted, the line transect survey was suspended and a 5.5 m rigid hulled inflatable boat (RHIB) was launched in order to make close approaches for photo-identification and biopsy. During these periods, the main vessel remained stationary or moved slowly to stay in the vicinity of the RHIB and whales. A team of four observers remained on the main vessel, two of them continuing to search with Big-Eye binoculars while the others monitored the acoustic data collection and assisted with visual data logging and communications.

B. Acoustic data collection

Acoustic recordings were made continuously through the whole survey using a 400 m long towed hydrophone array (Seiche Measurement UK Ltd). The array consisted of four hydrophone elements arranged as two pairs. Hydrophone pairs were located at 200 and 400 m and the spacing between elements within pairs was 3 m. Each hydrophone was a spherical ceramic connected to a 35 dB preamplifier with a high pass filter configured to be −3 dB at 2 kHz. Hydrophone sensitivity was approximately −165 dB re 1 V/1 μPa at 40 kHz and its response was approximately flat from 2 to 200 kHz. Signals from the hydrophone were recorded using an RME Fireface 800 sound card (Audio AG, Haimhausen, Germany) sampling at 192 kHz. The effective recording bandwidth was therefore from 2 to over 90 kHz. Recordings were made using IFAW LOGGER software and written to disk as four channel, 16 bit wav files. Recordings were made continuously whenever the hydrophone was deployed—both while on transect and during photo-identification periods.

C. Ancillary data

Depth sensors were incorporated into the array close to each hydrophone pair. Hydrophone depth and Global Positioning System (GPS) data were logged every 10 s by the LOGGER software.

D. Acoustic analysis

Clicks were detected offline using click detector modules in the PAMGUARD software (www.pamguard.org, Gillespie *et al.*, 2008). The PAMGUARD click detector was configured to first filter the data using a high pass second order Butterworth filter with a corner frequency at 4 kHz to remove low frequency noise. Data were then passed through a 25–40 kHz fourth order band-pass filter. The output of this band-pass filter then went to a threshold trigger to select sounds with significant energy (>8 dB above background noise) in the 25–40 kHz band. In the event of a trigger, short sound clips (2–3 ms) were made, using data from the output of the first filter. This allowed the broader band data (4–90 kHz) to be used for the next stage of the analysis, classification.

During the Gervais' beaked whale encounter, the hydrophone was hanging near vertical in the water. Although clicks were detected on all hydrophones, only data from the two hydrophones furthest from the boat, which had a better signal to noise ratio, were analyzed. Angles to detected clicks, relative to the array, were calculated using time of arrival differences between the two hydrophones.

Click files were viewed with the RAINBOWCLICK software (Gillespie and Leaper, 1996). This allows the user to easily view groups of clicks on a plot of angles to detected clicks against time and the waveforms and power spectra of individual clicks can be scrutinized. Clicks were selected for the latter stages of the analysis if they satisfied the following criteria:

(1) had significant energy in the 25–50 kHz energy band compared to lower and higher frequencies,
(2) had a waveform resembling that of published data for other beaked whale species, and
(3) formed part of a click train, i.e., they were arriving from the same angle as other clicks and time intervals between clicks appeared regular.

To search for tonal sounds of the type described by Caldwell and Caldwell (1991), all sound files from the encounter were also monitored carefully using high quality headphones (Sennheiser HD 280 pro) while the operator (C Dunn) simultaneously viewed a scrolling spectrogram display of data. An Fast Fourier Transform (FFT) length of 4096 samples was used with a 50% overlap and Hanning window, giving time and frequency resolutions on the spectrogram of approximately 21 ms and 47 Hz, respectively. Only spectral data from 2 to 16 kHz were viewed to improve screen resolution at those frequencies. One channel of the hydrophone pair at 200 m and one channel from the pair at 400 m were selected both for listening and for viewing to maximize the chances of picking up sounds from animals at the surface or at depth.

III. RESULTS

A. Visual

Nine Gervais' beaked whales were encountered between 08:14 and 14:50 local time (12:14–18:50 GMT[1]) on 4 October 2007. Sea conditions at this time were flat calm offering excellent sighting conditions. The initial sighting was made using Big-Eye binoculars at an estimated distance of 5870 m. The survey vessel remained in the vicinity of the animals for over 6 h while the RHIB maneuvered to approach animals during surfacing bouts. The encounter ended when it was judged that sufficient photo-identification and biopsy data had been collected.

The assemblage was encountered as three sub-groups consisting of three, two, and four individuals, including adults and sub-adults, with no calves noted. Sighting times and distances to the three groups are shown in Fig. 1. Sub-group A remained in the immediate area of the research vessel until 11:50 and was then not seen thereafter, sub-group B left the area during the encounter and was last seen at 10:21, and sub-group C appeared at 13:18. Photo-identification showed that the animals observed in the three sub-groups were different individuals. Sub-group A completed a number of short dives that were visually recorded, with the shortest duration being 9 min, the longest 28 min, and the mode being 18 min.

The species identification was based on a combination of visual cues as well as by genetic analysis of a biopsy sample. This was analyzed using standard extraction and genetic sequencing procedures, and the resulting sequence was checked against three reference libraries for identification consistency (personal communication, K. Robertson, SWFSC Molecular Genetics Laboratory, La Jolla, CA).

No cetaceans were sighted that morning during an hour of surveying prior to the Gervais' beaked whale encounter

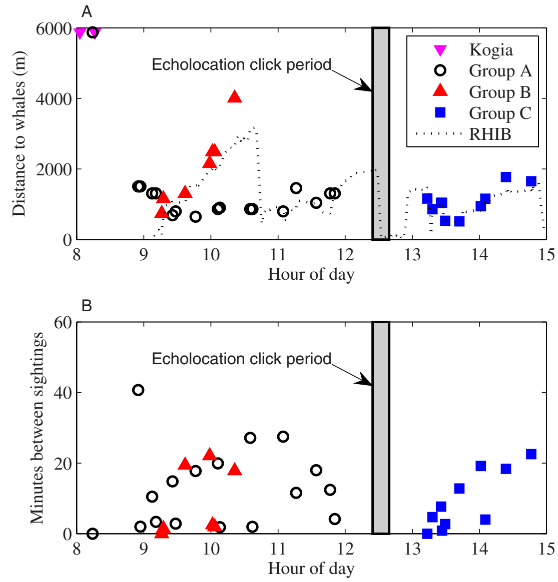

FIG. 1. (Color online) (a) Distances from the ship to sightings of Kogia, the three groups of Gervais' beaked whales, and to the RHIB and (b) time interval between visual sightings of beaked whales.

apart from an unknown *Kogia* species sighted at 08:02 and a dwarf sperm whale (*Kogia sima*) at 08:16, both close to the start of the Gervais' beaked whale encounter. Both *Kogia brevicips* and *Kogia Sima* are known to produce clicks at frequencies well above 100 kHz, similar to those of porpoises (Madsen *et al.*, 2005; V. Janik, personal communication) and therefore would not have been detected by the equipment used in this study. Both were approximately 5.9 km from the vessel and were 6 and 2 km from the Gervais' beaked whales, respectively. The *Kogia* were not re-sighted and no other species were seen until well after the encounter when a group of Cuvier's beaked whales were spotted at 16:19 at a distance of approximately 15 km from the Gervais' beaked whales. The sea conditions were calm and sighting conditions excellent throughout the day.

Figure 1(a) shows ranges (based on reticule measurements) between the recording vessel and whales observed at the surface during the encounter. The sightings immediately before and after the acoustic contact (see below) were at distances of 1309 and 1160 m from the vessel. Figure 1(b) shows times between sightings. For most of the encounter, sightings were quite regular, with one of the sub-groups sighted at the surface at least once every 10–15 min. However, a single long period with no whale sightings occurred between 11:50 and 13:18.

B. Acoustic

The hydrophone was deployed and recordings were made continuously from 09:00 until the end of the encounter. For most of the encounter, from 09:20 until 14:52, the vessel was stationary, allowing the hydrophone to hang near vertically in the water column. Depth sensors close to the front and rear pairs of hydrophones read 188 and 384 m, respectively, throughout this period.

During the entire encounter a total of 124 beaked whale clicks were detected on the lowest hydrophone pair. All of these detections occurred within a short time window between 12:24:30 and 12:39:19 ($\sim$15 min) which was within the longest (88 min) interval between sightings, the first click being detected 34 min after the most recent sighting (Fig. 1). Angles to the clicks were more or less constant during the encounter, varying by no more than 6° and at no time were clicks detected simultaneously at different angles, therefore giving no indication that the clicks came from more than one individual. Angles to clicks all indicated that the animal was deeper than the hydrophone, i.e., at a depth of over 384 m.

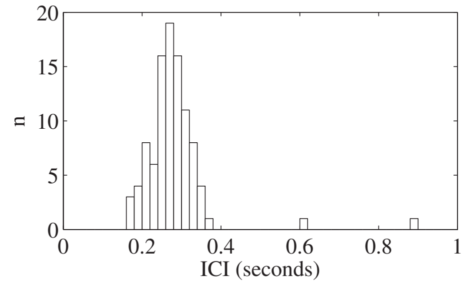

FIG. 2. Histogram of ICIs <1 s.

The clicks were detected in short sequences followed by gaps which varied in time from a few seconds to 336 s. Intervals between clicks within sequences are shown in Fig. 2. The mean ICI for intervals <0.5 s (the dominant peak in Fig. 2) was 0.27 s. There were no regular clicks with an ICI greater than 0.4 s and it is probable that the ICIs in Fig. 2 at 0.6 and 0.9 s are due to one and two missed clicks, respectively. A typical click waveform, power spectrum, and time-frequency (Wigner) distribution are shown in Fig. 3. For comparative purposes, the mean power spectrum for all of the Gervais' beaked whale clicks is shown with similar averaged spectra for clicks from Blainville's and Cuvier's beaked whales encountered during the same cruise and analyzed in the same way in Fig. 4. The click waveform is similar to that of Cuvier's and Blainville's beaked whales, having a duration of about 200 μs and energy concentrated

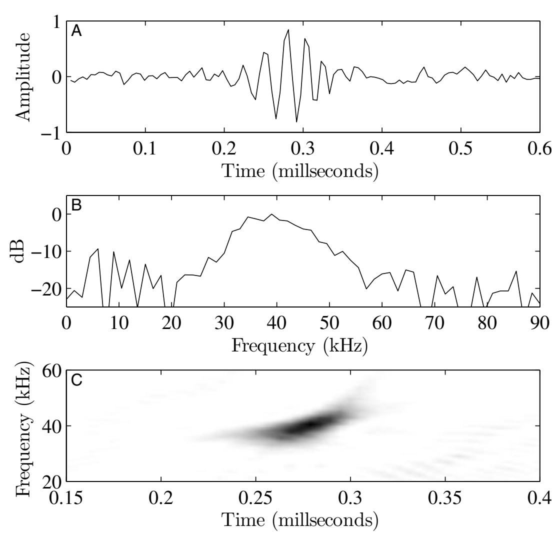

FIG. 3. (a) Waveform, (b) normalized power spectrum, and (c) time-frequency (Wigner) distribution for a typical detected click from a Gervais' beaked whale.

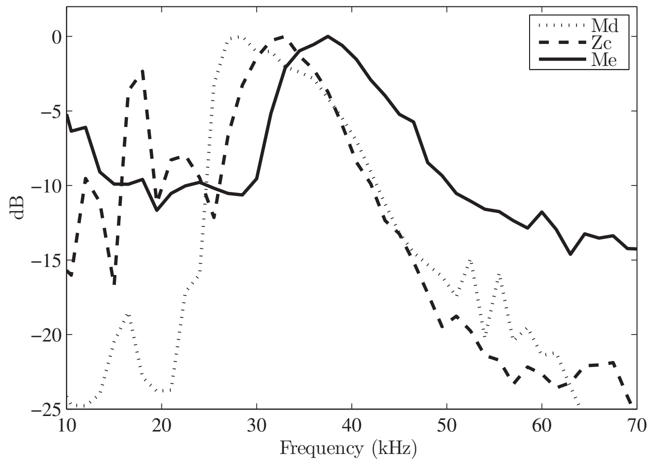

FIG. 4. Averaged power spectra for three beaked whale species (Md =Blainville's beaked whale, Zc=Cuvier's beaked whale, and Me=Gervais' beaked whale).

in the 30–50 kHz band. The spectral data indicated that Gervais' beaked whale clicks were at a slightly higher frequency than other species. Like these other species the Gervais' beaked whale click appeared to sweep up in frequency.

A single tonal sound was both detected on the spectrogram and heard with headphones. The sound was only detected on the hydrophone at 200 m depth. It was approximately 30 ms in length and was at a very narrow band frequency centered at 6 kHz. From a time of arrival measurement of the signal on the two hydrophones at 200 m, it was found that the sound was coming from the direction of the vessel and it is our belief that it is mechanical in nature.

IV. DISCUSSION

Data from DTAGs (Johnson *et al.*, 2004, 2006; Madsen *et al.*, 2005) show that other beaked whale species only echolocate when undertaking deep foraging dives. Our data indicate that the same may be true for Gervais' beaked whales since they were only detected acoustically during the longest interval between visual sightings of whales. However, since the individuals observed after the bout of clicking were different from those observed before it, we cannot be certain that the animals were engaged in a long foraging dive and had not simply departed from or arrived into the area.

The potential for underwater recordings to be contaminated by sounds from unseen animals other than the focal species is always a concern especially with species like beaked whales which seem to vocalize mainly at depth when they cannot be directly observed at the surface. In this case several pieces of information give us confidence that the clicks we detected were those of Gervais' beaked whales.

(1) The low density of cetaceans in the area allied to the good sighting conditions, high level of visual effort, and lack of detections of any other cetacean within several hours of the acoustic detection.
(2) The substantial spatial and temporal gap between this encounter and sightings of any other beaked whales.
(3) The fact that sound production appeared to be synchronized with a long period without visual sightings of the targeted group, as has been documented during deep foraging dives for other beaked whale species.
(4) The observation that the sounds have the same general characteristics of those of other beaked whale species recorded by this team using the same equipment, yet demonstrate sufficient differences to be distinctive.

Sighting and photo-identification records indicate that there were three individuals present in the surface encounter before the clicks were detected and four different animals during the surface encounter immediately afterward. The number of clicks detected (124) was considerably less than the 4000–5000 clicks per dive reported for Cuvier's and Blainville's beaked whales (Madsen *et al.*, 2005). Zimmer *et al.* (2005) showed that beaked whale clicks are highly directional and are therefore only likely to be detected if an animal happens to be orientated toward the hydrophone. Zimmer *et al.* (2008) modeled detection probability for Cuvier's beaked whales and showed that the probability of detecting any individual click with a remote hydrophone is low, but that the overall probability of detecting at least some clicks from a group is much higher. Our results are consistent with these findings.

The only previous recording of this species of which we are aware was made from a captive animal in a small tank by Caldwell and Caldwell (1991). The recording equipment used was not sensitive to the higher frequency sounds recorded in this study and no sounds of the type that they recorded could be found in our recordings. Caldwell and Caldwell (1991) described the sounds they recorded as having a high amplitude. One possible explanation for the clicks they reported is that the high frequency clicks were saturating their recording equipment, resulting in a broad band distortion that would have been within the bandwidth of their system.

It is not known whether the surfacing and diving behavior observed here is typical for all Gervais' beaked whales and they are certainly insufficient for drawing many conclusions. Clicks were only heard once during a period of over 6 h spent in the proximity of several animals. If this behavior is typical, then the probability of acoustic detection during an acoustic survey or for mitigation is likely to be low. This is not necessarily a severe problem for survey applications where additional survey effort can be expended. For mitigation applications though this would suggest that only a small degree of risk reduction could be provided by PAM.

Clicks were detected in a number of short sequences, followed by gaps of varying durations. All of the clicks were relatively quiet and were very close to the limits of detectability with the hardware used. It is therefore highly likely that many clicks were missed and that clicking was much more continuous than indicated by these data.

The waveform and spectrum of Gervais' beaked whale clicks are similar to those of Cuvier's and Blainville's beaked whales, but are at a slightly higher frequency. It would be unwise to draw too many conclusions from a recording of what may be a single animal, but if this difference in frequency is genuinely characteristic of the species, it may in the future be possible to tell some beaked whale species apart based on acoustic data alone.

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[1]All subsequent times in the paper are local Bahamas time=GMT−4.

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