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Citation: Proc. Mtgs. Acoust. **27**, 040002 (2016); doi: 10.1121/2.0000269
View online: https://doi.org/10.1121/2.0000269
View Table of Contents: https://asa.scitation.org/toc/pma/27/1
Published by the Acoustical Society of America

Proceedings of Meetings on Acoustics

Volume 27 http://acousticalsociety.org/

Fourth International Conference on the Effects of Noise on Aquatic Life

Dublin, Ireland

10-16 July 2016

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This investigation set out to obtain data on the ecology, foraging and acoustic behavior of Chilean blue whales (*Balaenoptera musculus*) in the Gulf of Corcovado, which is an important feeding ground. We deployed 17 suction cup attached sound and orientation recording tags (DTAGs) on blue whales in 2014-16, for a total duration of 124h 08 min. Acoustic data on the tags revealed a variety of different calls. These included SEP2 (Southeast Pacific) song, previously described in this area, as well as other call types not previously described for Chilean blue whales. Downsweep calls similar to those described for other blue whale populations were observed on several tags, as were various other less stereotyped calls. We are currently working on characterizing these call types and also on using the accelerometers to identify calls from the tagged animal. Tag data will prove useful for interpretation of data collected in this area from passive acoustic monitors (PAM), both for species identification and possibly also density estimation. Overall, this work has the potential to greatly increase knowledge of the biology, ecology and behavior of blue whales in the Gulf of Corcovado.

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1. INTRODUCTION

Blue whales are known principally by two contrasting accolades, firstly, as being the largest animal to have ever lived on Earth, and secondly, as having been hunted to near extinction during twentieth century whaling. During the whaling era over four thousand animals were caught in Chilean waters alone (Williams et al. 2011). The species has been slow to recover from almost total decimation and hence a valuable discovery was made in 1993, when a small blue whale population of 232 individuals was found in the Gulf of Corcovado in the Chiloense Ecoregion of Southern Chile (Hucke-Gaete et al. 2004). Genetic, acoustic and morphometric studies indicate that these blue whales are part of a wider Southeast Pacific population that is distinct from both the Antarctic (*B. musculus intermedia*) and "pygmy" (*B. musculus brevicauda*) blue whale subspecies (Branch et al. 2007, Buchan et al. 2014, Torres-Florez et al. 2014). Further investigations are required to establish the degree of isolation of the population and the health and viability of the individuals within it. Such knowledge will aid Chilean policy makers in generating informed management decisions regarding the conservation of this population.

This investigation, a collaborative effort between the Melimoyu Ecosystem Research Institute (MERI) and the Woods Hole Oceanographic Institution (WHOI), set out to obtain data on the ecology, foraging and acoustic behavior of individual blue whales in and around the Gulf of Corcovado, Chile (Fig. 1), through the deployment of suction cup attached digital acoustic tags (DTAGs; Fig. 2). DTAGs are miniature sound and orientation recording tags (Johnson and Tyack 2003), which contain a VHF transmitter used to track the tagged whale during deployment and to retrieve the tag after release. DTAGs contain hydrophones, depth sensors, and 3-dimensional accelerometers and magnetometers, and thus provide data on vocal and dive behavior, as well as movement. The tag is attached with four suction cups using a hand-held 8 m carbon fiber pole (Fig. 2), and can be programmed to release after durations of up to 30 hours. The aim was to achieve DTAG carries of several hours combined with visual tracking, radio tracking and photo-identification, and to integrate DTAG data with data from biopsies (genetics and stable isotopes), prey sampling, morphometric sampling, and passive acoustic monitoring (e.g., Buchan et al. 2014, 2015). These combined efforts seek to better understand blue whale ecology, behavior and habitat use and to establish abundance estimates in the study area.

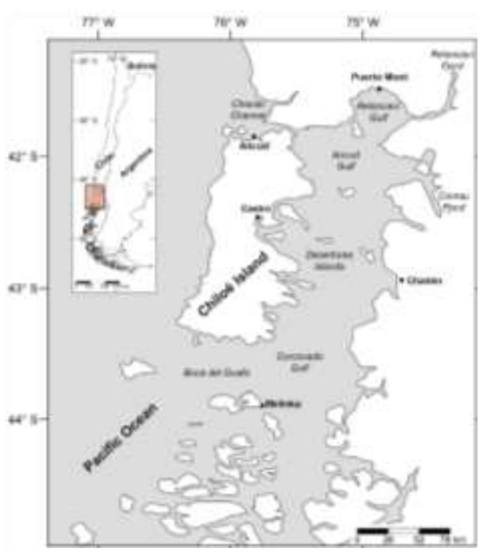

Figure 1. Map of the study area

Figure 2. DTAG about to be attached via hand-held pole to a blue whale in the Gulf of Corcovado. Note that the tag attaches via four suction cups and that it is very small relative to the animal's size. Photo taken by Daniel Casado.

2. METHODS

The months of February and March were chosen to conduct field efforts, based on historical blue whale sightings, acoustic detections and weather data. Each day, weather and sea-state permitting, visual search efforts to detect marine mammals began at sunrise on the main vessel. In 2014, transects were undertaken, and in following years efforts were focused in areas where whales had been found to be prevalent. All cetacean sightings were recorded in LOGGER (http://www.marineconservationresearch.co. uk/downloads/logger-2000-rainbowclick-software-downloads/), and where possible photo-identification images were collected. Once blue whales were detected, the possibility for tagging was assessed and if conditions were suitable, tagging commenced.

A. TRACKING, VISUAL DATA COLLECTION AND PHOTO-ID

To visually search for animals to tag, and to observe the behavior of the animals during tagging and tracking, a marine mammal observer platform (5m above sea level) was installed on main vessel. Observers scanned with the naked eye and 7 X 50 binoculars. This platform was equipped with a computer running the behavior logging program LOGGER (recording data such as species, group size, behavior, latitude/longitude) and a VHF digital direction finder system for tracking the tag. Video and/or digital photographs to record species and any identifying marks were collected whenever possible.

B. TAGGING

The tagging boat was deployed with a driver, photographer, and tagger to deliver the tag using the hand-pole. Attempts were made to tag each whale in a group when whales appeared to be coordinated and were likely to remain together, thus minimizing the risk of tag loss.

Visual observers on the main vessel helped direct the tag boat towards animals, monitored tagging approaches, and ensured tagging permit compliance. Data sheets and computer data logs were kept on the main vessel and tag boat, detailing each tagging approach. If tagging was unsuccessful after several approaches, tagging efforts were suspended. During tagging efforts video and/or 35mm digital photographs were collected whenever possible, as were sloughed skin and fecal samples.

Once a whale was successfully tagged and all relevant data collected by the tag team, the tag boat returned to the main vessel. The main vessel was then used to track and maintain visual and photo-identification efforts for the duration of tracking and behavioral observations (except for night hours). At night, the main VHF receiving antenna on the vessel was used for radio tracking of the tagged whale. Tagging attempts continued during daylight hours and a day was only considered complete when all tags were recovered and there was no longer enough daylight to attempt further tagging. Tags were recovered with a dip net from the main vessel. Tag data were offloaded onboard, and the tags were recharged and sterilized for subsequent use.

C. PASSIVE ACOUSTIC MONITORING

Moorings equipped with passive acoustic monitors (PAM) were deployed in two critical habitat areas to monitor the presence of blue whales in 2015-2016, to supplement PAM data collected in 2012-2013. Moorings consisted of surface arrays with Soundtrap recorders (http://www.oceaninstruments.co.nz/). Recorders were retrieved and redeployed monthly.

3. RESULTS

Three cruises have been undertaken, in February and March of 2014, 2015 and 2016, for a total of 53 workable sea days. A total of more than 3046 nm and 555 hours of 'on effort' survey were completed (Figure 3). The survey effort generated 345 sightings of six cetacean species: blue whale, *Balaenoptera musculus*, humpback whale, *Megaptera novaeangliae*, bottlenose dolphin, *Tursiops truncatus*, Chilean dolphin, *Cephalorhynchus eutropia*, Peale's dolphin, *Lagenorhynchus australis*, and Burmeister's porpoise (*Phocoena spinipinnis*). However, blue whales were the primary focus species of the cruises and search efforts were biased toward finding this species.

A. PHOTO-IDENTIFICATION

A total of 117 blue whale groups were photo documented over the three field seasons, with 32 different individuals photo-identified in 2014 and 2015 (analysis of 2016 data is currently ongoing). Of the 244 total encounters with blue whales, most were with individual animals, although some were in groups of two (often mother-calf pairs) or three, with an overall mean group size of 1.16 (SD 0.41).

B. DTAG EFFORT

A total of l24h 08min of blue whale DTAG data were collected, consisting of 17 deployments (Table 1, Figure 3). The mean deployment duration was 7 h 18 min (S.D. 360.1 min), with the longest at 24h 45 min, providing an interesting insight into the diurnal nature of blue whale behavior in this area. Sloughed skin samples were obtained from the suction cups of most recovered tags and were stored for genetic tests. High sloughing rates may have been the cause for early releases in some of the deployments, although in the case of the 24 hour deployment, sloughed skin impeded the tag release mechanism, resulting in a longer than programmed deployment.

Dives were generally shallow, predominantly between 10 and 50 m in depth. Occasional deeper dives were recorded, with a maximum depth of 157m. The consistent shallow nature of dives suggests that prey were present in the upper part of the water column.

DTAG audio was sampled at either 120 or 500 kHz and sensors were sampled at 200 or 500 Hz. Audio data were serially downsampled to 1kHz for analysis in MATLAB.

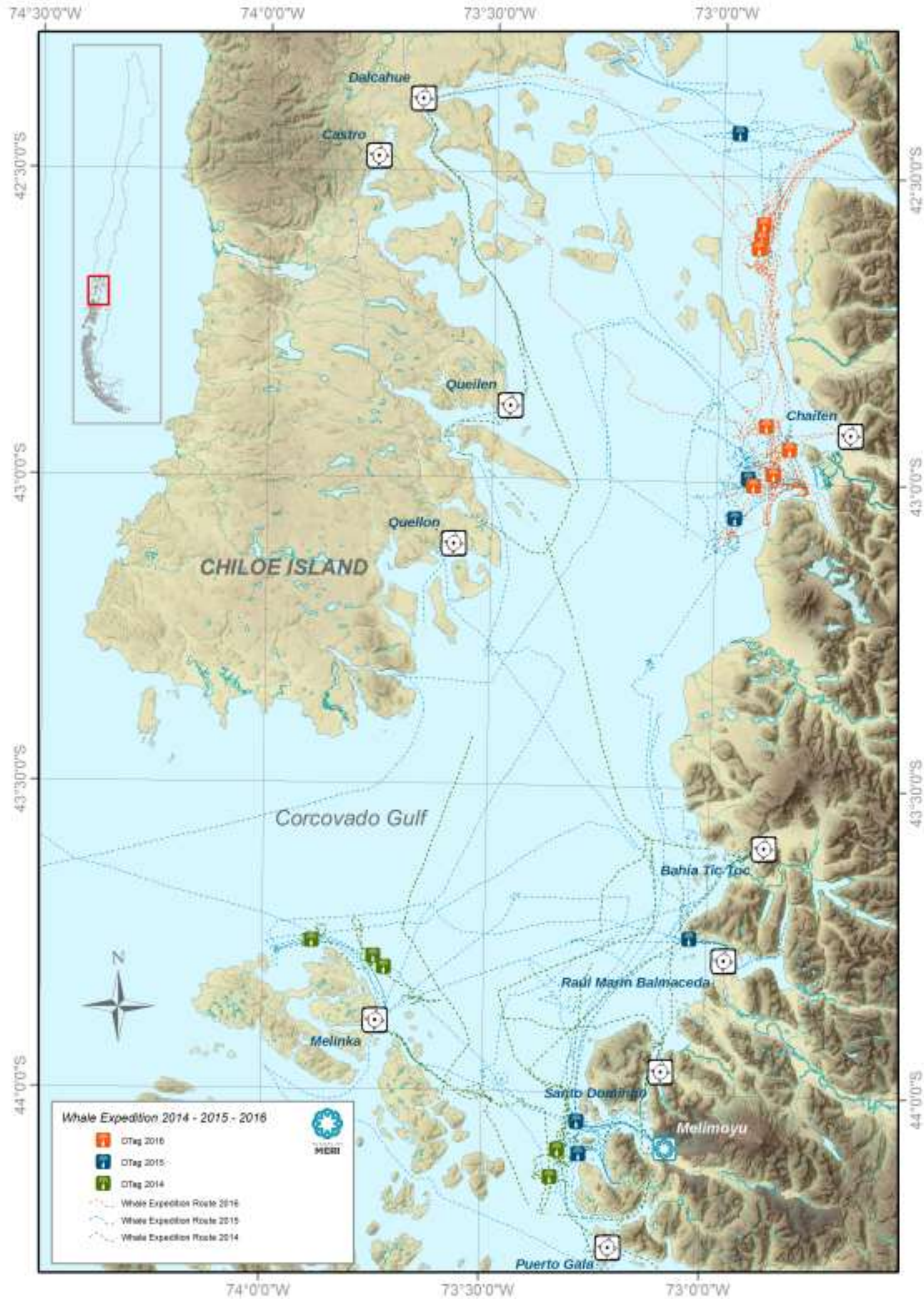

Figure 3. Map of the study area, showing cruise tracks and locations of tag deployments for 2014-16. White symbols show locations of night anchorages.

Table 1. Details of DTAG deployments.

Date	TagID	Duration
17-Mar-14	bm14_076a	00 hr 07 min
17-Mar-14	bm14_076b	05 hr 53 min
23-Mar-14	bm14_082a	03 hr 46 min
23-Mar-14	bm14_082b	01 hr 18 min
24-Mar-14	bm14_083a	10 hr 07 min
17-Feb-15	bm15_048a	24 hr 45 min
19-Feb-15	bm15_050a	06 hr 53 min
22-Feb-15	bm15_053a	09 hr 00 min
23-Feb-15	bm15_054a	10 hr 18 min
26-Feb-15	bm15_057a	03 hr 31 min
05-Mar-15	bm15_064a	10 hr 17 min
18-Feb-16	bm16_049a	12 hr 45 min
19-Feb-16	bm16_050a	06 hr 48 min
23-Feb-16	bm16_054a	08 hr 46 min
26-Feb-16	bm16_057a	00 hr 15 min
28-Feb-16	bm16_059a	00 hr 39 min
02-Mar-16	bm16_062a	09 hr 00 min
Total	17 tags	124 hr 08 min

i. Acoustic analysis

Acoustic data on the tags revealed a variety of different calls. These included SEP2 (Southeast Pacific) song, previously described in this area by Buchan et al. (2014; Figure 4), as well as other call types not previously described for Chilean blue whales. Downsweep calls similar to those described for other blue whale populations (e.g., Oleson et al. 2007) were observed on several tags (Figure 5), as were various other short, less stereotyped calls (see examples in Figures 6 and 7). We are currently working on characterizing these call types and also on using the accelerometers to identify calls from the tagged animal, as described by Goldbogen et al. (2014) (Saddler et al., in prep).

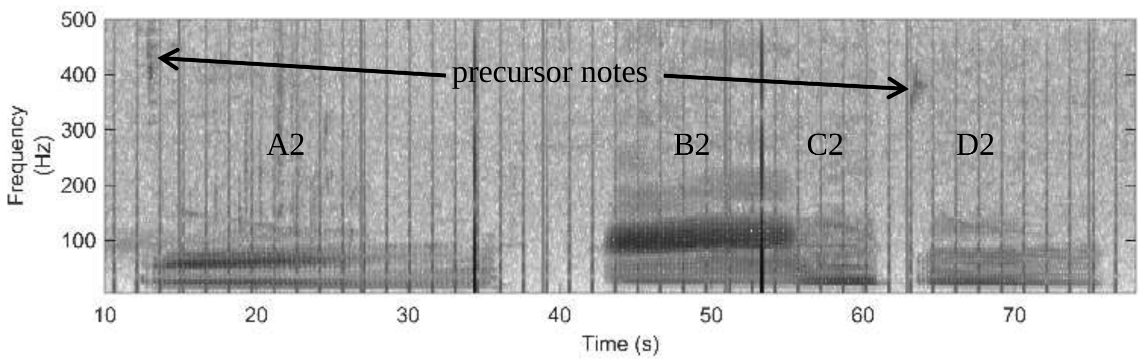

Figure 4. Spectrogram of a Chilean blue whale SEP2 call recorded on a DTAG. The six call components identified by Buchan et al. (2014) are labeled (A2, B2, C2, D2, and two higher frequency "precursor" notes). Vertical lines are signals from the DTAG antenna. Spectrograms were made in MATLAB with a 256 point FFT, and a Hamming window with 99% overlap.

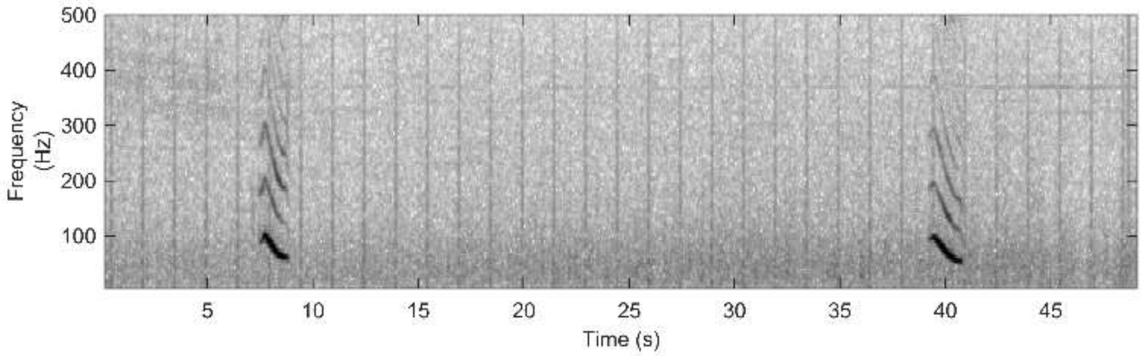

Figure 5. Spectrogram of Chilean blue whale downsweep calls recorded on a DTAG. Vertical lines are signals from the DTAG antenna. Spectrograms were made in MATLAB with a 256 point FFT, and a Hamming window with 99% overlap.

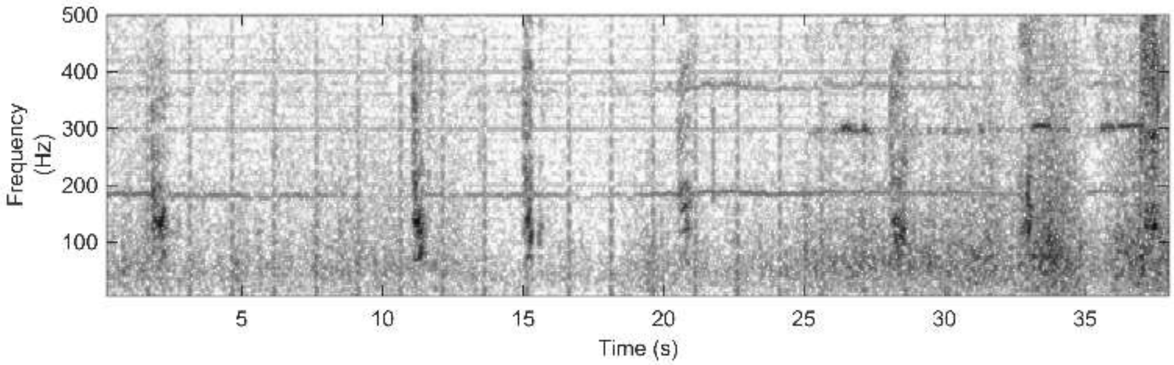

Figure 6. Spectrogram of Chilean blue whale "grunt" calls recorded on a DTAG. Vertical lines are signals from the DTAG antenna. Spectrograms were made in MATLAB with a 256 point FFT, and a Hamming window with 99% overlap.

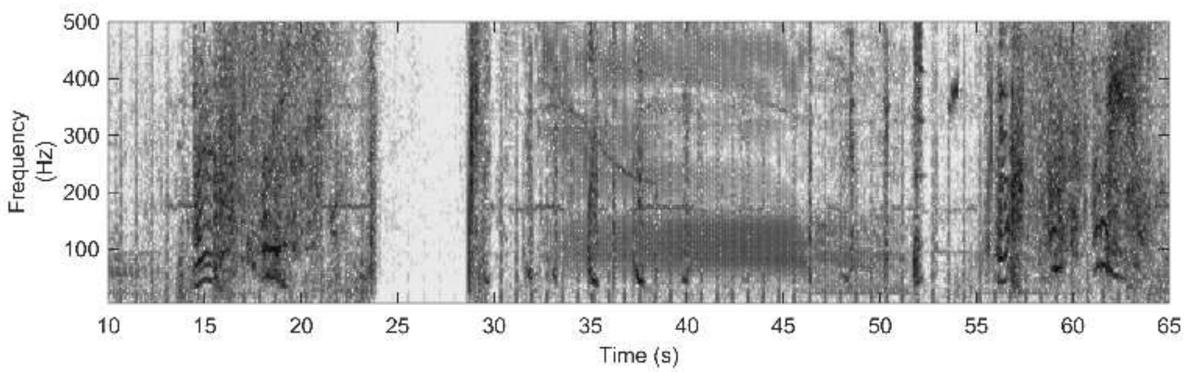

Figure 7. Spectrogram of a variety of calls recorded on a DTAG on a Chilean blue whale. Note calls at approximately 15, 18, 29, 32, 33, 35, 37, 40, 48, 56, 59, and 62 seconds. The gap at 24-29 sec is when the tag is in the air at the surface. The pulsed calls evident at 33 to52 sec are B2 and C2 components of a SEP2 call, as shown in Fig 4, and the tonal call at approximately 400Hz at 54 sec is the 2nd "precursor" tone, also as shown in Figure 4. This SEP2 call was likely produced by a different whale. Vertical lines are signals from the DTAG antenna. Spectrograms were made in MATLAB with a 256 point FFT, and a Hamming window with 99% overlap.

C. PASSIVE ACOUSTIC MONITORING

Passive acoustic monitoring data collected in 2012-2013 were previously used to describe structure (Buchan et al. 2010, 2014) and seasonal patterns of occurrence (Buchan et al. 2015) of Chilean blue whale call types SEP1 and SEP2. We are currently exploring patterns of occurrence of these call types in PAM data collected in 2015-2016. In addition, we are examining both PAM data sets for other blue whale sounds as well as sounds of other species. The effects of abundant ship noise on blue whale calling behavior are also being examined (see paper in this volume by Colpaert et al.).

4. IMPACT AND FUTURE WORK

The collaboration between the MERI and WHOI teams has been highly successful and has now expanded to include multiple other researchers doing work on a variety of topics, including kinematics of foraging behavior, prey mapping, and photogrammetry using drones. We anticipate that acoustic data from the tags will provide individual call rates, which will enable density estimations from recordings made from passive acoustic monitors (PAM; e.g., Marques et al. 2013). Overall, this work has the potential to greatly increase knowledge of the biology, ecology and behavior of blue whales in the Gulf of Corcovado. This work will also yield insights into how blue whales utilize the study area, and will help make informed decisions about the potential for anthropogenic impacts on blue whales in this area. For example, DTAG dive profiles showing that these whales spend much of their time near the surface (e.g., Figure 8) highlight the potential risk from ship strikes in this area. In addition, ship noise has potential to impact blue whale communication (Colpaert et al., this volume). Thus, this ongoing research promises to provide information for policy makers regarding how best to protect the unique habitats that exist within the Gulf of Corcovado.

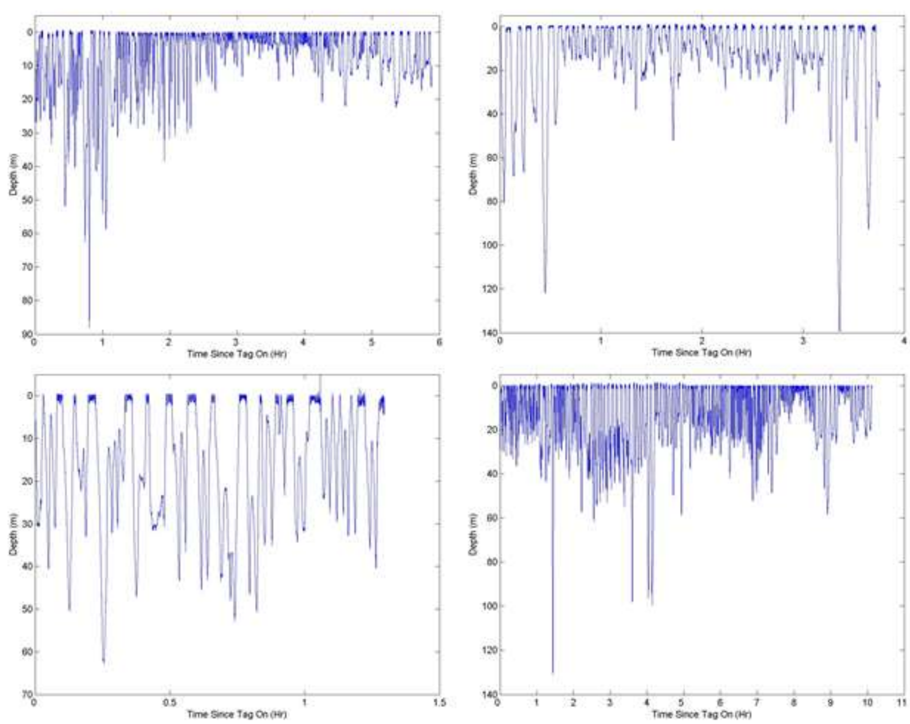

Figure 8. Dive profiles of four animals tagged in 2014 (note different axis scales).

ACKNOWLEDGMENTS

This work was carried out under Chilean research permit PINV 38-2014, 2015, 2016 Ballena Azul, Golfo Corcovado, from the Ministerio de Economia, Fomento y Turismo, Subsecreteria de Pesca y Acuicultura. Thanks to the crews of the vessels Centinela and Khronos, to Pepe and Thomas Montt, and to Daniel Casado. Thanks to Frants Jensen for assistance with analysis of tag data and to Wouter Colpaert and Esteban Tapia Brunet for assistance with maps used as figures. Thanks also to our collaborators Michael Moore, John Durban, Joe Warren, Jeremy Goldbogen, Paolo Segre, and Dave Cade.

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