Acoustic behavior of blue whales (*Balaenoptera musculus*) in the Gulf of Corcovado, Chile, recorded on DTAGs

Alessandro Bocconcelli[1],Mark Saddler[2], Leigh Hickmott,[3,4] Gustavo Chiang[5],
Paulina Bahamonde, Francesco Caruso[6,] and Laela Sayigh[2]

(1)Woods Hole Oceanographic Institution, Applied Ocean Physics & Engineering, Woods Hole, USA

(2) Woods Hole Oceanographic Institution, Department of Biology, Woods Hole, USA

(3) Scottish Oceans Institute, East Sands, University of St Andrews, St Andrews, UK

(4) Open Ocean Consulting, Petersfield, Hampshire, UK

(5) Melimoyu Ecosystem Research Institute, MERI Foundation, Santiago, CHILE

(6) Institute for Coastal Marine Environment, National Research Council, Torretta Granitola, ITALY

INTRODUCTION

Blue whales are known principally by two contrasting accolades, first, as being the largest animal to have ever lived on Earth, and second, 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). This investigation set out to obtain data on the 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).

Our goal was to characterize the vocal repertoire of individual whales using a technique described by Goldbogen et al. (2014), in which the production of low frequency calls by the tagged whale creates body vibrations that are recorded on the tag's accelerometers.

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**

RESULTS AND CONCLUSIONS

Seventeen tag deployments were achieved in 2014-2016, for a total of 124 hours of data (Table 1). Acoustic data on the tags have revealed a variety of different call types. These include calls previously identified as "SEP2" calls (Southeast Pacific; Buchan et al. 2014) (Fig 3), downsweep calls similar to "D" calls described for blue whales in other areas (e.g., Oleson et al. 2007) (Fig 4), as well as several other call types.

Although we had hoped to attribute calls to the tagged (focal) whales by confirming their occurrence on the tags' accelerometers, we have found several lines of evidence that suggest that the accelerometers are recording body vibrations from received calls, as well as produced calls. First, we sometimes see just a portion of a call on the accelerometers (Fig 5). Second, we often see the six part SEP2 call interrupted by surfacings (Fig 6). Finally, we see overlapping, simultaneous calls on the accelerometers (Fig 7).

We are hoping to establish a threshold value for the accelerometer signals above which we can confidently conclude that that the call was produced by the tagged whale.

Tag data promise to enhance our interpretation of recordings collected in this area from passive acoustic monitors (PAM), both for species identification and possibly also density estimation. Thus, this work has potential to contribute to efforts to protect this important population of endangered blue whales.

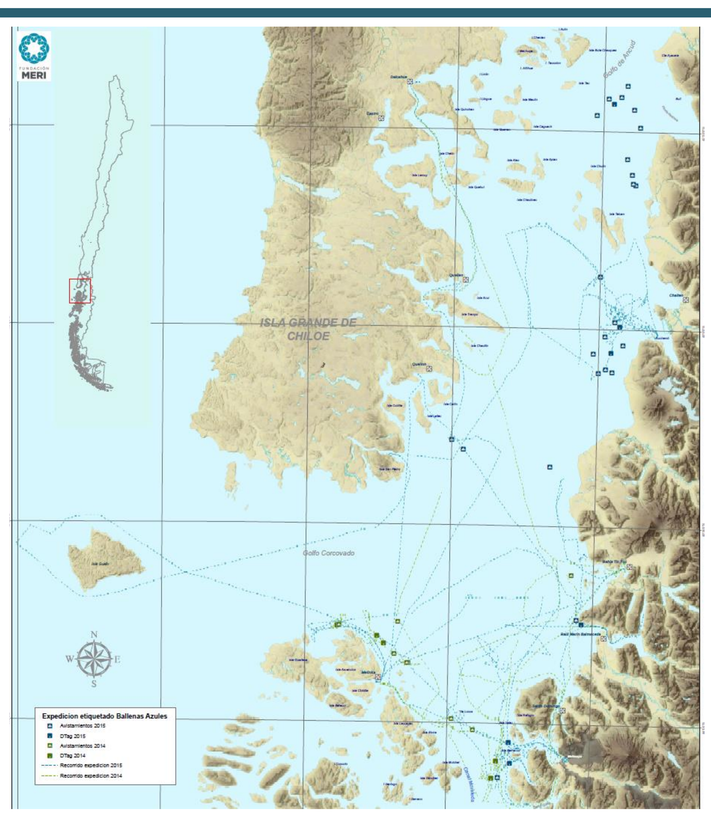

Figure 1. Map of the study region on the coast of Chile, showing locations of sightings ("avistamientos") and tag deployments, as well as the cruise track ("recorrido expedicio"), for 2014 and 2015.

Figure 2. Upper left: DTAG being attached via a hand-held pole; lower left: close-up of a DTAG; right: DTAG attached to a blue whale

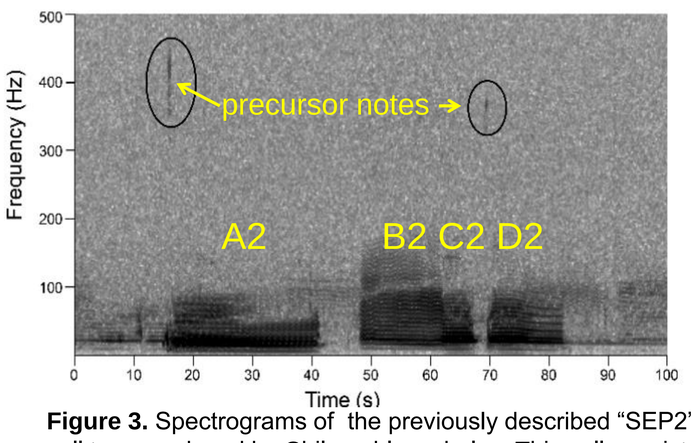

Figure 3. Spectrograms of the previously described "SEP2" call type produced by Chilean blue whales. This call consists of six parts, labelled A2, B2, C2 and D2, plus two higher frequency "precursor" notes, which are circled (Buchan et al. 2014). This loud call was recorded on a Marine Autonomous Recording Unit (MARU) in the study area.

METHODS

DTAGs (v3) are sound and movement recording tags, which are equipped with two hydrophones, a depth sensor, and 3-axis accelerometers and magnetometers (Fig 2; Johnson and Tyack 2003). Accelerometers were sampled at frequencies ranging from 200-500 Hz, which are high enough to detect most blue whale calls (Goldbogen et al. 2014).

DTAGs are attached with four suction cups using a hand-held 8m carbon fiber pole (Fig 2), and can be programmed to release after durations of up to 24 hours. The tags contain a VHF transmitter used to track the tagged whale during deployment and to retrieve the tag after release.

An 18.6m fishing vessel, the MV Centinela, was employed as the principle survey vessel. Field efforts were carried out in February and March during 2014-2016, based on historical sightings, acoustic detections, and weather data.

Acoustic data were downsampled in multiple steps from either 120 or 500kHz and analyzed in MATLAB using DTAG scripts (http://soundtags.st-andrews.ac.uk/dtags/dtag-3/) that were modified for lower frequency baleen whale calls. Audio spectrograms were viewed simultaneously with spectrograms of the three accelerometer channels (e.g, Fig 4) in order to document calls that were recorded on the accelerometers.

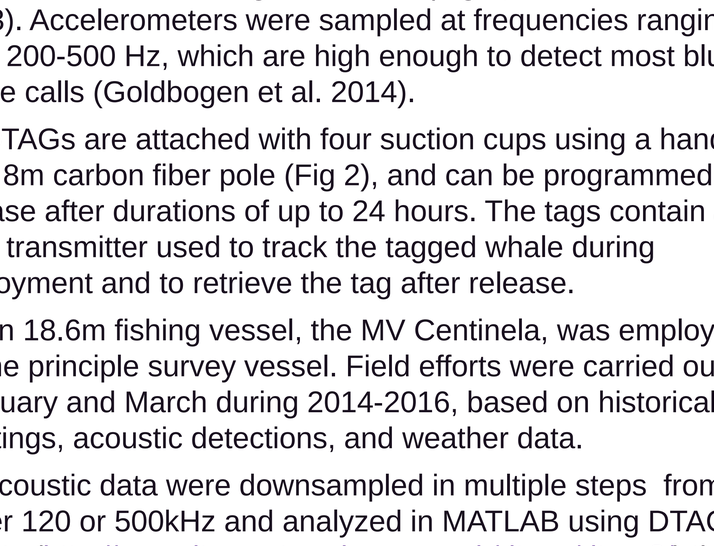

Figure 4. Spectrogram of two loud downsweep calls recorded on the hydrophones (top panel) and also on all three accelerometer channel (lower 3 panels)

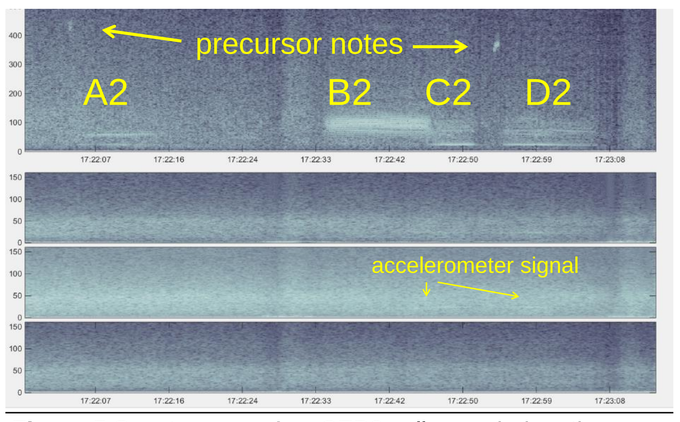

Figure 5 Spectrogram of an SEP2 call recorded on the hydrophones (top panel), with only a portion of the call visible on the accelerometers (lower 3 panels)

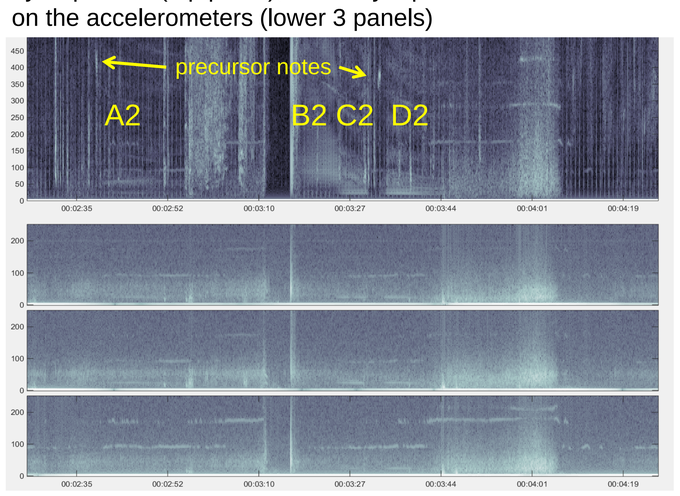

Figure 6. Spectrogram of an SEP2 call recorded interrupted by a surfacing at approximately 3:10 (top panel: hydrophone; lower 3 panels: accelerometers)

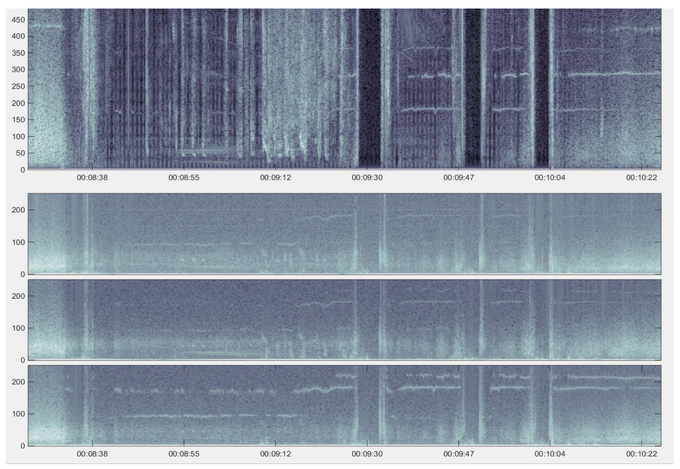

Figure 7. Spectrogram of an SEP2 call with overlapping short tonal calls at appr 0855 (top panel: hydrophone; lower 3 panels: accelerometers)

BIBLIOGRAPHY

Branch, T. A., Abubaker, E. M. N., Mkango, S. and Butterworth, D. S. (2007). Separating southern blue whale subspecies based on length frequencies of sexually mature females. Marine Mammal Science, 23(4), 803–833. doi:10.1111/j.1748-7692.2007.00137.x

Buchan, S., Hucke-Gaete, R., Rendell, L. and Stafford, K. (2014). A new song recorded from blue whales in the Corcovado Gulf, Southern Chile, and an acoustic link to the Eastern Tropical Pacific. Endangered Species Research, 23(3), 241–252. doi:10.3354/esr00566

Goldbogen, J. A., Stimpert, A. K., DeRuiter, S. L., Calambokidis, J., Friedlaender, A. S., Schorr, G. S., Moretti, D. J., Tyack, P. L, and Southall, B. L. (2014). Using accelerometers to determine the calling behavior of tagged baleen whales. The Journal of Experimental Biology: jeb-103259

Hucke-Gaete, R., Osman, L. P., Moreno, C. A., Findlay, K. P., and Ljungblad, D. K. (2004). Discovery of a blue whale feeding and nursing ground in southern Chile. Proceedings of the Royal Society of London. Series B: Biological Sciences, 271(Suppl 4), S170-S173

Johnson, M. P., and Tyack, P. L. (2003). A digital acoustic recording tag for measuring the response of wild marine mammals to sound. IEEE Journal of Oceanic Engineering, 28(1), 3-12

Oleson, E. M., Calambokidis, J.,; Burgess, W. C., McDonald, M. A., LeDuc, C. A., and Hildebrand, J. A. (2007). Behavioral context of call production by eastern North Pacific blue whales. Marine Ecology-Progress Series, 30, 269 - 284

Torres-Florez, J. P., Hucke-Gaete, R., Rosenbaum, H. and Figueroa, C. C. (2014). High genetic diversity in a small population: the case of Chilean blue whales. Ecology and Evolution, 4(8), 1398–1412. doi:10.1002/ece3.998

Williams, R., Hedley, S. L., Branch, T. a, Bravington, M. V, Zerbini, A. N. and Findlay, K. P. (2011). Chilean blue whales as a case study to illustrate methods to estimate abundance and evaluate conservation status of rare species. Conservation Biology : The Journal of the Society for Conservation Biology, 25(3), 526–35. doi:10.1111/j.1523-1739.2011.01656.x