Investigating the ecology and behavior of blue whales (*Balaenoptera musculus*) in the Gulf of Corcovado, Chile

by

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Technical Report

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Front Cover Figure Caption:
Photograph of a blue whale in poor body condition in the Gulf of Corcovado, Chile in March 2015. Photograph taken by Gloria Howes under Chilean research permit: Ministerio de Economia, Fomento y Turismo, Subsecreteria de Pesca y Acuicultura, MERI 488-FEB-2015 Ballena Azul, Golfo Corcovado.

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 is vitally important and will aid Chilean policy makers in generating informed management decisions regarding the conservation of this population.

Long-Term Goals
The principle goal of this project was to continue the investigation into the ecology, foraging and acoustic behavior of blue whales in the Gulf of Corcovado, Chile, that began in 2014 with the support of the Melimoyu Ecosystem Research Institute (MERI).

Objectives
This investigation had four principle objectives, (1) to obtain data on the diving, foraging and vocal rates of individual blue whales in and around the Gulf of Corcovado (Fig. 1), through the deployment of suction cup attached digital acoustic tags (DTAGs), (2) to collect aerial photogrammetry measurements of blue whales, (3) to collect biopsy samples from encountered blue whales and (4) to conduct prey sampling trawls in the vicinity of foraging whales.

During the 2014 cruise a number of blue whales were observed that appeared emaciated and in poor body condition. These observations formed the basis for the objectives of the 2015 cruise plan. It was apparent that in order to study body condition, it would be necessary to collect genetic data on the type of blue whales observed during the cruise via biopsy sampling and to employ new techniques to quantify body size parameters. A collaboration with Michael Moore (WHOI) and John Durban (NOAA, South West Fisheries Science Center, La Jolla, USA) was established with Moore and Durban leading the aerial photogrammetry component of the cruise.

DTAG Study
This investigation set out to acquire 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 developed at WHOI (Johnson and Tyack 2003). These tags contain a VHF transmitter used to track the tagged whale during deployment and to retrieve the

tag after release. DTAGs record sound at the whale, as well as depth, and 3-dimensional acceleration and magnetometer information, and thus provide data on vocal, movement and dive behavior. 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.

Figure 1. Maps indicating the location of study region on the coast of Chile (black box on the right) and an enlargement on the left, showing the principle study area.

Photogrammetry Study

Data for Southern Chile blue whales has suggested that they are related to animals found off Northern Peru and the Galapagos Islands (NPG), and that they are intermediate in size between Antarctic and Eastern North Pacific blue whales. Using a small unmanned hexacopter, the APH-22 (Aerial Imaging solutions, Old Lyme, CT) operating at 45-48m in altitude, aerial images are collected of free swimming whales. Total, rostral (tip of rostrum to center of blowhole) and tail (trailing tip of dorsal fin to fluke notch) lengths of blue whales in the waters of Southern Chile are calculated to compare to data published for Pacific and Antarctic populations to further understand the provenance of these animals. Secondary to the photogrammetry study, a prototype quadcopter was tested as a remote means to collect breath samples.

Biopsy Sampling

To compliment the photogrammetry investigation and understanding of the genetic stock from which the blue whales of the Gulf originate, remote biopsy sampling was conducted opportunistically. These data will form part of a global stock assessment of blue whales being conducted by NOAA SWFSC, La Jolla, USA.

Figure 2. The DTAG (bottom left) and the attachment method via hand-held pole (top left); images on the right show the tag attached to a blue whale with its four suction cups and the tag's small size relative to the animal's size.

Prey Sampling

To further investigate foraging, qualitative zooplankton samples were taken at the locations of feeding whales. Prey sampling net trawls were used to collect prey in order to characterize food sources. This data will contribute to the food web modeling, stable isotope analysis and contaminant biomagnification investigations being undertaken by Fundación MERI in the region.

The months of February and March were chosen to conduct the field effort, based on historical blue whale sightings, acoustic detections and weather data.

Project Personnel and Research Vessel

Cruise personnel included Gustavo Chiang (MERI) who acted as the chief scientist, Alessandro Bocconcelli (WHOI), who was in charge of field operations, Leigh Hickmott (Open Ocean Consulting and the University of St. Andrews), who was in charge of data collection, Michael Moore (WHOI) and John Durban (NOAA) led the photogrammetry efforts. Gloria Howes (MERI) and Paulina Bahamonde (MERI) collected photo-identification images and assisted with field logistics. Laela Sayigh (WHOI) assisted with data analysis on shore. An 18.6 m fishing vessel, the MV *Centinela*, was employed as the principle survey vessel, and proved to be an ideal vessel for the

Figure 3. The MV *Centinela*

experimental requirements (Fig. 3). The MV *Centinela* was capable of housing a scientific crew of 8, carrying and deploying a 4.2 m tagging boat (Zodiac with a 25 Hp 4 stroke engine) and providing a large and high visual observer platform.

Field Methods

Each day, weather and sea-state permitting, visual search efforts to detect marine mammals began at sunrise on the main vessel. All cetacean sightings were recorded in LOGGER (see Tracking and Visual Data Collection below and Appendix I), and where possible photo-identification images were collected. Once blue whales were detected, the possibility for tagging and or photogrammetry was assessed and if conditions were suitable tagging or photogrammetry commenced.

Tracking, visual data collection and photo-identification

To visually search for study animals, and to observe the behavior of the animals during tagging and tracking, a marine mammal observer platform was installed on the deck of the flying bridge of the *Centinela*. 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; see Appendix I) 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.

Tagging

The tagging boat was deployed with a driver (Bocconcelli), photographer (Howes) and tagger (Hickmott) 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 samples (see Genetic samples below).

Once a whale was successfully tagged and all relevant data collected by the tag team, the zodiac 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 or whales (the main vessel was capable of tracking more than one animal using separate sets of antennae). 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.

Photogrammetry

During the period when the photogrammetry team was aboard, photogrammetry was given a priority over tagging to maximize opportunities to collect whale measurements for analysis.

An APH-22 hexacopter (Aerial Imaging Systems, Old Lyme, CT) (described in detail by Goebel et al. (2015)), being a proven device for such photogrammetry work was used (Durban et al. 2015). The small APH-22 (<2kg, 82cm wingspan) was deployed from the bow of the Centinella and operated within line-of-sight by a pilot (Durban) using a 2.4GHz radio control, and was hand launched and retrieved from the foredeck by a ground station operator (Moore)(Fig. 4). When animals were found the Centinela approached to within 300m and the hexacopter was launched to a typical altitude of 50-60m to collect aerial images. The downward-looking video feed from the onboard camera (Olympus E-PM2 with M.Zuiko 25mm F1.8 lens), which was transmitted in real time by 5.8GHz radio link at the ground station allowed the ground station operator to advise the pilot on fine scale adjustments to frame the animals for photo capture of high-resolution (12.3MP) still images on the camera’s flash memory.

Figure 4. The APH-22

Genetic Samples

Biopsy Sampling - To collect skin and blubber samples from free ranging blue whales, a 150lb draw weight Barnett Wildcat crossbow was used to deploy biopsy bolts fitted with a sterile stainless steel cutting tip (50 or 25mm X 5mm)(Fig. 5). Collected biopsy samples were stored in liquid nitrogen for later analysis.
Sloughed Skin - Sloughed skin samples were opportunistically collected from the DTAG’s suction cups, catalogued and stored in liquid nitrogen.

Figure 5. Stainless steel biopsy tips were used to collect skin and blubber samples. Biopsy bolts were deployed using a crossbow.

Prey Sampling
A 250 µm mesh, 50 cm diameter and 3 m long zooplankton net was towed horizontally from the Centinela at 2 knots for 20-30 minutes. Once the trawl was complete the net was hauled to the surface, where the accumulated plankton was separated by size and species, labelled and stored at -20 °C in preparation for analysis.

All genetic and prey sampling specimens will contribute to analysis being conducted by Dr. Gustavo Chiang (University of Concepcion, Chile) as part of a wider study: 'Biomagnification and potential effects of Persistent Organic Pollutants (POPs) and trace metals in the aquatic food webs of the Antarctic Peninsula and Patagonia'.

Results

Field Effort
A 26 day cruise was completed (11th February to 8th March 2015), departing from the port of Dalcahue, Chiloé Island, Chile. Search effort was planned to focus within the Gulf of Corcovado and visit known blue whale habitat use areas around Melinka, Melimoyu and Tic Toc. It became apparent during the cruise that the north eastern region of the gulf was more productive and resulted in the greatest number of blue whale sightings.
During the 26 day trial, 1690 nm were covered during 280 hours of 'on effort' surveying (Fig. 6).

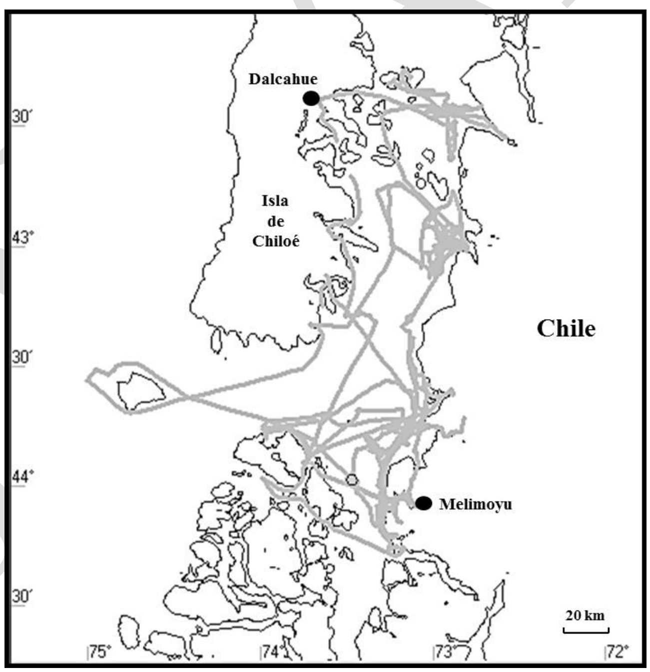


Figure 6. The study area and grey vessel track of the Centinela, showing where search effort was conducted.

The survey effort resulted in 325 sightings of 10 mammal species, with sightings being made on each of the 26 survey days (Table 1). Six different cetacean species were recorded, with blue whales totaling 73 of the 129 sightings (Table 1 & Fig. 7). Notably, 9 sightings were made of

Burmeister's porpoise (*Phocoena spinipinnis*), these were considered valuable sightings as none were made during the 2014 cruise (Table 1 & Fig. 7).

In addition to the cetacean detections there were numerous sightings of two otariid species, the South American fur seal (*Arctocephalus australis*) and the South American sea lion (*Otaria flavescens*) (Table 1 & Fig. 7). Both otter species from the region were also observed, the South American marine otter (*Lontra felina*) and the Southern river otter (*Lontra provocax*) (Table 1 & Fig. 7). Data of all small cetacean sightings are being shared with Dr. Sonja Heinrich, University of St Andrews, Scotland. These sightings will be included in habitat use and management models for the Gulf of Corcovado being developed by Dr. Heinrich.

Scientific Name	Common Name (Spanish)	Common Name (English)	Number of Sightings	Mean Group Size, SD (Range)
Arctocephalus australis	Lobo fino	South American fur seal	121	1.8, 1.7 (1 – 14)
Balaenoptera musculus	Ballena azul	Blue whale	73	1, 0.3 (1 – 2)
Cephalorhynchus eutropia	Delfín chileno	Chilean dolphin	13	3, 2.1 (1 – 9)
Lagenorhynchus australis	Delfín austral	Peale´s dolphin	30	2.5, 1.4 (1 – 5)
Lontra felina	Chungungo	Marine otter	1	1
Lontra provocax	Huillin	Southern river otter	3	1, 0 (1)
Megaptera novaeanglinae	Ballena Jorobada	Humpback whale	3	1, 0 (1)
Otaria flavescens	Lobo marino	South American sea lion	71	4.6, 13.8 (1 – 100)
Phocoena spinipinnis	Marsopa espinosa	Burmeister's porpoise	9	2.3, 1 (1 – 9)
Tursiops truncatus	Tursión	Bottlenose dolphin	1	60

Table 1. Table of mammal species recorded, with the number of sightings per species, mean group size, standard deviation and ranges.

Photo-identification

10,130 photo-identification images were taken of six marine mammal species during 45 encounters (Table 2). 29 blue whale groups were photo documented between the 12th February and 08th March (Tables 2 and 3). 27 individual blue whales were photo-identified, 26 of which were new whales and included three different mother and calf pairs (Table 3). One animal, Bm002 that was first observed in 2014, was resighted on two occasions during the 2015 cruise (Tables 3 and 4). In 2014 Bm002 was considered emaciated and again in 2015 the animal appeared in relatively poor body condition (Tables 3 and 4). Of the 27 whales identified, 7 were considered to appear emaciated during the photographic analysis (Table 3). The poor condition of these animals was evident from observations of their vertebrae being clearly visible while surfacing to breathe.

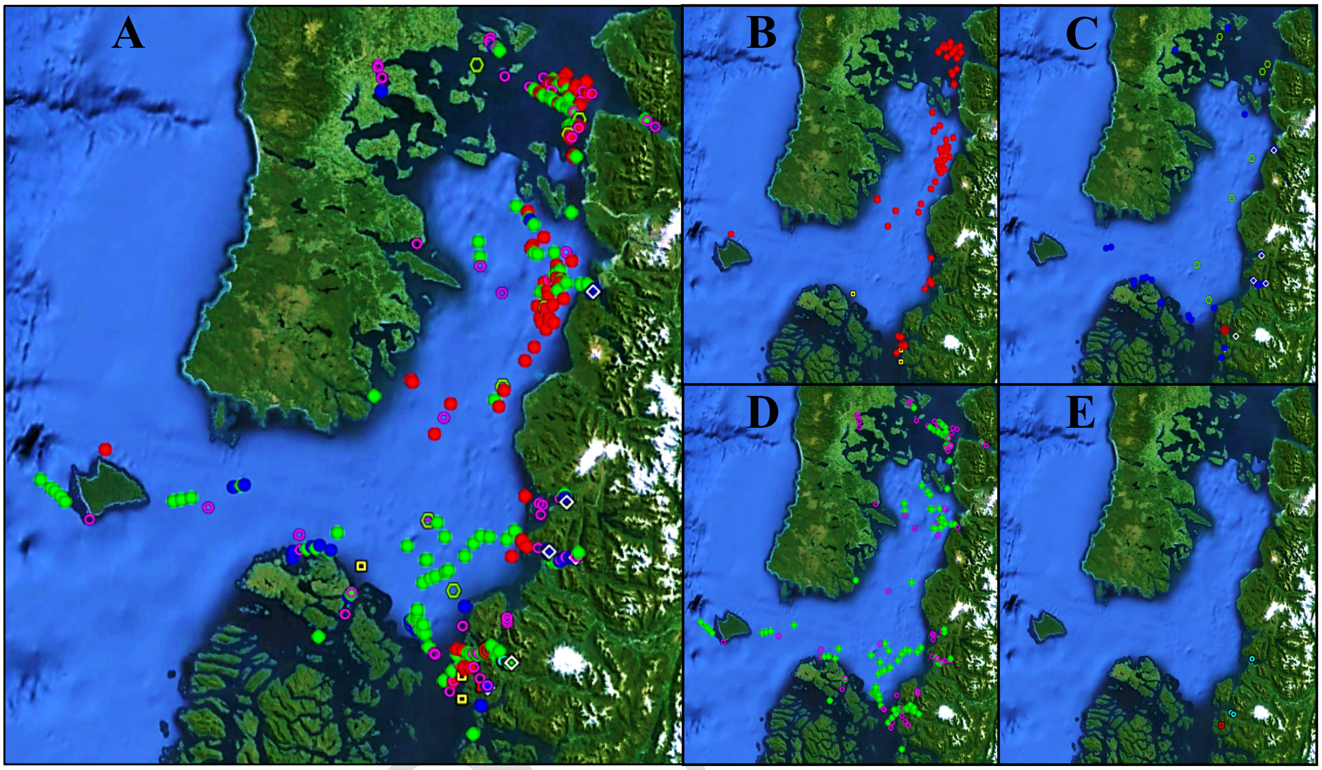


Figure 7. Locations of all sightings (map A). All blue whale (red) and humpback whale (yellow) sightings (map B). All Chilean dolphin (white), Peale´s dolphin (blue), bottlenose dolphin (red) and Burmeister's porpoise (green) sightings (map C). All South American fur seal (green) and South American sea lion (purple) sightings (map D). All marine otter (red) and Southern river otter (blue) sightings (map E).

11 of the 27 animals were seen on two different survey days, with the remaining 16 whales only being seen on one day. Bm008 may be considered the most resident whale, with 15 days between sightings. The other ten resighted whales were only seen the day after their initial sighting and not again (Table 3).

Scientific Name	Common Name	Number of Photo-ID Encounters
Balaenoptera musculus	Blue whale	29
Megaptera novaeanglinae	Humpback whale	2
Tursiops truncatus	Bottlenose dolphin	1
Lagenorhynchus australis	Peale´s Dolphin	7
Cephalorhynchus eutropia	Chilean dolphin	2
Phocoena spinipinnis	Burmeister's porpoise	4

Table 2. Marine mammal species documented using photo-identification, with the number of encounters per species.

Date	EncSeq	Latitude	Longitude	Time (local)	Group Size	No. Animals ID'ed	IDs	Age Class
12-Feb-15	2	-43.2864	-73.5001	13:21	1	1	Bm006	Adult
14-Feb-15	1	-44.1371	-73.3202	09:08	1	1	Bm007	Adult
16-Feb-15	1	-42.8673	-72.9999	17:48	5	2	Bm008 Bm009 (E)	Adult Sub-Adult
17-Feb-15	1	-43.0589	-72.9582	16:07	2	2	Bm010 (E)(T) Bm011	Adult Female Calf
18-Feb-15	1	-43.0192	-72.9799	08:30	2	2	Bm010 (E) Bm011	Adult Female Calf
18-Feb-15	2	-42.9819	-72.9463	15:00	1	1	Bm012	Adult
19-Feb-15	1	-42.9937	-72.9304	11:54	3	2	Bm012 (T) Bm009 (E)	Adult Sub-Adult
22-Feb-15	1	-44.0484	-73.2839	09:06	1	1	Bm002 (E)(T)	Adult
23-Feb-15	2	-44.1013	-73.2779	12:04	2	2	Bm013 (E)(T) Bm014	Adult Female Calf
24-Feb-15	1	-43.7371	-73.0562	11:42	2	2	Bm013 Bm014	Adult Calf
24-Feb-15	2	-43.3095	-73.4604	15:38	1	1	Bm002 (E)	Adult
26-Feb-15	1	-43.7475	-73.0387	11:00	2	2	Bm015 Bm016 (T)	Adult Adult
03-Mar-15	1	-43.3512	-73.1597	13:28	2	2	Bm017 Bm018	Adult Female Calf
04-Mar-15	1	-43.0407	-72.9172	08:02	1	1	Bm019	Adult
04-Mar-15	2	-43.1013	-72.9751	10:54	2	2	Bm019 Bm020	Adult Adult
04-Mar-15	3	-43.1091	-72.9530	13:59	1	1	Bm008	Adult
04-Mar-15	5	-43.1109	-72.9998	17:03	1	1	Bm019	Adult
04-Mar-15	6	-43.0636	-73.0184	18:04	1	1	Bm021	Adult
05-Mar-15	1	-42.4172	-72.9844	15:52	2	2	Bm020 Bm022	Adult Adult
05-Mar-15	2	-42.4311	-72.9661	21:19	3	4	Bm020 Bm023 Bm024 (E) Bm025 (E)(T)	Adult Adult Adult Adult
06-Mar-15	1	-42.4444	-72.8967	12:10	1	1	Bm026	Adult
06-Mar-15	2	-42.4129	-72.9419	15:27	1	1	Bm026	Adult
06-Mar-15	3	-42.3851	-72.9211	16:10	1	1	Bm026	Adult
08-Mar-15	1	-42.6352	-72.8863	10:26	1	1	Bm027 (E)	Adult
08-Mar-15	2	-42.6318	-72.8949	11:05	2	2	Bm028 Bm029	Adult Adult
08-Mar-15	3	-42.6082	-72.8996	11:31	2	2	Bm028 Bm029	Adult
08-Mar-15	4	-42.5686	-72.9169	13:36	1	1	Bm021	Adult
08-Mar-15	5	-42.4900	-72.8749	14:22	3	3	Bm021 Bm024 (E) Bm030	Adult Adult Adult
08-Mar-15	7	-42.4595	-73.0244	17:27	1	1	Bm031	Adult

Table 3. Blue whale encounter and photo-identification summaries from all encounters in February. (E) = appeared emaciated, (T) = tagged with a DTAG.

Humpback whales were encountered on two occasions (Table 2). One animal was a new animal, but the second was a resight of Mn001 seen in 2014, indicating that some animals return to the Gulf annually (Table 5).

Table 4. Photo-identification images of the 27 blue whales photo-identified during the cruise.

	
Bm002 (Left Dorsal)	Bm002 (Right Dorsal)
	
Bm006 (Left Dorsal)	Bm006 (Right Dorsal)
	
Bm007 (Right Dorsal)	
	
Bm008 (Left Dorsal)	Bm008 (Right Dorsal)
	
Bm009 (Left Dorsal)	Bm009 (Right Dorsal)


Bm010 (Left Dorsal)


Bm010 (Right Dorsal)


Bm011 (Left Dorsal)


Bm011 (Right Dorsal)


Bm012 (Left Dorsal)


Bm012 (Right Dorsal)


Bm013 (Left Dorsal)

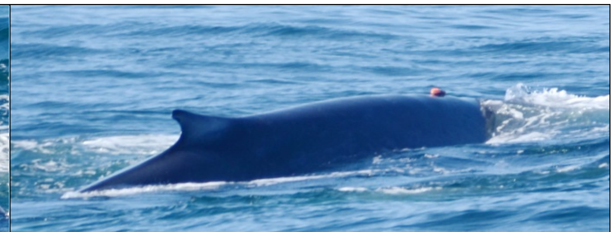
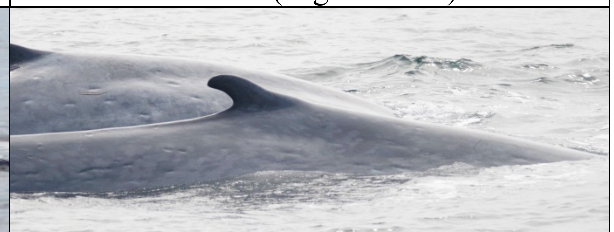

Bm013 (Right Dorsal)


Bm014 (Left Dorsal)


Bm014 (Right Dorsal)


Bm015 (Left Dorsal)


Bm015 (Right Dorsal)

	
Bm016 (Left Dorsal)	Bm016 (Right Dorsal)
	
Bm017 (Left Dorsal)	Bm017 (Right Dorsal)
	
Bm018 (Left Dorsal)	Bm018 (Right Dorsal)
	
Bm019 (Left Dorsal)	Bm0019 (Right Dorsal)
	
Bm020 (Left Dorsal)	Bm020 (Right Dorsal)
	
Bm021 (Left Dorsal)	Bm021 (Right Dorsal)

Bm022 (Left Dorsal)

Bm022 (Right Dorsal)

Bm023 (Left Dorsal)

Bm023 (Right Dorsal)

Bm024 (Left Dorsal)

Bm024 (Right Dorsal)

Bm025 (Left Thorax)

Bm025 (Right Thorax)

Bm026 (Left Dorsal)

Bm026 (Right Dorsal)

Bm027 (Left Dorsal)

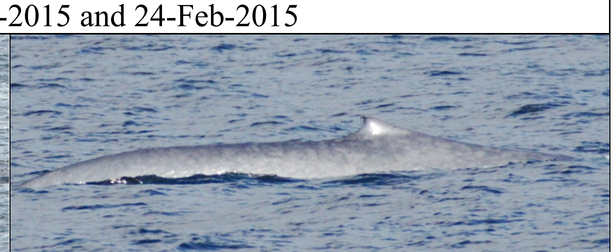
 Bm028 (Left Dorsal)	 Bm028 (Right Dorsal)
 Bm029 (Left Dorsal)	 Bm029 (Right Dorsal)
 Bm030 (Left Dorsal)	 Bm030 (Right Dorsal)
 Bm031 (Left Dorsal)	
Resight of Bm002 21-Mar-2014, 22-Feb-2015 and 24-Feb-2015	
 Bm002 (Left Dorsal) 2014	 Bm002 (Right Dorsal) 2014
 Bm002 (Left Dorsal) 2015	 Bm002 (Right Dorsal) 2015

Table 4. Photo-identification images of the 27 blue whales photo-identified during the cruise.

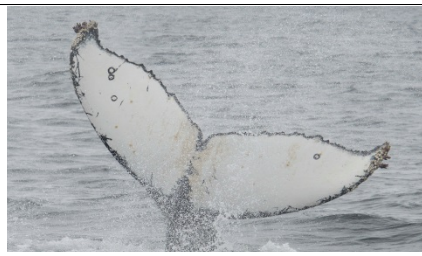
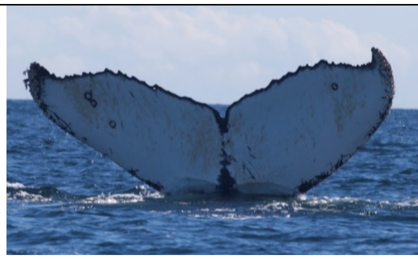
 Mn001	 Mn012
Resight of Mn001	
 Mn001 17-Mar-2014	 Mn001 21-Feb-2015

Table 5. Photo-identification images of the two humpback whales, including the resight of Mn001.

DTAG Study

During the cruise six different blue whales were tagged using the DTAG, resulting in the collection of 64 hours 44 minutes of tag data (Table 6). Deployment durations had a mean of 10 hours 47 minutes, with the longest deployment being 24 hours 45 minutes, providing an interesting insight into the diurnal nature of blue whale behavior in the Gulf. As in 2014, sloughed skin samples were recovered from the tag suction cups from each deployment. Although sloughing skin can cause tags to release early, in the case of the 24 hour deployment, sloughed skin impeded the tag release mechanism, resulting in the longer than programmed deployment and valuable dataset.

Date	Animal ID	Age Class	Deployment ID	Deployment Duration (Hr:min)	Deployment Time (local) & Location
17-Feb-15	Bm010	Adult Female	bm15_048a	24 hrs 45 min	18:39 -43.0085 -72.9597
19-Feb-15	Bm012	Adult	bm15_050a	06 hrs 53 min	13:21 -42.9543 -72.9360
22-Feb-15	Bm002	Adult	bm15_053a	09 hrs 00 min	11:56 -44.1412 -73.2840
23-Feb-15	Bm013	Adult Female	bm15_054a	10 hrs 18 min	15:58 -44.0929 -73.2505
26-Feb-15	Bm016	Adult	bm15_057a	03 hrs 31 min	11:19 -43.5785 -73.0483
05-Mar-15	Bm025	Adult	bm15_064a	10 hrs 17 min	20:39 -42.4602 -72.9923

Table 6. Blue whale DTAG deployment summaries.

Diving behavior recorded by the DTAG, indicates that dives were typically between 10 and 50 meters in depth and as in 2014, some deeper dives were recorded, to a maximum depth of 157 meters (Fig. 8). The shallow nature of the dives indicates that prey are present in the upper part of the water column. These dive profiles provide an insight into the high degree of time that blue whales in the region spend near the surface, highlighting the risk this species may be exposed to in the Gulf from the threat of ship strikes.

Analyzing DTAG data is a long, detailed and complex task, as a result of this, collaborations are being formed with Dr. Jeremy Goldbogen, Stanford University, USA, an expert in blue whale foraging behavior.

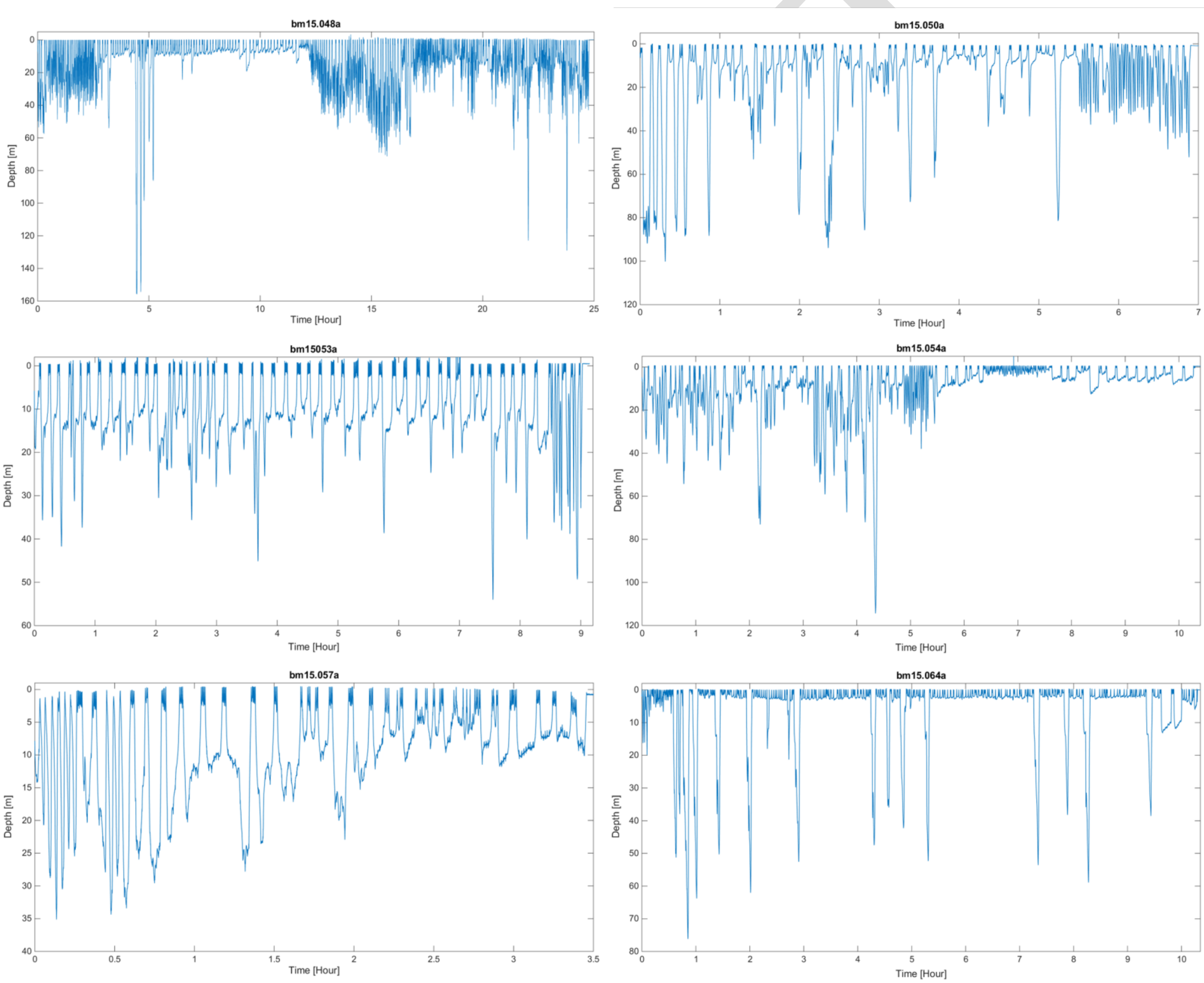


Figure 8. Dive profiles of the six tagged blue whales. Deployment duration in hours (x axis) and dive depth in meters (y axis).

DTAG acoustic data are currently being analyzed, led by Laela Sayigh (WHOI) and preliminary results are being presented at the Society of Marine Mammalogy Bi-annual Conference, in December 2015.

Photogrammetry

21 blue whales were imaged in the Gulf of Corcovado (Fig. 9). Whales ranged in size from 14.4m calves, to 23.6m adults. The results from the photogrammetry study have been analyzed and submitted for publication in the journal Marine Mammal Science (lead author – Durban).

Additionally, a prototype quadcopter (Mariner, FPV-Factory) was tested for remote collection of breath samples, using a 96 well culture plate mounted on the quadcopter. A reasonable sample of blow was acquired during a surfacing sequence from an adult female.

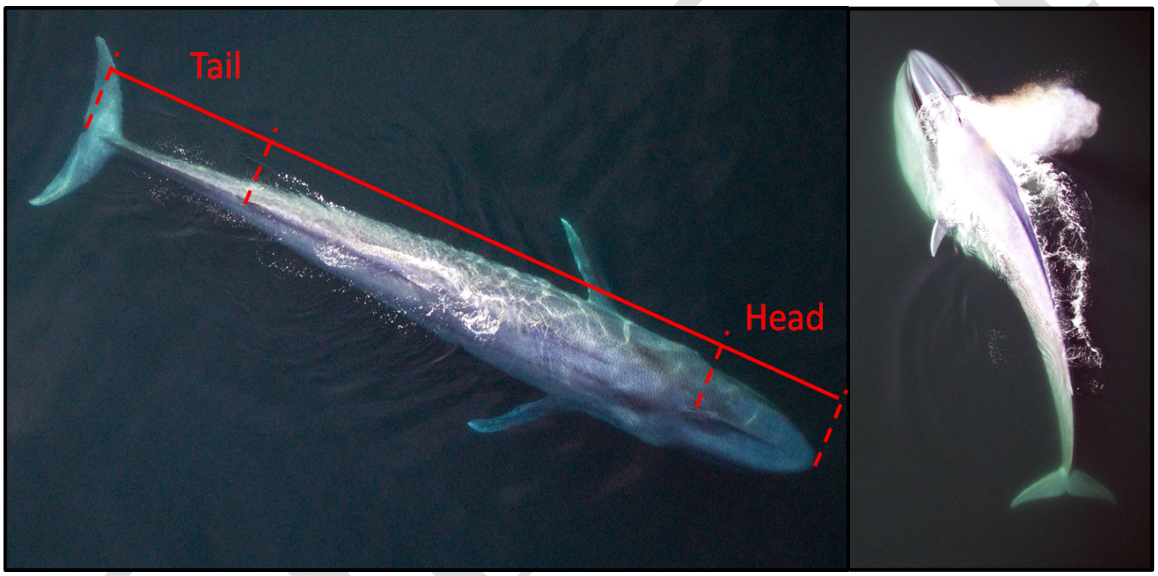


Figure 9. Photogrammetry images of blue whales from the Gulf of Corcovado and the morphometric measurement criteria.

Genetic Samples

During the cruise and subject to the circumstances surrounding the higher priority tasks of tagging and photogrammetry, biopsy samples were collected from blue whales, humpback whales and common bottlenose dolphins (*Tursiops truncatus*) (Table 7). A total of 9 biopsies were collected from blue whales, and an additional 6 sloughed skin samples were collected from tagged animals. These 15 samples represent genetic samples from 12 different individuals. Two of the sampled animals were calves over 6 months of age. In addition, one humpback whale biopsy and three common bottlenose dolphin samples were collected. A single blow sample was also collected from a blue whale using a drone, proving the technique viable for future investigations.

All genetic samples are currently being stored in a -80° freezer at the Andrés Bello National University, Santiago, Chile. CITES permits are being completed (Bahamonde) for the export of the samples to the USA, where they will be analyzed in a collaborative partnership between NOAA and MERI.

Date Collected	Sample Number/ID	Specie	Animal ID	Collection Method	Latitude (SOUTH)	Longitude (WEST)
2015-Feb-16	160215_CHILE_Bm_01	*B. musculus*	Bm008	Biopsy	42.88894	73.04075
2015-Feb-17	170215_CHILE_Bm_02	*B. musculus*	Bm011	Biopsy	43.00262	72.96165
2015-Feb-17	170215_CHILE_Bm_03	*B. musculus*	Bm010	DTAG skin sample	42.95245	72.96111
2015-Feb-19	190215_CHILE_Bm_04	*B. musculus*	Bm012	DTAG skin sample	42.91751	72.96111
2015-Feb-21	210215_Chile_Mn_01	*M. novaeangliae*	Mn001	Biopsy	43.52368	73.37444
2015-Feb-22	220215_CHILE_Bm_05	*B. musculus*	Bm002	Biopsy	44.19673	73.28853
2015-Feb-22	220215_CHILE_Bm_06	*B. musculus*	Bm002	DTAG skin sample	44.08237	73.05817
2015-Feb-23	230215_Chile_Tt_01	*T. truncatus*	NA	Biopsy	44.03872	73.20527
2015-Feb-23	230215_Chile_Tt_02	*T. truncatus*	NA	Biopsy	44.03872	73.20527
2015-Feb-23	230215_Chile_Tt_03	*T. truncatus*	NA	Biopsy	44.03872	73.20527
2015-Feb-23	230215_CHILE_Bm_07	*B. musculus*	Bm013	Biopsy	44.09299	73.25058
2015-Feb-23	230215_CHILE_Bm_08	*B. musculus*	Bm014	Biopsy	43.94135	73.29961
2015-Feb-23	230215_CHILE_Bm_09	*B. musculus*	Bm013	DTAG skin sample	43.75244	73.33218
2015-Feb-26	260215_CHILE_Bm_10	*B. musculus*	Bm016	Biopsy	43.58255	73.04945
2015-Feb-26	260215_CHILE_Bm_11	*B. musculus*	Bm016	DTAG skin sample	43.37974	73.29633
2015-Mar-03	030315_CHILE_Bm_12	*B. musculus*	Bm017	Blow sample	43.28714	73.14321
2015-Mar-03	030315_CHILE_Bm_13	*B. musculus*	Bm018	Biopsy	43.28909	73.10100
2015-Mar-04	040315_CHILE_Bm_14	*B. musculus*	Bm020	Biopsy	43.08907	72.95376
2015-Mar-04	040315_CHILE_Bm_15	*B. musculus*	Bm019	Biopsy	43.1149	72.99744
2015-Mar-06	060315_CHILE_Bm_16	*B. musculus*	Bm025	DTAG skin sample	42.43552	73.10822

Table 7. Summary information of the collected genetic samples.

Prey Sampling

During the cruise it was possible to conduct five prey sampling trawls (Table 8). Opportunities to conduct trawls were limited due to time required by higher priority activities and the time required to prepare, deploy and recover the trawl equipment. Krill and other zooplankton were collected and samples will be analyzed (Chiang) to determine levels of nitrogen and carbon stable isotopes, mercury and organic pollutants.

Sample ID	Date	Latitude (S)	Longitude (W)	Trawl Duration
170215_Chile_ZP01	17-Feb-2015	-72.96165	-43.00262	30 min
170215_Chile_ZP02	17-Feb-2015	-72.96165	-43.00262	30 min
210215_Chile_ZP03	21-Feb-2015	Bahia low	Bahia low	30 min
230215_Chile_ZP04	23-Feb-2015	-73.25599	-44.09498	30 min
230215_Chile_ZP05	05-Mar-2015	-72.99231	-42.46024	20 min

Table 8. Coordinates and durations of the prey sampling trawl locations.

Passive Acoustic Monitoring

Moorings equipped with passive acoustic monitors (PAM) were deployed in two critical habitat areas to monitor the presence of marine mammals. Deployments were carried out by Bocconcelli (WHOI), who trained Howes (MERI) to retrieve and re-deploy the PAM devices to allow long term monitoring.

Impact and Future Work

The cruise proved hugely successful, with all objectives being achieved. The cruise and the wealth of data collected have permitted a number of significant collaborations, notably John Durban (NOAA), Jeremy Goldbogen (Stanford) and Sonja Heinrich (St Andrews). The elements of the cruise data have been submitted for peer reviewed publication, while others are being presented at international conferences.

The cruise provided a valuable opportunity to employ new techniques, specifically the drone technologies and thus collect new and novel data. With the project now in its second year, the team was able to tailor the cruise to address questions raised during the first preliminary cruise in 2014. This continued effort over multiple years, is providing the means to build robust datasets to investigate the status of blue whales in the Gulf of Corcovado. This is of particular significance after the mass stranding of over 300 baleen whales in southern Chile in 2015. Data acquired during the MERI cruises will aid the understanding of how large baleen whales are using the southern Chilean habitats and vitally help to inform conservation management decisions for the region.

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References

Goebel, M. E., Perryman, W. L., Hinke, J. T., Krause, D. J., Hann, N. A., Gardner, S., and LeRoi, D.J. (2015). A small unmanned aerial system for estimating abundance and size of Antarctic predators. Polar Biol. doi:10.1007/s00300-014-1625-4.

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.

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.

Durban, J. W., Fearnbach, H., Barrett-Lennard, L. G., Perryman, W.L. and LeRoi, D. J. (2015). Photogrammetry of killer whales using a small hexacopter launched at sea. Journal of Unmanned Vehicle Systems 3: 131-135.

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.

Appendix I

Instructions for blue whale behavioral data collection

Behavioral data should be collected at 3-minute point samples, using a timer that can be set to ring repeatedly at 3 minute intervals.
When the timer goes off, data are collected from the next sighting of the tagged animal. If the tagged animal is not visible within 2 minutes, this will be a "missed point."
As soon as the animal is sighted after the timer goes off, obtain a waypoint from the GPS. This will enable us to synchronize the behavioral, tag and LOGGER data. Next, get a range and magnetic compass bearing to the animal, this will enable reconstruction of whale movements. Then collect remaining categories as outlined below.

Categories on the data sheet (See Figure A1):
1) Time: Real time of observation
2) Wpt: Waypoint number from GPS
3) Range/bearing: estimate range in meters to tagged animal and get a magnetic compass bearing
4) Group size: Number of animals in current group
5) Spread: see categories outlined at bottom of sheet (Figure A1). These will not be relevant if there is only one whale.
6) Synch: see categories at bottom of sheet (Figure A1). These will not be relevant if there is only one animal.
7) Behav: Choose predominant activity for previous 3 minute interval: Travel, Forage, Prob Forage, Rest, Social, Mill, Other/Unknown. If there are others that should be added based on observations, feel free to do so.
8) Activ Level: see categories at bottom of sheet (Figure A1). These are helpful to know if the animal is moving quickly, slowly, etc.
9) NN Dist (BL): This is the distance of the nearest neighbor in body lengths. Not relevant if only one animal is present.
10) NN ID: This is the ID of the nearest neighbor, and would require that animals are distinctive enough to assign descriptive names, such as those seen at the bottom of the sheet for group composition; e.g., AM for adult male, C for calf (Figure A1). Not relevant if only one animal present
11) Comments: anything else that doesn't fit in the other boxes. This would include relevant photo frame numbers, any information about group geometry, composition, ID's (i.e., 1 adult male, 2 adult females, 2 calves, etc., see codes at bottom of sheet (Figure A1)), whether or not there are other blue whales in the area and how far, whether there are any other species visible and their distance, Beaufort sea state (BSS – affects sighting conditions), and distance, number and type of boats in the area, and any other information that could be relevant or useful.

Blue Whale Focal Follow Page___of ___

Date:		Crew:		Tag#/Focal:		Photos:	

Time	Wpt	Range/ bearing	Group size	Spread	Synch	Behav	Activ Level	NN Dist	NN ID	Comments: photos, group geometry, group comp. ids, other blue whales & distance, other spp. & distance, BSS, other boats: distance, number, type, any other info

Group spread (score-majority of group):	Synchrony (score-entire group):	Activity:	Group composition:
VT=<1 Body Length (very tight)	H: High: all together @ point	H=High	AM: Adult males
TI=1-3 BLs (tight)	M: Medium: all surface w/in 30"	M=Med.	AF: Adult females
MO=3-5 BLs (moderate)	L: Low: all don't surface w/in 30"	L=Low	AU: Adult-unkn.
LO=5-10 BLs (loose)			J: Juvenile
*if >10 BLs (~30m): not part of focal group			C: Calves
			UN: Unknown

Figure A1: Data sheet for behavioral observations of tagged whales