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Southeast Pacific blue whale song recorded off Isla Chañaral, Northern Chile

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26 *** Text:**

27 Determining the distribution and seasonal movements of baleen whales is fundamental
28 to the development of conservation strategies and marine spatial planning, which ensure
29 their continued protection (e.g., Pompa, Ehrlich, and Ceballos (2011), Mullen, Peterson,
30 and Todd (2013), Redfern et al. (2013a, 2013b)). One method widely used to monitor
31 distribution and movements of cetaceans is Passive Acoustic Monitoring (PAM) (e.g.,
32 Mellinger, Stafford, Moore, Dziak, and Matsumoto (2007), Van Parijs et al. (2009)). The
33 loud, repetitive, low-frequency songs of baleen whales make these animals particularly
34 good candidates for acoustically determining their occurrence and in turn their
35 distribution (e.g., Stafford, Nieukirk, and Fox (1999a, 1999b), Cerchio, Jacobsen, and
36 Norris (2001), Širović, Hildebrand, Wiggins, and Thiele (2009), Buchan, Huckle-Gaete,
37 Rendell, and Stafford (2015)). Endangered (<https://www.iucn.org/>) blue whales
38 (*Balaenoptera musculus*) produce distinct song types recorded in different oceanic
39 regions with largely distinct spatial and temporal distributions (e.g., McDonald,
40 Mesnick, and Hildebrand (2006) and references therein, Stafford, Chapp, Bohnenstiel,
41 and Tolstoy (2011), Samaran et al. (2013), Buchan, Huckle-Gaete, Rendell, and Stafford
42 (2014), Buchan et al. (2015), Balcazar et al. (2017)). Song in blue whales is assumed to
43 serve some reproductive function as it is believed to be produced only by males (Oleson
44 et al., 2007a) and is produced throughout the animals' migratory range (Stafford et al.
45 (1999a), Stafford, Nieukirk, and Fox (2001)). Blue whale song remains relatively stable
46 over time, although there is some intra-annual variation in song production (Oleson,
47 Wiggins, and Hildebrand, 2007b) and a decrease in the frequency of tonal song
48 components has been reported over decadal timescales (McDonald, Hildebrand, and
49 Mesnick (2009), Gavrilov, McCauley, and Gedamke (2012)). Therefore, PAM offers a

50 very useful method to monitor the distribution of blue whale acoustic groups
51 worldwide.

52

53 The predominant song type of Southeast Pacific blue whales, known as the Southeast
54 Pacific 2, (SEP2) (Buchan et al., 2014) has been recorded in Chilean Patagonia (Buchan
55 et al., 2014, and 2015), off Juan Fernandez (Truong, Širović, Tripovich, and Rogers,
56 2016), and in the eastern Tropical Pacific (Stafford et al. (1999b), Buchan et al. (2015)).
57 This acoustic presence supports a migratory range for this group between Chilean
58 Patagonia and the eastern Tropical Pacific. This migratory range is also supported by
59 genetic sampling of the individuals within this range (Torres-Florez, Huckle Gaete, and
60 LeDuc, 2014), photo-identification (Torres-Florez et al., 2015), and studies using
61 satellite tags (Huckle-Gaete et al., 2018). Placed within the migratory corridor of south
62 Pacific blue whales, Isla Chañaral is part of the Humboldt Archipelago, a series of
63 coastal islands within the productive Humboldt Current System (Thiel et al., 2007)
64 (Figure 1). The waters surrounding Isla Chañaral, which lies 3.5 nautical miles from the
65 mainland, are a known summer feeding ground primarily for fin whales (*Balaenoptera*
66 *physalus*) (Pérez-Álvarez et al. (2006), Toro, Vilina, Capella, and Gibbons (2016),
67 Sepúlveda, Santos, and Pavez (2017), Sepúlveda, Pérez-Álvarez, and Santos-Carvallo
68 (2018)), but also blue whales, humpback whales (*Megaptera novaeangliae*), sei whales
69 (*Balaenoptera borealis*), and minke whales (*Balaenoptera bonaerensis*) have also been
70 sighted (Capella, Vilina, and Gibbons (1999), Sepúlveda pers. Comm.). This area has
71 long since been the focus of a Marine Protected Area proposal. The acoustic identity of
72 the blue whales that visit this area is unknown. In this study, we report the analysis of
73 new PAM data from Northern Chile to examine whether there is evidence of southeast
74 Pacific blue whales (SEP2 song type) in this area.

75

76 Passive acoustic data were collected within the Isla Chañaral channel, between the Isla
77 Chañaral and the mainland, at 29°00'44" S and 71°31'26" W (Figure 1) during three
78 periods of two weeks in January and February 2017 (see Patris, Malige, and Glotin
79 (2017) for details). A 'BOMBYX II', which includes a Cetacean Research C57
80 hydrophone (sensitivity of $-187 \text{ dB re } 1 \text{ V } \mu\text{Pa}^{-1}$, flat response down to 20 Hz,
81 omnidirectional at frequencies less than 10 kHz), powered by a 9V source and high-pass
82 filtered ($C=47\mu\text{F}$, frequency cut 0.15 Hz) and a commercial SONY PCM-M10 recording
83 device (gain 6, $R_{in} = 22 \text{ k}\Omega$) equipped with a 256 GB memory card, set up in a
84 specialized tube made by OSEAN SA (France) able to resist high pressure, was
85 deployed between 15 and 20 m below the surface on a mooring where the maximum
86 water column depth was 70 m. The 'BOMBYX II' was deployed by the University of
87 Toulon and CNRS (DYNI team, LIS).

88

89 Recording was done at a sample rate of 48 kHz so as to record a vast diversity of
90 cetaceans, ranging from large whales to dolphins, and at 16-bits, allowing for high
91 sensitivity without saturating the memory¹. No low-pass filter (such as an anti-aliasing
92 filter) was used for this recording, since it was not considered necessary for our purpose.
93 Acoustic data were recorded between the 16 January and the 27 February 2017. No data
94 were recorded during the 30 and 31 January and during the night between the 13 and 14
95 February because of instrument redeployment.

96

97 The SEP2 song is made up of a four-unit phrase (A, B, C, D, see Figure 2) lasting 60 s
98 that is repeated every two minutes, in long series lasting for hours. All units are long
99 and stable pulsed sounds; thus their power spectra show a set of discrete frequencies

(Patris, Malige, Glotin, Asch, and Buchan, 2019). The energy of the spectra is generally concentrated around the 24 Hz peak. Unit A has an average duration of 22 s, unit B of 13 s, unit C of 5 s, and unit D an average duration of 13 s. Usually, not all units are visible due to low signal to noise ratio (SNR) and units C and D contain most of the signal's energy. In this study SEP2 song phrases were annotated whenever at least the 24 Hz-frequency peak of units C and D were visible. The SEP2 songs of Southeast Pacific blue whales were annotated manually, i.e., a box was drawn around the C and D units of the SEP2 song phrase, on the spectrogram visible in Raven Pro 1.5 (Bioacoustics Research Program, 2012). The following parameters were used: 8,192 sample FFT, 50% overlap, Hann window, with a Raven scale set to view 60 Hz over 200 s. Herein, we refer to all phrases with at least C and D units as SEP2 song phrases.

A nonsystematic double check of the data by another analyst showed that few phrases (with only unit B visible) were not counted by the first analyst (missed detections). Units C and D were not visible due to noise or propagation effects that mask low frequencies. Furthermore, unit A and the pair C-D are sometimes confoundable (having similar characteristics in duration and peak frequency). Thus, in some cases, unit A and the pair C-D of the same phrase were counted as two distinct occurrences of a phrase (false positive). As the second analysis was not systematic on all data but only on a portion of it (one third), it served to evaluate the importance of errors during the counting of the first analysis. Based on this double check, we estimate the error in counting SEP2 occurrences to be less than 3%.

A total of 913 h of acoustic recordings were analyzed, over which 1,981 SEP2 song phrases were identified, annotated and counted by the first analyst (Figure 3). As

presented in these studies, we also noted the presence of two short high frequency precursors before units A (around 430 Hz) and D (around 350 Hz) (see Figure 2). Two faint downsweeps are identified in phrases with high signal-to-noise ratio: in unit A (duration of 5 s from 150 Hz to 120 Hz) ($n = 10$) and in unit B (duration of 12 s from 450 Hz to 300 Hz) ($n = 10$), see Figure 2. This sound may be a byproduct of the pulsed low frequency sound, a resonance artefact or sound made independently. In the latter, no mechanism of sound production has been proposed to explain this superposition of two sounds, called two-voiced sounds (Brown, 2008) and this has not been described for other blue whale's song types (McDonald et al., 2006).

There was no noticeable trend in the total number of SEP2 song phrases counted over the study period although, overall, more phrases were counted in January (64 phrases/day in average) compared to February (36 phrases/day) (See Figure 3). No significative difference was found between day and night in the number of phrases. Although this is a short period study, these results show low but consistent acoustic presence of Chilean blue whales throughout the months of January and February off Isla Chañaral.

From the Raven Pro selection tables, we calculated the time between SEP2 phrases, i.e., the inter-phrase interval (IPI), (Fig. 4). The peaks at 2 and 4 min are characteristic of SEP2 individual song (Buchan, Rendell, and Huckle-Gaete, 2010) and suggest that phrases could be produced by single singers rather than multiple overlapping singers. There is only one instance of song phrase overlap on January 28, 2017, reflected by shorter IPIs of 50-70s, which might suggest the presence of two singers. This is consistent with limited opportunistic sighting observations: A single blue whale

performing circular dives and fluking, consistent with foraging behavior (Buchan and Quiñones, 2016), was observed by S. Buchan on February 15-17 and 23, 2017 within the Chañaral Channel and to the South of Isla Chañaral; and sightings of two blue whales together on January 16, 2017 (observed by J. Patris, S. Buchan, and F. Malige).

The number of phrases per day reported remains low compared to acoustic studies from Chilean Patagonia, where over one thousand SEP2 phrases were automatically detected per day between the months of March and May 2012-2013, which is thought to be the time of maximum abundance of animals in this region (Hucke-Gaete, Osman, Moreno, Findlay, and Ljungblad (2003), Buchan et al. (2015), Galletti-Vernazzani, Jackson, Cabrera, Carlson, and Brownell Jr (2017)). Since there is not yet year-round data off Isla Chañaral, it is impossible to compare seasonal trends in acoustic presence of Chilean blue whales at both sites. However, sighting data off Isla Chañaral (Sepulveda et al., 2017) and in Chilean Patagonia (Hucke-Gaete et al. (2013), Galletti-Vernazzani et al. (2017)) still suggest much higher abundance in Chilean Patagonia, which is considered the primary feeding ground for Chilean blue whales.

During visual inspection of the data set, no Antarctic blue whale song type (Ljungblad, Clark, and Shimada (1998), Matsuoka, Murase, Nishiwaki, Fukuchi, and Shimada (2000)) has been detected, although it has been recorded in the Chilean Patagonia (Buchan, Hucke-Gaete, Stafford, and Clark, 2018) and also in low-latitude East Pacific Ocean (Stafford et al., 2004). No SEP1 blue whale's song type (Cummings and Thompson, 1971) has been detected in this data set. SEP1 has been recorded in Chilean Patagonia, off Juan Fernandez Archipelago and in the East Tropical Pacific (Cummings and Thompson (1971), Truong et al. (2016), Stafford et al. (1999b)) but is the least

common of the two Southeast Pacific song types (Buchan et al. (2015), Saddler et al. (2017)).

This is the first report of Southeast Pacific blue whale song (or any baleen whale call) in the coastal waters off Northern Chile and in the Humboldt Current System. Given the high levels of productivity of this system, and considering that Southeast Pacific blue whales are known to migrate between wintering grounds near Galapagos and summer feeding grounds in Chilean Patagonia (Hucke-Gaete et al. (2003 and 2018), Buchan et al. (2015), Torres-Florez et al. (2015), Buchan and Quinones (2016)), it would make sense that some animals would take advantage of the available prey in the Humboldt Current System. In particular, the dense patches of Humboldt Current krill (*Euphausia mucronata*) known to be exploited by fin whales off Isla Chañaral (Toro et al., 2016) would also offer foraging opportunities for blue whales that are on their way to or from their primary feeding ground in Chilean Patagonia. The presence of southeast Pacific blue whales off Isla Chañaral is further evidence of the importance of this area for the conservation of endangered baleen whale populations.

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Figure captions and captions

Figure 1. Map of the deployment zone of the BOMBYX II device (left). The green zone around the Island is a marine protected area (Reserva Marina Isla Chañaral). General location in South America (right).

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459 Figure 2. Time frequency representation of a SEP2 song recorded off Isla Chañaral, on
460 February 2, 2017 (Fast Fourier transform, Blackman window of 65,536 points,
461 overlapping 75%) using Octave software (Eaton, Bateman, and Hauberg, 2009). The
462 line at 213 Hz is a constant electronic noise coming from the coupling between the
463 hydrophone and the recording device. Units A, B, C, D are clearly visible as well as
464 precursors and downsweeps belonging to the song.

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Figure 3. Number of SEP2 phrases counted in the first season of recording off Isla Chañaral. The device was off duty during January 30 and 31 (asterisks) and the February 13 and 14.

Figure 4. Histogram of the inter-phrase intervals (IPIs) between two occurrences of SEP2 phrases, from the Raven Pro selection table.

1 i During the analysis, other vocalizations were found: blue whale “D-calls”, fin whale
2 (*Balaenoptera physalus*) vocalizations, bottlenose dolphins' (*Tursiops truncatus*) echolocation
3 clicks, whistles and low-frequency vocalizations, and dusky dolphin (*Lagenorhynchus obscurus*)
4 burst of pulses (see Patris, 2019). This dataset can be obtained asking the authors.