1   **Discovering sounds in Patagonia, characterizing sei whale (*Balaenoptera borealis*)**

2   **downsweeps in the south-eastern Pacific Ocean.**

4   **Running title: Sei whale vocalizations in Chile**

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13 Abstract

14 The sei whale (*Balaenoptera borealis*) is one of the least known whale species.

15 Information on sei whales distributions and its regional variability in the south-eastern

16 Pacific Ocean are even more scarce than that from other areas. Vocalizations of sei

17 whales from this region are not described yet. This research presents the first

18 characterization of sei whale sounds recorded in Chile during austral autumn of 2016

19 and 2017. A total of 41 calls were identified to be sei whale downsweeps. In 2016, calls

20 ranged from an average maximum frequency of 105.3 Hz down to an average minimum

21 35.6 Hz over 1.6 s with a peak frequency of 65.4 Hz. During 2017, calls ranged from an

22 average maximum frequency of 93.3 Hz down to 42.2 Hz (over 1.6 s) with a peak

23 frequency of 68.3 Hz. The absolute minimum frequency recorded was 30 Hz and the

24 absolute maximum frequency was 129.4 Hz. Calls generally occurred in pairs, but triplets

25 or singles were also registered. These low frequency sounds share characteristics with

26 recordings of sei whales near the Hawaii Islands, but with differences in the maximum

27 frequencies and duration. These calls distinctly differ from sounds previously described

28 for sei whales in the Southern Ocean and are the first documented sei whale calls in the

29 south-eastern Pacific.

1. Introduction

The sei whale (*Balaenoptera borealis*; Lesson 1828) is the third largest rorqual in the Balaenopteridae family, after the blue whale (*B. musculus*) and the fin whale (*B. physalus*). It is also one of the least known whales. The sei whale is a cosmopolitan species found in temperate oceans and subpolar areas (Mackintosh, 1942; Gambell, 1968; Rice, 1998; Horwood, 2002; Reeves *et al*., 2002; Jefferson *et al*., 2008). It prefers deep offshore waters with temperatures below 20°C and avoids semi enclosed bodies of water (Omura and Nemoto, 1955; Gambell, 1985). North Atlantic, North Pacific and Antarctic populations are almost certainly separated and probably subdivided into geographic stocks (Horwood, 1987; Baker *et al.,* 2004; Kanda *et al*., 2006; Huijser *et al*., 2018). International Whaling Commission in 1991 divided the global sei whale population in "stocks" (based on the distribution of catches, sightings and mark-recapture data) for management purposes (Donovan, 1991). However, genetic studies provide a different population distribution. For example, in the North Atlantic Ocean, the sei whale population from Iceland, the Gulf of Maine and the Azores share the same genetic diversity, showing the wide latitudinal and longitudinal ranges they moved. Furthermore, the genetic divergence between North Pacific and North Atlantic stocks is well known, but no studies of this genetic structure between hemispheres or within the Southern Ocean have been presented (Huijser *et al*., 2018). In the Southern Hemisphere, sei whale sightings were recorded from the Subtropical Convergence to the Antarctic Convergence, but the only observation record of adult animals come from the austral summer in south of the Antarctic Convergence (Gambell, 1974; Lockyer, 1977). In general, sei whales migrate seasonally from the reproduction areas in low latitudes in winter to their feedings areas in high latitudes in summer (Reeves *et al*., 1998).

54 Reproduction areas are poorly known (Perry *et al*., 1999) and feeding areas show great

55 variability between years (Jonsgård and Darling, 1977). Population boundaries and

56 migratory patterns are also poorly understood. In the austral summer there are

57 concentrations of sei whales between 40° and 50°S; older, larger individuals tend to

58 travel to northern Antarctic, while smaller, younger individuals tend to stay at lower

59 latitudes (Rice, 1998; Acevedo *et al*., 2017).

60 Because of their smaller size, speed and elusiveness, sei whales were comparatively less

61 important as target species for hunting until the early 1960s. After the decline of the

62 most profitable species such as blue whales, fin whales and humpback whales, the

63 whaling industry increased the hunting pressure on sei whales (Gambell, 1985). Thirty

64 years ago, between the Antarctic and the North Pacific, many whales were taken from

65 the coasts of Peru and Chile (Tonnessen and Johnsen, 1982). Most captures were carried

66 out by the pelagic whaling in the Antarctic, which hunted more than 110,000 sei whales

67 between 1960 and 1970 (Horwood, 2002). The International Whaling Commission

68 estimated the size of the sei whale populations in the South Hemisphere to be 37,000

69 individuals after the cessation of the commercial captures in 1984, while this number

70 was estimated 191,000 in the 1940s (Gambell, 1985). Between 1929 and 1983 sei whales

71 captures represented 17.3% of the total catch of whales in Chile. It was the third most

72 hunted species with approximately 1,664 individuals captured principally on the north

73 and central coasts (Aguayo-Lobo, 1974; Aguayo-Lobo *et al*., 1998), although these

74 include an unknown number of Bryde whales (Valdivia *et al*., 1981; Gallardo *et al*., 1983;

75 Aguayo-Lobo *et al*., 1998). After the whale-hunting moratorium imposed by the

76 International Whaling Commission in 1980, several research projects focused on the

77 populations and recovery status of the large whales such as right whales, humpback

78   whales, blue whale and fin whales (Reeves *et al.*, 2002). Since 1976, sei whales have

79   been listed as endangered (IUCN 2018). Today, sei whales are the least studied of the

80   large whales and there has been a lack of data since the end of the commercial hunting

81   (Prieto *et al.*, 2011).

82   In Chile, there are opportunistic sightings and strandings of sei whales from Antofagasta

83   (in the north) to the Magellan Straight (in the south), including the islands of Juan

84   Fernandez (Gallardo *et al.*, 1983; Schlatter, 1987; Aguayo-Lobo *et al.*, 1998; Findlay *et*

85   *al.*, 1998; Pastene and Shimada, 1999; Guzmán, 2006; Acevedo *et al.*, 2017). Many

86   sightings in Central Chile and Northern Patagonia (33°-48°S) have been reported since

87   1966, when 286 whales were sighted in March of 1966 (between 43° and 45°S); 114 in

88   October of the same year (between 46° and 48°S), all between 30 and 190 km off the

89   shore (Aguayo-Lobo, 1974). In March 1968 Japanese whalers reported the sightings of

90   several hundreds of sei whales between 46° 40' and 48°S, with a peak concentration 30

91   km off the coast of the Tres Montes Peninsula at the northern limit of The Penas Gulf

92   (Pastene and Schimada, 1999). In 2015, at Penas Gulf the largest recorded baleen whale

93   mass mortality event was reported with 363 registered carcasses of baleen whales

94   (Häussermann *et al.*, 2017). Genetic and morphological analysis confirmed that the

95   examined animals were sei whales (Häussermann *et al.*, 2017). These historical sightings

96   support the hypothesis of Guzman (2006) about the presence of sei whales feeding in

97   Chilean Patagonia between Chiloe island and the Magellan Strait (Acevedo *et al.*, 2017).

98   Since the sei whale is endangered and poorly known, population studies are crucial as a

99   support for its conservation. Autonomous passive acoustic monitoring devices facilitate

100   the monitoring of cetaceans by recording their vocal signals. Passive acoustic data can

101   then be used to characterize and understand their acoustic behavior and determine

102   their distribution patterns in time and space (Clark and Ellison, 1989; Richardson *et al.*,

103   1995).

104   Acoustic signals produced by sei whales are poorly known (Prieto *et al.*, 2011). To date,

105   vocalizations have been described from six different geographic areas: New England

106   (USA), Nova Scotia (Canada), Hawaii (USA), Azores (Portugal), Auckland Islands (New

107   Zealand,) and Antarctic Peninsula (Thompson *et al.*, 1979; McDonald *et al.*, 2005; Rankin

108   and Barlow, 2007; Baumgartner *et al.*, 2008; Calderan *et al.*, 2014; Romagosa *et al.*,

109   2015). There is no record of sei whale vocalizations from the South-eastern Pacific

110   Ocean. Comparison from intraspecific sounds from different geographic regions is

111   interesting for possible acoustic clues to both stock and taxonomic identities.

112   Consequently, the aim of this work is to describe sei whale vocalizations based on

113   opportunistic recordings at the Penas Gulf, Chile and to obtain a framework baseline

114   about the characterizes of sei whales populations in the South-eastern Pacific Ocean.

115   2. Methods

116   Two cruises to the Penas and Tres Montes Gulf (46.2-48.0° S, 74.0-75.4° W) aboard the

117   motor sailing vessel Saoirse were carried out in May 2016 and May 2017 during which

118   biological, oceanographic and acoustics studies were carried out (fig 01). Marine

119   mammals were identified visually with binoculars and the naked eye for a team of

120   experienced marine mammal observers in the vessel.

121   Two different hydrophones were used for the recordings: an icListenHF hydrophone

122   (sensitivity -171 dBV re 1 µPa with pre-amp; frequency response 10–200kHz from Ocean

123   Sonic, Canada); and a SoundTrap 202 STD hydrophone (sensitivity -205 dBV re 1 µPa;

124   frequency response 60000Hz ±3 dB from Ocean Instruments, New Zealand). Also, we

125   made stereo recordings on several occasions with an HTI-96-MIN hydrophone (flat

126   frequency response from 0.02 to 30 kHz) connected to a handy recorder (H4nPro from

127   ZOOM).

128   Opportunistic and planned recordings were carried out depending on the weather

129   conditions and the vessel location. In 2016, recordings were not more than one day in

130   each location where hydrophones were suspended over the side of the vessel. However,

131   in 2017, also, in 3 different locations, hydrophone were deployed between 2-5 days. In

132   these cases, hydrophones were deployed at a depth of 5 or 10 m on rocky bottom with

133   about 40 meters bottom depth using a row with a mooring at the end and surface buoys

134   on the opposite side. In both years, during the day or night, hydrophones were deployed

135   at a depth of 5 and 10 meters from the stationary vessel. Opportunistic recordings were

136   continuous, but in the night when the vessel was at anchor, the recordings were in

137   intervals of 10-30 minutes each hour to guarantee the capacity of the acoustic personnel

138   to study the recording during the next day.

139   During all the recordings, the engine vessel was turn off. All the recordings were stored

140   in the internal card memory of the equipments, and at the end of the day these were

141   download in a portable computer.

142   Audio data were analyzed using Raven Pro 1.5 (Cornell University, Ithaca, NY). Low and

143   high frequency (Hz), frequency range (Hz), peak frequencies (the frequency at which the

144   maximum power occurred within a call) and duration (s) for all calls found and attributed

145   to sei whales were analysed from spectrograms and waveform plots created in Raven

146   Pro 1.5 (Hann window; 50% overlap; window size 14563 samples; DFT 16384 samples).

147   Figure 01. Study area including sighting and recording locations. The whale tail indicates

148   the area where sei whale were sighted and vocalizations were identified.

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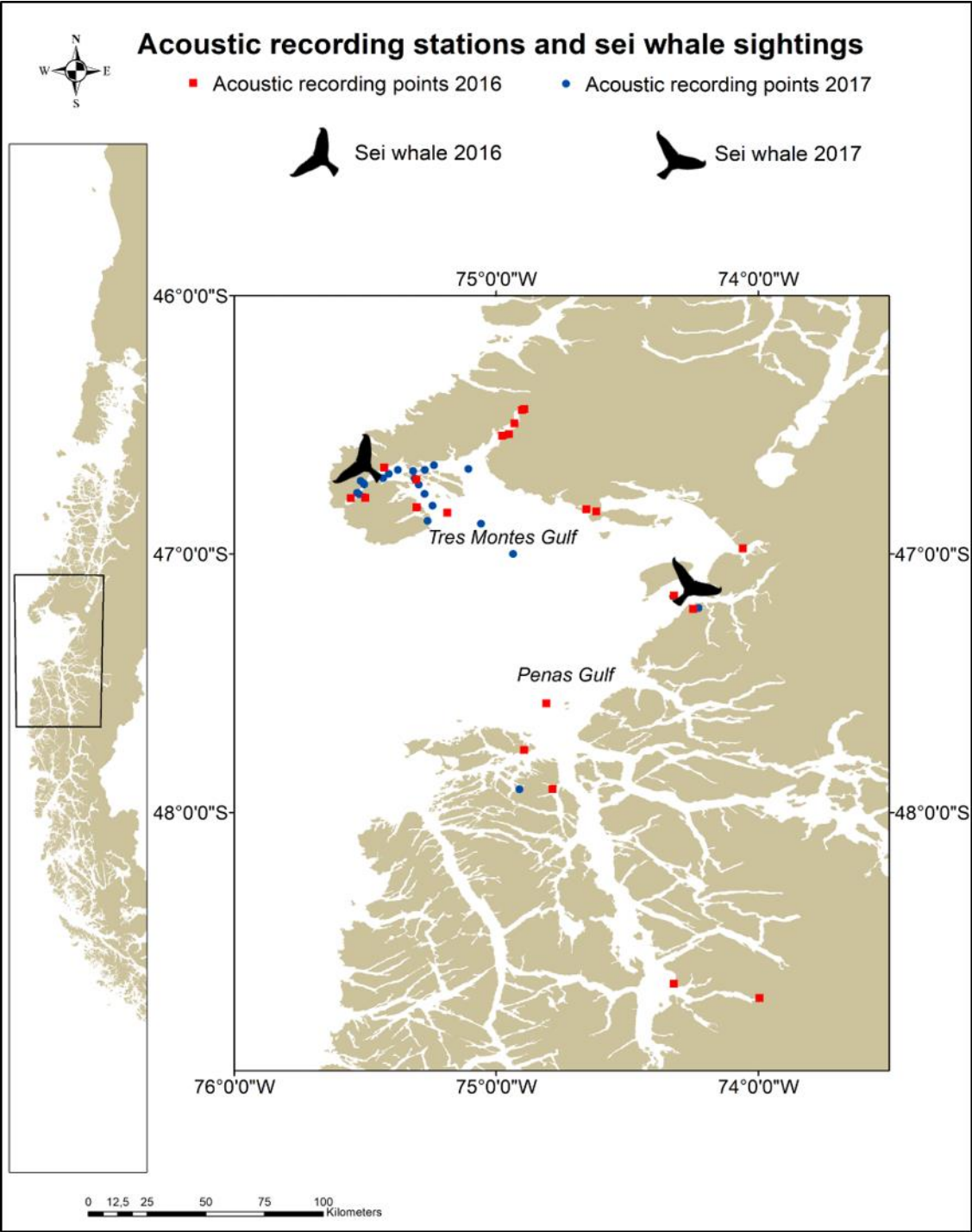
3. Results

Sei whales were sighted in both expeditions (2016 and 2017). In addition, during one day in 2017, humpback whales were sighted. Sound was recorded during 16 days in 2016 in 23 opportunistic recordings locations and during 19 days in 24 locations in ~~2017~~ 2017. A total of 363 hours was recorded between both expeditions, because the recordings were not continuous during every day, 136 hours (63 archives) in 2016 and 227 hours (483 archives) in 2017. Recordings were not the same duration or the same sampling rate because they were opportunistic. Sei whale calls were found in 8 archives for 3 days, on 7 May 2016 and 10-11 May 2017, at 2 different locations (one in 2016 and other in 2017) (Table 1). In acoustic data from 2016, sei whale calls were detected when sei whales were sighted closer the vessel (fig 02). In 2017, between 8 and 10 May, sei whales were sighted in the area after sei whale calls had been recorded (fig 02). Sei whale calls from 2016 were only recorded around midday, while in 2017 they were recorded in the late afternoon or at night (Table 1).

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176 Figure 02. Photographed sei whale at Penas and Tres Montes Gulf a) 7 May, 2016.
177 Photo by: Katie McConnell; b) 10 May, 2017. Photo by: Keri-Lee Pashuk.

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182   Table 1. Sei whale recordings at Penas and Tres Montes Gulf.

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Year	Date	Local Hour	Latitude	Longitude	Sampling rate	Hydrophone depth (meters)	Recording duration (minutes)	Hydrophone	Sightings
2016	07-may	14:07	S47°09.625'	W074°19.266'	44100	5	34	HTI-96-MIN hydrophone + Handy recorded	2 individuals of sei whale closer to the vessel. Figure 02 (a).
2017	10-may	19:43 22:43 23:43	S46°46.100'	W75°31.400'	48000	10	30 minutes each hour	SoundTrap 202 STD	3 individuals of sei whale in the area between 8-10 May. Figure 02 (b).
2017	11-may	00:43 02:43 05:43 07:43	S46°46.100'	W75°31.400'	48000	10	31 minutes each hour	SoundTrap 202 STD	3 individuals of sei whale in the area between 8-10 May. Figure 02(b).

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185   Only in two occasions humpback whale sounds above 2000 Hz were detected, in the rest

186   of the analyzed audios, only sei whale sounds were detected without associated calls.

187   Only calls with high-visual quality were measured. All vocalizations reported in this study

188   were identified as downsweep calls (fig 03). We identified a total of 41 calls; 5 calls in

189   2016 and 36 in 2017. In 2016, calls ranged from an average maximum frequency of 105.3

190   Hz (SD=18.3 Hz) down to an average minimum frequency of 35.6 Hz (SD=4.6 Hz) over 1.6

191   s (SD=0.1 s) with a peak frequency of 65.4 Hz (SD=14.1 Hz) (Table 2). In 2017, calls ranged

192   from an average maximum frequency of 93.3 Hz (SD=10.9 Hz) down to 42.2 Hz (SD=5.6

193   Hz) over 1.6 s (SD=0.3 s) with a peak frequency of 68.3 Hz (SD=14.2 Hz). The minimum

194   frequency was 30 Hz and the maximum frequency was 129.4 Hz. Calls occurred in pairs

195   (n=12), singles (n=5) or triplets (n=4) (Table 2).

196   Figure 03. Spectrogram of sei whale vocalization recorded with the hydrophone (32768

197   FFT, Hamming window). A. five seconds spectrogram zoomed in on a pair of calls. B. five

198   seconds spectrogram of a pair of call. C. A pair and a single call of sei whale call within

199   15 seconds.

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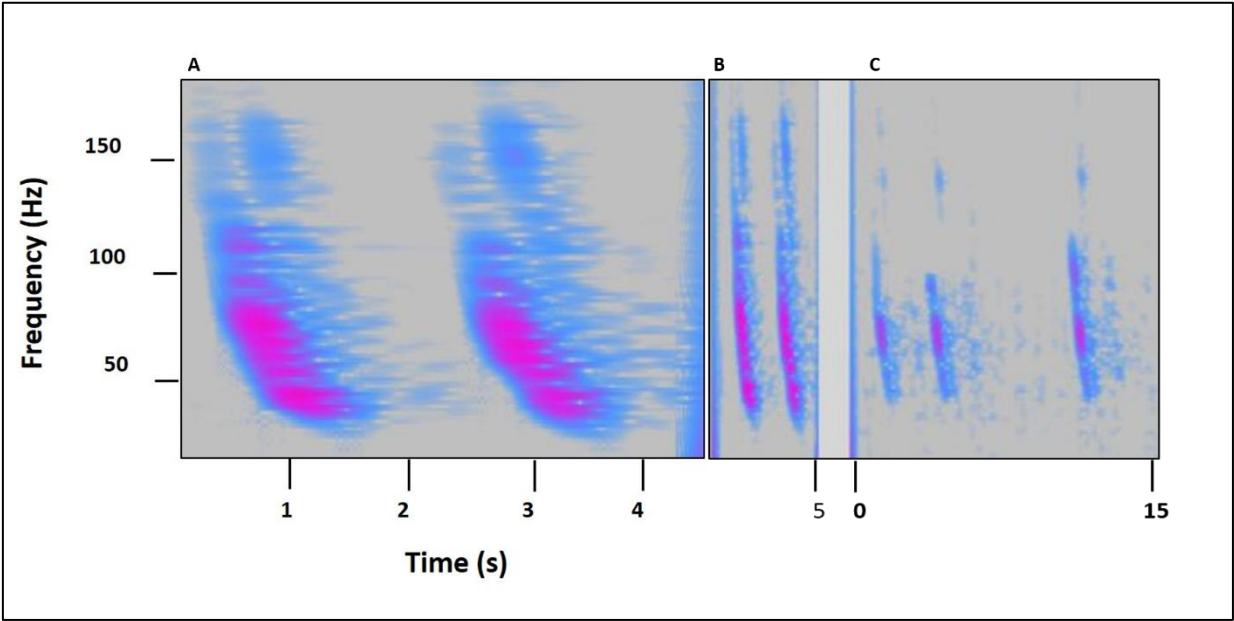
202   Table 2. Comparison of the frequency and timing of recorded calls in the present study

203   with studies in other areas. Values are mean value ± standard deviation. ND = no data

204   (the study did not include that information)

Source	Location	Year/nº vocalizations	High Frequency (Hz)	Low frequency (Hz)	Peak frequency (Hz)	Duration (s)
Present study	Chile, South-eastern Pacific	2016/5	105.3±18.3	35.6±4.6	65.4±14.1	1.6±0.1
		2017/36	93.3±10.9	42.2±5.6	68.3±14.2	1.6±0.3
Romagosa *et al.* (2015)	Azores, Northern Atlantic Ocean	2012/53	99.8±13.6	37.4±8.4	52.0±11.4	1.21±0.33
Calderan *et al.* (2014)	Auckland Islands, Southern Atlantic Ocean	2013/4	78.0±2.0	69.0±08	73.8±0.5	1.1±0.0
		2013/4	83.3±4.1	53.8±4.9	78.3±3.1	1.2±0.0
		2013/30	66.3±10.7	36.6±2.1	45.8±11.0	1.2±0.3
Gedamke and Robinson (2010)	East Antarctica, Southern Ocean	2006/ND	570	170	ND	ND
Baumgartner *et al.* (2008)	New England, North western Atlantic Ocean	2006-2007/108	82.3 ±15.2	34.0±6.2	ND	1.38±0.37
Rankin and Barlow (2007)	Hawaii, Pacific Ocean	2002/2	100.3±11.1	44.6±2.9	ND	1.2±0.007
		2002/105	39.4±3.4	21±2.4		1.2±0.11
McDonald (2005)	West Antarctica, Southern Ocean	2003/50	433	192	ND	0.45±0.3
Knowlton *et al.* (1991)	Canada, Northern Atlantic Ocean	1986-1989/ND	3500	1500	ND	0.5-0.8
Thompson (1979)	Canada, Northern Atlantic Ocean	ND	3000	ND	ND	0.7

205

206   4. Discussion

207   Given that recordings from this project were opportunistic and without digital acoustic

208   recording tags (DTAG) deployed in sei whales we cannot prove the origin of the calls.

209   However, we can confirm with reasonable certainty that vocalizations recorded off

210   Penas and Tres Montes Gulf were produced by sei whales, due to the sightings of this

211   species during the recordings and the expeditions. Blue whales (*Balaenoptera*

212   *musculus*), fin whale (*Balaenoptera physalus*) or minke whales (*Balaenoptera*

213   *acutorostrata*) produce downsweep as well (Thompson *et al*., 1996; Schevill and

214   Watkins, 1972; Watkins, 1981). Bryde whales (*Balaenoptera brydei*) has also several call

215   types, included downsweep, but inhabit tropical and subtropical waters and we do not

216   have any record in this area yet (Omura, 1959; Wade and Gerrodette, 1993; Oleson, *et*

217   *al*., 2003). Generally, fin whales downsweep have initial frequencies below 35 Hz and

218   final frequencies around 20-18 Hz (Watkins, 1981), similar than minke whales but with

219   shorter durations (0.2-0.3 sec) and higher frequencies (130-60 Hz) (Schevill and Watkins,

220   1972). Minke whales in the North Atlantic produce long pulse trains (Mellinger *et al*.,

221   2000), these were not recorded in this area, fin and minke whales downsweep are

222   definitively different than our recordings. Only downsweeps from blue whales described

223   in Chile, through the DTAG data, has a lower peak frequency and duration; minimum

224   frequency is higher than our results and downsweep had been accompanied by the

225   Southeast Pacific type 2 (SEP2) (Saddler *et al*., 2017), supporting our results, that our

226   records are really from sei whales. In addition, sei whale vocalizations described here

227   show very similar characteristics to those described off Azores Islands by Romagosa *et*

228   *al.* (2015), off New England by Baumgartner *et al*. (2008) and off Hawaii by Rankin and

229   Barlow (2007). In these areas, sei whale vocalizations are characterized by low frequency

230   downsweeps. However, sei whales sweeps recorded off Nova Scotia by Thompson

231   (1979) and Knowlton et al. (1991) or in Antarctic waters by McDonald (2005), Gedamke

232   and Robinson (2010) are different from our recording and are characterize by higher

233   frequencies.

234   Rankin and Barlow (2007) describe two ranges for the low frequency downsweeps, 100-

235   44 Hz and 39-21 Hz with durations of 1.0 s and 1.3 s, respectively. In the present study,

236   the minimum frequency was 30 Hz, being the average calls in the upper range defined

237   by those authors. The range of frequencies described here are similar to what

238   Baumgartner *et al*. (2008), Newhall *et al*. (2012) and Romagosa *et al*. (2015) reported,

239   although the maximum frequency reported in the present study is higher. The higher

240   frequency calls recorded in the North Pacific (Hawaii) and in the present study are

241   similar, but our results showed higher frequencies in the top range (maximum off 111.4

242   Hz versus 129.4 Hz, respectively) and a longer duration (maximum 1.27 s versus 2.27 s,

243   respectively). The similarities could be expected due to the possibility of there being a

244   stereotypical call used in feeding grounds, as suggested by Romagosa *et al*. (2015).

245   However, sei whales recorded in this study have shown a different call with higher

246   frequencies and longer durations than those detected from North Atlantic or North

247   Pacific waters.

248   In the sub-Antarctic Auckland Islands, a series of four calls is predominant (Calderan *et*

249   *al.*, 2014), but the calls recorded at Penas Gulf occurred principally in pairs, although

250   single calls and triplets were also detected. During this study, no four-call series were

251   recorded as have been recorded in North Atlantic or Pacific waters (Baumgartner *et al*.,

252   2008, Newhall *et al*., 2012, Romagosa *et al*., 2015).

253 Sei whale calls from Antarctic waters are characterized by broadband, tonal, frequency

254 modulated vocalizations between 100 and 600 Hz with durations between 1 and 3 s

255 (McDonald 2005, Gedamke and Robinson, 2010). These calls do not present similarities

256 with the calls recorded here. This may be due a geographic separation of the

257 populations, suggesting that different sei whale populations produce different

258 stereotypic calls. The structure of the calls of sei whales is more variable between whales

259 than within an individual whale (Baumgartner *et al.*, 2008). This suggests that sei whales

260 present in Antarctic waters do not transit through southern Chile, or at least near shore

261 Patagonia, in their migration to the breeding grounds in lower latitudes. Thus, the sei

262 whales found in Chile, near shore in Penas and Tres Montes Gulf, might represent a

263 different population. As recordings were opportunistic, the duration of recordings was

264 variable, and this maybe influenced in the few calls that we recorded., so visual

265 observations, tagging efforts and genetic studies are needed to verify this hypothesis.

266 In the present study, most acoustic activity was recorded during the night, while

267 Baumgartner and Fratantoni (2008), Newhall *et al.* (2012) and Romagosa *et al*. (2015)

268 recorded calls mostly during the day. These darkness patterns coincide with results from

269 humpback whales songs reported from Chile (Español-Jiménez and van der Schaar,

270 2018). However, low frequency sei whale downsweeps may have a different function

271 from the stereotyped humpback vocalizations considered as songs (Edds-Walton 1997).

272 Though the behavior of sei whales is poorly studied, most studies on this species state

273 that sei whales prefer offshore waters, but these new records and sightings along the

274 coast of Penas and Tres Montes Gulf (Aguayo-Lobo 1974; Pastene and Schimada, 1999;

275 Häussermann *et al*., 2017), demonstrated a wide habitat range, with the whales

276 probably following productive feeding areas. If this is true, it is reasonable to assume

277 that the calls of sei whale's calls are influenced by the feeding conditions (as proposed

278 by Baumgartner and Fratantoni (2008)) and have communicative functions, e.g.

279 cooperatively searching for prey as suggested Newhall *et al*. (2012). Baumgartner and

280 Fratantoni (2008) hypothesize that calling rates are reduced at night while the whales

281 are feeding but increase with social activity during the day when copepods are either

282 more difficult or less efficient to capture at depth. Our data could not support this

283 hypothesis since calls were recorded at night and it was not possible to observe what

284 activities the whales were engaged in. Another factor that could be important in the

285 discussion about the acoustic behavior is background noise, which might be masking

286 biologically important signals and impede the communications between individuals

287 (Clark *et al.,* 2009).

288 This new description of sei whale calls adds knowledge to the vocalizations and

289 distribution of an endangered species (IUCN, 2018) red-listed under criteria A-1. It is also

290 listed in Appendix I ("Endangered migratory species") and II ("Migratory species with

291 unfavorable conservation status which require international agreements for their

292 conservation and management") in the Convention on the Conservation of Migratory

293 Species of Wild Animals (Bonn Convention 1979). Satellite tracking of the Chilean sei

294 whale population, individual photo identification, distribution and characteristics of the

295 prey species, behavioral, genetic and oceanographic studies are necessary to test some

296 hypotheses and improve our understanding of this species.

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311   References

312   Acevedo, C., Aguayo-Lobo, A., González, A., Haro, D., Olave, C., Quezada, F., Martínez,

313   F., Garthe, S., and Cáceres, B.: Occurrence of sei whales (*Balaenoptera borealis*) in the

314   Magellan Strait from 2004-2015, Chile, Aquat. Mamm., 43 (1), 63, 2017.

315   Aguayo-Lobo, A.: Baleen whales of continental Chile, Pp: 209 – 217, William E. Schevill,

316   Editor. The Whale Problem: A Status Report. Harvard University Press, 419 pp, 1974.

317   Aguayo-Lobo, A., Torres, D., and Acevedo J.: Los mamíferos marinos de Chile: I. Cetacea,

318   Serie Científica INACH, 48, 19–159, 1998.

319   Baker, C. S., Dalebout, M. L., Funahashi, N., Ma, Y. U., Steel, D., and Lavery, S.: Market

320   surveys of whales, dolphins and porpoises in Japan and Korea, 2003–2004, with

321   reference to stock identity of sei whales. Paper SC/56/BC3 presented to the IWC

322   Scientific Committee, June 2004 (unpublished). Available from the IWC Office

323   Baumgartner, M.F., and Fratantoni, D.M.: Diel periodicity in both sei whale vocalization

324   rates and the vertical migration of their copepod prey observed from ocean gliders,

325   Limnol. Oceanogr., 53, 2197–2209, 2008.

326   Baumgartner, M.F., Van Parijs, S.M., Wenzel, F.W., Tremblay, C.J., Carter Esch, H., and

327   Warde, A.M.: Low frequency vocalizations attributed to sei whales (*Balaenoptera*

328   *borealis*), J. Acoust. Soc. Am., 124 (2), 1339-1349, 2008.

329   Calderan, S., Miller, B., Collins, K., Ensor, P., Double, M., Leaper, R., and Barlow, J.: Low-

330   frequency vocalizations of sei whales (*Balaenoptera borealis*) in the Southern Ocean, J.

331   Acoust. Soc. Am., 136 (6), EL418-EL423, 2014.

332   Clark, C.W., and Ellison, W.T.: Numbers and distributions of bowhead whales, *Balaena*

333   *mysticetus*, based on the 1986 acoustic study off Pt Barrow Alaska, Report of the

334   International Whaling Commission, 39, 297-303, 1989.

335   Clark, C.W., Ellison, W.T., Southall, B.L., Hatch, L., Van Parijs, S.M., Frankel, A., and

336   Ponirakis, D.: Acoustic masking in marine ecosystems: Intuitions, analysis, and

337   implication, Mar. Ecol. Prog. Ser., *395*, 201-222, 2009.

338   Donovan, G.P.: A review of IWC stock boundaries, International Whaling Commission,

339   Special Issue, 13, 39-68, 1991.

340   Edds-Walton, P.L.: Acoustic communication signals of mysticete whales, Bioacoustics 8,

341   47–60, 1997.

342   Español-Jiménez, S., and van der Schaar, M.: First record of humpback whale songs in

343   Southern Chile: Analysis of seasonal and diel variation, Mar. Mam. Sci., 34 (3): 718–733,

344   2018.

345   Findlay, K., Pitman, R., Tsurui, T., Sakai, K., Ensor, P., Iwakami, H., Ljungblad, D., Shimada,

346   H., Thiele, D., Van Waerebeek, K., Hucke-Gaete, R., Sanino-Vattier, G.P. :1997/1998 IWC-

347   Southern Ocean whale and ecosystem research (IWC/SOWER) blue whale cruise, Chile,

348   Report presented to the International Whaling Commission, Muskat, Oman, 1998.

349   Gallardo, V.A., Arcos, D., Salamanca, M., and Pastene, L.A.: On the occurrence of Bryde's

350   whale (*Balaenoptera edeni* Anderson 1878) in an upwelling area off Central Chile, Report

351   of the International Whaling Commission, 33, 481-488, 1983.

352   Gambell, R.: Seasonal cycles and reproduction in sei whales of the Southern

353   Hemisphere, Discovery Reports, 35, 31-134, 1968.

354   Gambell, R.: A review of population assessments of Antarctic sei whales, Report of the

355   International Whaling Commission, Special Issue 1, 44-49, 1974.

356   Gambell, R.: Sei whale, *Balaenopera borealis*, Lesson 1828, Pp: 155 – 170. In: Sam H.

357   Ridgway and Richard Harrison Editors. Handbook of Marine Mammals. Vol 3. The

358   Sirenian and Baleen whales. Academic Press, London, 369 pp., 1985.

359   Gedamke, J., and Robinson, S.M.: Acoustic survey for marine mammal occurrence and

360   distribution off East Antarctica (30–80°E E) in January-February 2006, Deep Sea Res., II

361   57, 968–981, 2010.

362   Guzmán, A.: Avistamientos de ballena azul *Balaenoptera musculus* (Linnaeus, 1758) y sei

363   *B. borealis* Lesson, 1828 en la costa nor-occidental de la isla de Chiloé, Chile (Blue whale

364   *Balaenoptera musculus* (Linnaeus, 1758) and sei whales B. borealis Lesson, 1828

365   sightings in the north-occidental coastal in the Chiloé islands, Chile). Boletín del Museo

366   Nacional de Historia Natural, Chile, 55, 51-60, 2006.

367   Häussermann, V. Gutstein, C.S., Bedington, M., Cassis, D., Olavarria, C., Dale, A.C.,

368   Valenzuela-Toro, A.M., Perez-Alvarez, M.J., Sepúlveda, H.H., McConnell, K.M., Horwitz,

369   F.E., and Försterra, G.: Largest baleen whale mass mortality during strong El Niño event

370   is likely related to harmful toxic algal bloom, PeerJ, 5, e3123, 2017.

371   Horwood, J.W.: The sei whale: Population biology, ecology and management, London:

372   Croom Helm, 1987.

373   Horwood, J.W.: Sei whale *Balaenoptera borealis*, In W. F. Perrin, B. Würsig, and J. G. M.

374   Pp. 1069-1070. Thewissen (Eds.), Encyclopedia of marine mammals. San Diego:

375   Academic Press, 1352 pp., 2002.

376 Huijser, L. A., Bérubé, M., Cabrera, A. A., Prieto, R., Silva, M. A., Robbins, J., Kanda, N.,

377 Pastene, L. A., Goto, M., Yoshida, H., Víkingsson, G. A., and Palsboll, P. J. : Population

378 structure of North Atlantic and North Pacific sei whales (Balaenoptera borealis) inferred

379 from mitochondrial control region DNA sequences and microsatellite

380 genotypes. Conservation Genetics, 19, 1007-1024, 2018.IUCN 2018. The IUCN Red List

381 of Threatened Species. Version 2018-1.

382 Jefferson, T.A., Webber, M.A., and Pitman, R.L. (Eds.).: Marine mammals of the world: A

383 comprehensive guide to their identification, San Diego: Academic Press., 616 pp., 2008.

384 Johnson, S. C. Johnson, S.C., Širović, A., Buccowich, J.S., Debich, A.J., Roche, L.K., Thayre,

385 B., Wiggins, S.M., Hildebrand, J.A., Hodge, L.E.W., and Read, A.J.: Passive acoustic

386 monitoring for marine mammals in the Jacksonville Range Complex, Marine Physical

387 Laboratory Technical Memorandum 548, Scripps Institution of Oceanography,

388 University of California San Diego, La Jolla, CA. 2010.

389 Jonsgård, Å., and Darling, K.: On the biology of the eastern North Atlantic sei whale,

390 *Balaenoptera borealis* Lesson, Reports of the International Whaling Commission, 1, 124–

391 129. Special issue, 1977.

392 Kanda, N., Goto, M. and Pastene, L.A.: Genetic characteristics of western North Pacific

393 sei whales, *Balaenoptera borealis*, as revealed by microsatellites, Marine Biotechnology,

394 8, 86–93, 2006.

395 Knowlton, A., Clark, C. W. and Kraus, S. D.: Sounds recorded in the presence of sei whales

396 *Balaenoptera Borealis*, Abstract Book of The Ninth Biennial Conference on the Biology

397 of Marine Mammals., 40 pp. Chicago, Illinois, USA, 1991.

398   Lockyer, C.: Some possible factors affecting the age distribution of the catch of sei

399   whales in the Antarctic, Reports of the International Whaling Commission, Special Issue,

400   1, 63-70, 1977.

401   Mackintosh, N.A.: The southern stocks of whalebone whales, Discovery Reports, 22,

402   197-300, 1942.

403   McDonald, M. A., Hildebrand, J. A., Wiggins, S. M., Thiele, D., Glasgow, D. and Moore, S.

404   E.: Sei whale sounds recorded in the Antarctic, J. Acoust. Soc. Am., 118, 3941–3945,

405   2005.

406   Mellinger, D. K., Carson, C. D., and Clark, C. W.: Characteristics of minke whale

407   (Balaenoptera acutorostrata) pulse trains recorded near Puerto Rico. Marine Mammal

408   Science, 16(4), 739-756, 2000

409   Newhall, A.E., Lin, Y.-T., Lynch, J.F., Baumgartner, M.F., and Gawarkiewicz, G.G.: Long

410   distance passive localization of vocalizing sei whales using an acoustic normal mode

411   approach, J. Acoust. Soc. Am., 131 (2), 1814–1825, 2012.

412   Oleson, E. M., Barlow, J., Gordon, J., Rankin, S., and Hildebrand, J. A.: Low frequency calls

413   of Bryde's whales. Marine Mammal Science, 19(2), 160-172, 2003.

414   Omura, H., and Nemoto, T.: Sei whales in the adjacent waters of Japan. III. Relation

415   between movement and water temperature, Reports of the International Whaling

416   Commission, Special Issue, 10, 79–87, 1955.

417   Omura, H.: Bryde's whale from the coast of Japan. The Scientific Reports of the Whales

418   Research institute, 14, 1-33, 1959, 1959.

419   Pastene, L.A., and Shimada, H.: Report of a sighting survey in Chile's exclusive economic

420   zone with comments on sei whale distribution, Anales del Instituto de la Patagonia, Serie

421   Ciencias Naturales (Chile), 27, 51-62, 1999.

422   Perry, S.L., DeMaster, D.P. and Silber, G.K.: The great whales: history and status of six

423   species listed as endangered under the U.S. Endangered Species Act of 1973, Mar. Fish.

424   Rev., 61, 1–74, 1999.

425   Prieto, R., Janiger, D., Silva, M.A., Waring, G.T., and Gonçalves, J.M.: The forgotten

426   whale: A biblio-metric analysis and literature review of the North Atlantic sei whale

427   *Balaenoptera borealis*, Mammal Rev., 42 (3), 235-272, 2011.

428   Rankin, S., and Barlow, J.: Vocalizations of the sei whale *Balaenoptera borealis* off the

429   Hawaiian Islands, Bioacoustics, 16, 137–145, 2007.

430   Richardson, W.J., Greene, C.R.J., Malme, C.I., and Thomson, D.H. Pp: 33–58. Marine

431   mammals and noise: Measurement procedures in. Academic Press, San Diego, CA. 576

432   pp., 1995.

433   Reeves, R.R., Silber G., and Payne, P.M.: Draft recovery plan for the fin whale

434   *Balaenoptera physalus* and sei whale *Balaenoptera borealis*, prepared for the Office of

435   Protected Resources, National Marine Fisheries Service, Silver Spring, MD, 1998.

436   Reeves, R.R., Stewart, B.S., Clapham, P.J., and Powell, J.A. (Eds.).: Marine mammals of

437   the world, New York: Alfred A. Knopf/Chanticleer Press, 2002.

438   Rice, D.W.: Marine mammals of the world: Systematics and distribution, (Special

439   Publication Number 4). Lawrence, KS: The Society for Marine Mammalogy. 231 pp.,

440   1998.

441   Romagosa, M., Boisseau, O., Cucknell, A. C., Moscrop, A., and McLanaghan, R.: Source

442   level estimates for sei whale (*Balaenoptera borealis*) vocalizations off the Azores, J.

443   Acoust. Soc. Am., 138 (4), 2367-2372, 2015.

444   Saddler, M.R., Bocconcelli, A., Hickmott, L.S., Chiang, G., Landea-Briones, R.,

445   Bahamonde, P.A., … and Sayigh, L.S.: Characterizing Chilean blue whale vocalizations

446   with DTAGs: a test of using tag accelerometers for caller identification, Journal of

447   Experimental Biology, jeb-151498. 2017.

448   Schevill, W.E., and Watkins, W.A.: Intense low-frequency sounds from an Antarctic

449   minke whale, *Balaenoptera acutorostrata*, Breviora, 388, 1-8. 1972.

450   Schlatter, R.: Avistamientos de mamíferos marinos durante SIBEX-Fase 2, en el estrecho

451   de Bransfield y aguas adyacentes (Sightings of marine mammals during SIBEX-Phase 2,

452   in the Bransfield Strait and adjacent waters), Serie Científica INACH, 36, 167-174, 1987.

453   Thompson, T.J., Winn, H.E., and Perkins, P.J.: Mysticete sounds. Behaviour of Marine

454   Mammals, Cetaceans, edited by H. E. Winn and B. L. Olla (Plenum, New York), 3, 403–

455   431, 1979.

456   Thompson, P. O., Findley, L. T. and Vidal, O.: Underwater sounds of blue whales,

457   *Balaenoptera musculus*, in the Gulf of California, Mexico. Mar. Mamm. Sci. 12, 293-296.

458   1996.

459   Tonnessen, J.N. and Johnsen, A.O.: The history of modern whaling, University of

460   California Press. Berkeley, California. 798 pp., 1982.

461   Valdivia, J., Ramirez, P., and Franco, F.: The exploitation of Bryde's whales in the

462   Peruvian Sea, Report of the International Whaling Commission, 31, 441-448, 1981.

463 Wade, P. R., and Gerrodette, T.: Estimates of cetacean abundance and distribution in

464 the Eastern Tropical Pacific. Report of the International Whaling Comission, 43, 477-493,

465 1993.