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**

5 Sonia Español-Jiménez[1], Paulina A. Bahamonde[1,2], Gustavo Chiang[1], Verena

6 Häussermann[3]

7 [1] MERI Foundation, Avenida Kennedy 5682, Santiago de Chile, Chile.

8 [2] Núcleo Milenio INVASAL, Concepción, Chile.

9 [3] Facultad de Ciencias Naturales, Escuela de Ciencias del Mar, Pontificia Universidad

10 Católica de Valparaíso, Avenida Brasil 2950, Valparaíso, Chile, and Huinay Scientific

11 Field Station, Chile.

12 sespanol@fundacionmeri.cl

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, at 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, it is well known the genetic divergence between North Pacific and North Atlantic stocks, 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*.,

54   1998). Reproduction areas are poorly known (Perry *et al.*, 1999) and feeding areas show

55   great 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 Tres Montes Gulf (46.2-48.0° S, 74.0-75.4° W) aboard the motor

117 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 2017 the hydrophones were deployed for 2 to 5

130   days in 3 locations. In these cases, hydrophones were deployed at a depth of 5 or 10

131   meters on rocky bottom with no more than 40 meters depth. Hydrophones were hold

132   on a row with an anchorage in the end and superficial buoys in the opposite side. In both

133   years, during the day or night, hydrophones were deployed at a depth of 5 and 10

134   meters from the stationary vessel. In the opportunistic recordings, recordings were

135   continuously, but in the night when the vessel was anchorage, the recordings were in

136   intervals between 10-30 minutes each hour for guarantee the capacity of the acoustic

137   personal to study the recording in the next day.

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

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

140   download in a portable computer.

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

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

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

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

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

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

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

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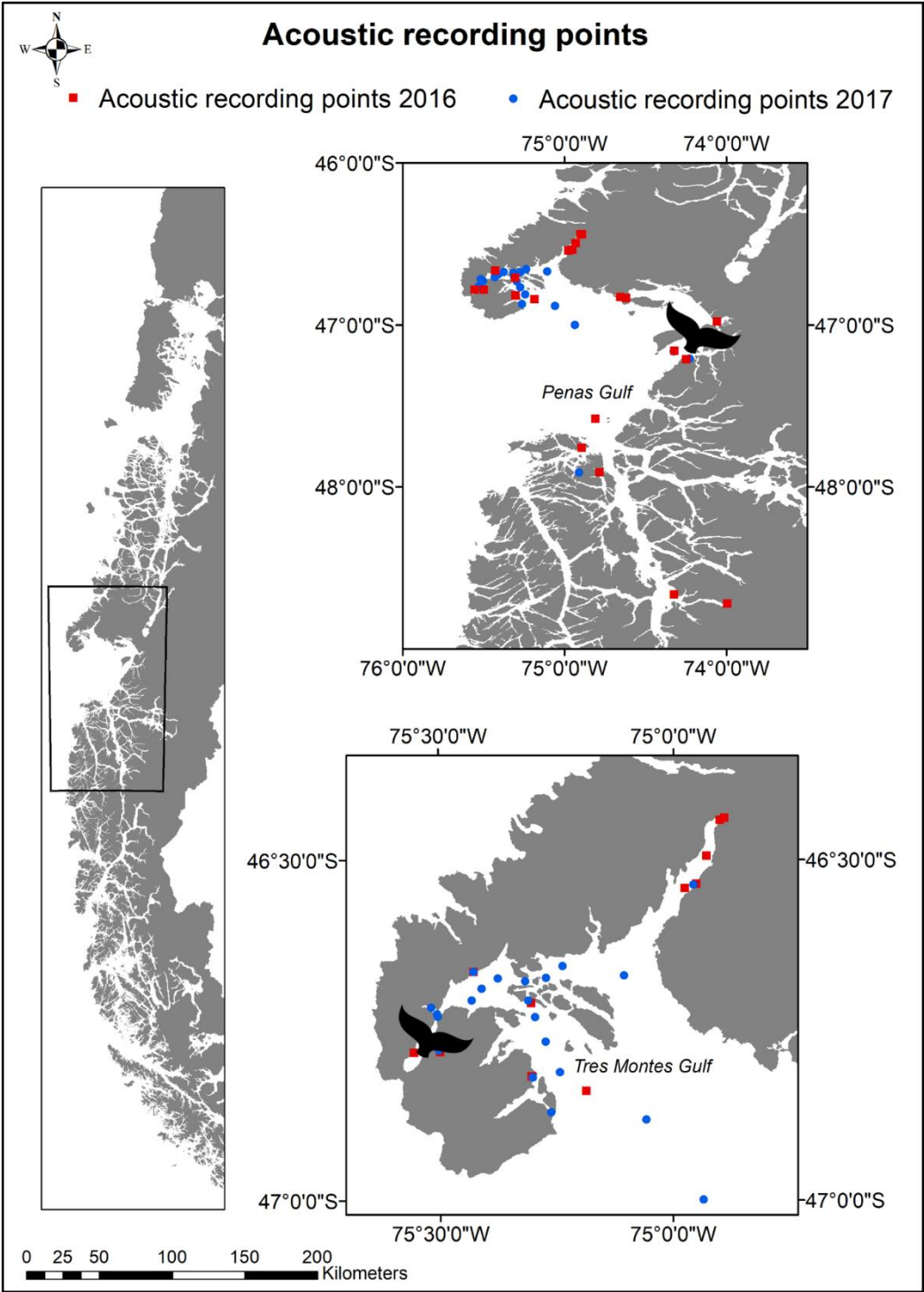
149   3. Results

150   Sei whales were sighted in both expeditions (2016 and 2017). In addition, during one

151   day in 2017, humpback whales were sighted. Sound was recorded during 16 days in 2016

152   and during 19 days in 2017. A total of 363 hours was recorded between both

153   expeditions, because the recordings were not continuous during every day, 136 hours

154   in 2016 and 227 hours in 2017. Sei whale calls were found in 8 archives for 3 days, on 7

155   May 2016 and 10-11 May 2017, at 2 different locations (one in 2016 and other in 2017)

156   (Table 1). In acoustic data from 2016, sei whale calls were detected when sei whales

157   were sighted closer the vessel (fig 02). In 2017, between May 8th and 10th, sei whales

158   were sighted in the area were after sei whale calls had been recorded (fig 02). Sei whale

159   calls from 2016 were only recorded around midday, while in 2017 they were recorded

160   in the late afternoon or at night (Table 1).

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173 Figure 02. Photographed sei whale at the Penas Gulf a) May 7th, 2016. Photo by: Katie
174 McConnell; b) May 10th, 2017. Photo by: Keri-Lee Pashuk.

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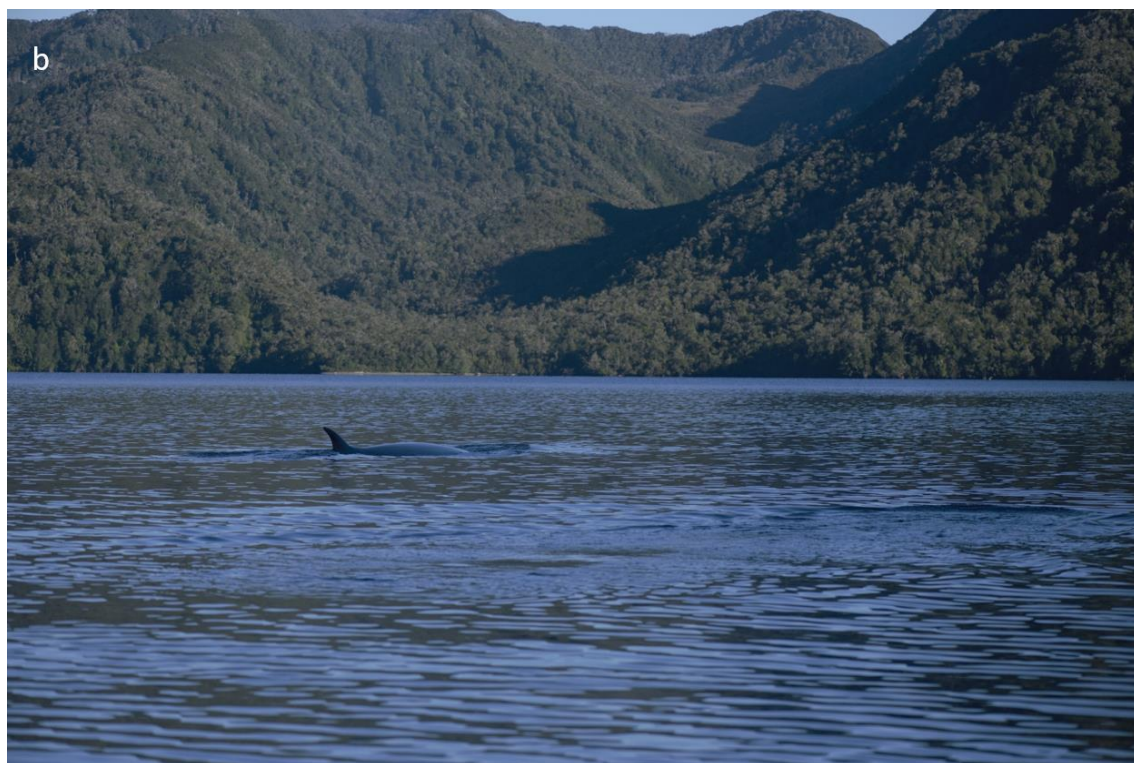
179   Table 1. Sei whale recordings at the Penas Gulf.

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Year	Date	Local Hour	Latitude	Longitude	Sampling rate	Hydrophone Deep (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	13	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	13	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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182   Only in two occasions humpback whale sounds above 2000 Hz were detected, in the rest

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

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

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

186   2016 and 36 in 2017. In 2016, calls ranged from an average maximum frequency of 105.3

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

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

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

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

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

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

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

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

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

196 15 seconds.

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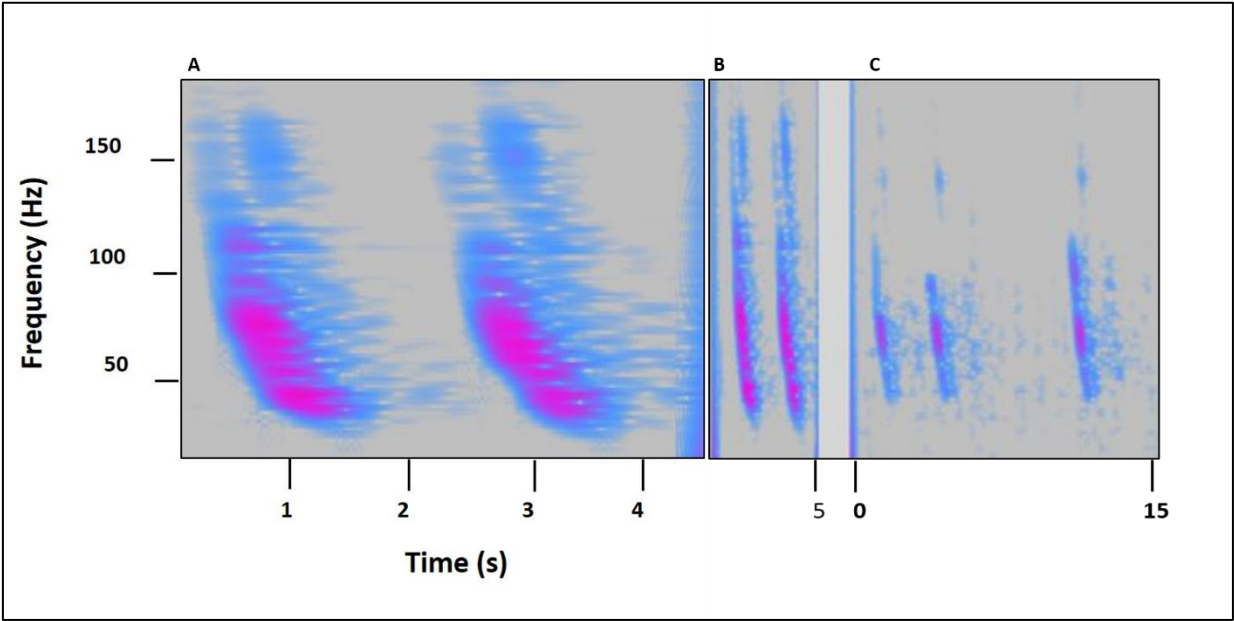
199   Table 2. Comparison of the frequency and timing of recorded calls in the present study

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

201   (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

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203   4. Discussion

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

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

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

207   Penas Gulf were produced by sei whales, due to the sightings of this species during the

208   recordings and the expeditions. Blue whales (*Balaenoptera musculus*), fin whale

209   (*Balaenoptera physalus*) or minke whales (*Balaenoptera acutorostrata*) produce

210   downsweep as well (Thompson *et al*., 1996; Schevill and Watkins, 1972; Watkins, 1981).

211   Bryde whales (*Balaenoptera brydei*) has also several call types, included downsweep,

212   but inhabit tropical and subtropical waters and we do not have any record in this area

213   yet (Omura, 1959; Wade and Gerrodette, 1993; Oleson, *et al*., 2003). Generally, fin

214   whales downsweep have initial frequencies below 35 Hz and final frequencies around

215   20-18 Hz (Watkins, 1981), similar than minke whales but with shorter durations (0.2-0.3

216   sec) and higher frequencies (130-60 Hz) (Schevill and Watkins, 1972). Minke whales in

217   the North Atlantic produce long pulse trains (Mellinger *et al*., 2000), these were not

218   recorded in this area, fin and minke whales downsweep are definitively different than

219   our recordings. Only downsweeps from blue whales described in Chile, through the

220   DTAG data, has a lower peak frequency and duration; low frequency is higher and

221   downsweep had been accompanied in the recorders by the Southeast Pacific type 2

222   (SEP2) (Saddler *et al*., 2017), supporting our results, that these records are really from

223   sei whales. In addition, sei whale vocalizations described here show very similar

224   characteristics to those described off Azores Islands by Romagosa *et al.* (2015), off New

225   England by Baumgartner *et al*. (2008) and off Hawaii by Rankin and Barlow (2007). In

226   these areas, sei whale vocalizations are characterized by low frequency downsweeps.

227   However, sei whales sweeps recorded off Nova Scotia by Thompson (1979) and

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

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

230   frequencies.

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

232   44 Hz and 39-21 Hz with durations of 1.0 s and 1.3 s, respectively. In the present study,

233   the minimum frequency was 30 Hz, being the average calls in the superior range defined

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

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

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

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

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

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

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

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

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

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

244   Pacific waters.

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

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

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

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

249   2008, Newhall *et al*., 2012, Romagosa *et al*., 2015).

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

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

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

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

254 populations, suggesting that different sei whale populations produce different

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

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

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

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

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

260 different population. The few calls obtained in both expeditions maybe was due the

261 duration of recorded in each site since they were opportunistic recordings, so visual

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

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

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

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

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

267 2018). However, low frequency sei whale downsweeps may have a different function

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

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

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

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

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

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

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

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

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

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

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

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

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

281 activities the whales were engaged in. Other factor could be important in the discussion

282 about the acoustic behavior is the background noise, which masking biological

283 important signals and impede the communications between individuals (Clark *et al.,*

284 2009).

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

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

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

288 unfavorable conservation status which require international agreements for their

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

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

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

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

293 hypotheses and improve our understanding of this species.

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