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. Recordings were done opportunistically. A total of 41 calls were identified to

20   be sei whale downsweeps. In 2016, calls ranged from an average maximum frequency

21   of 105.3 Hz down to an average minimum 35.6 Hz over 1.6 s with a peak frequency of

22   65.4 Hz. During 2017, calls ranged from an average maximum frequency of 93.3 Hz down

23   to 42.2 Hz (over 1.6 s) with a peak frequency of 68.3 Hz. The absolute minimum

24   frequency recorded was 30 Hz and the absolute maximum frequency was 129.4 Hz. Calls

25   generally occurred in pairs, but triplets or singles were also registered. These low

26   frequency sounds share characteristics with recordings of sei whales near the Hawaii

27   Islands, but with differences in the maximum frequencies and duration. These calls

28   distinctly differ from sounds previously described for sei whales in the Southern Ocean

29   and are the first documented sei whale calls in the 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) software.

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

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

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

146   in Raven Pro 1.5 (Hann window; 50% overlap; window size 14563 samples; DFT 16384

147   samples).

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

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

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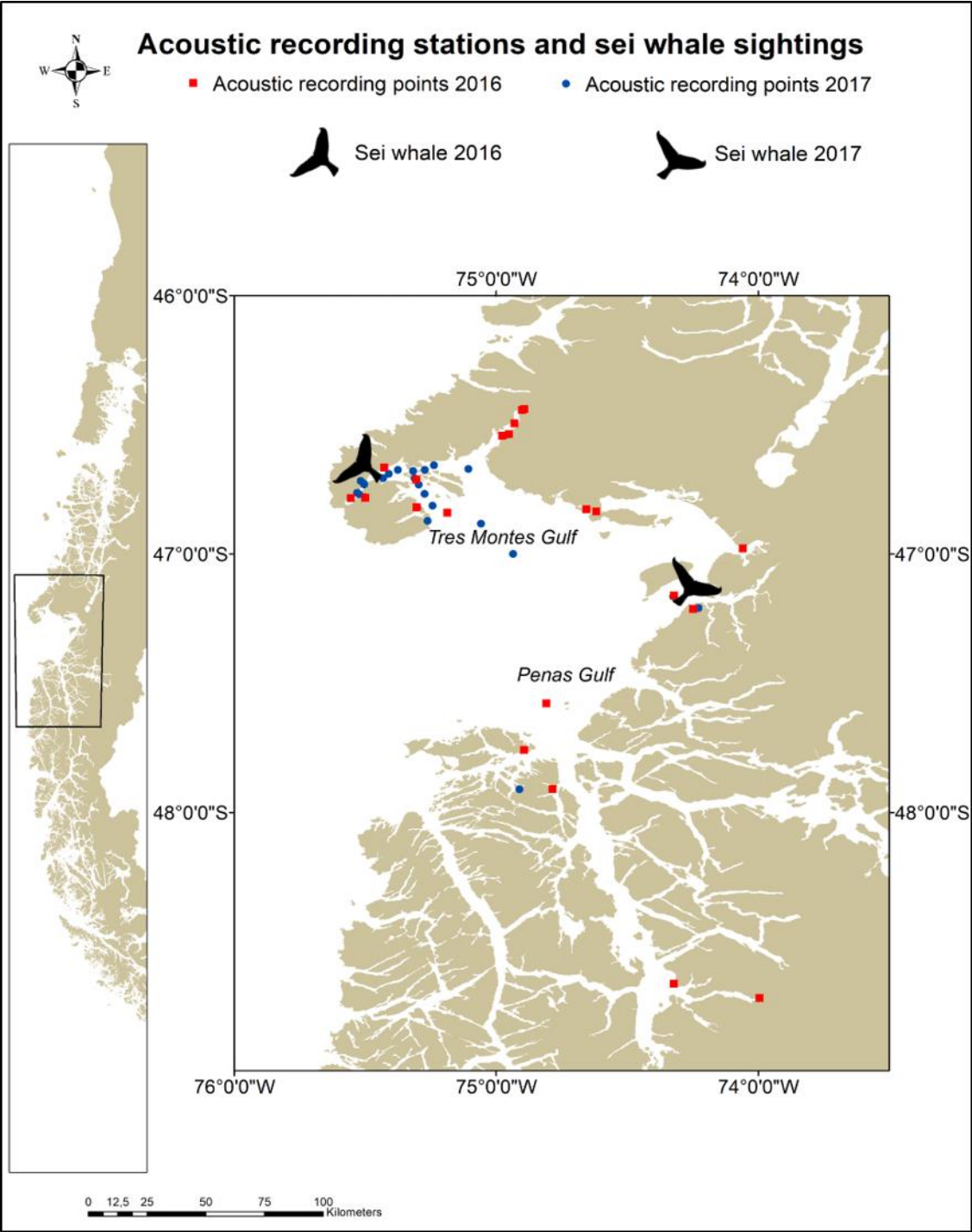
151   3. Results

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

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

154   in 23 opportunistic recordings locations and during 19 days in 24 locations in 2017. A

155   total of 363 hours was recorded between both expeditions, because the recordings were

156   not continuous during every day, 136 hours (63 archives) in 2016 and 227 hours (483

157   archives) in 2017. Recordings were not the same duration or the same sampling rate

158   because they were opportunistic. Sei whale calls were found in 8 archives for 3 days, on

159   7 May 2016 and 10-11 May 2017, at 2 different locations (one in 2016 and other in 2017)

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

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

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

163   2016 were only recorded around midday, while in 2017 they were recorded in the late

164   afternoon or at night (Table 1).

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

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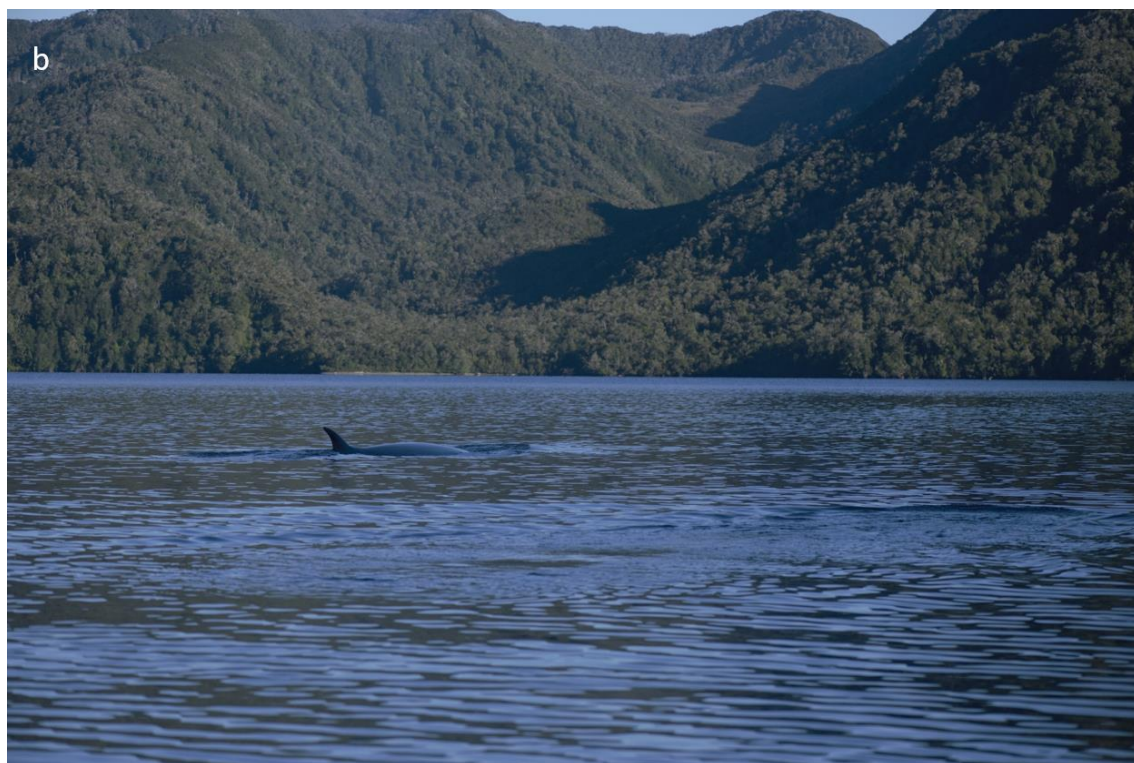
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181   Table 1. Sei whale recordings at Penas and Tres Montes Gulf.

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

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

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

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

188   2016 and 36 in 2017. In 2016, calls ranged from an average maximum frequency of 105.3

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

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

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

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

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

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

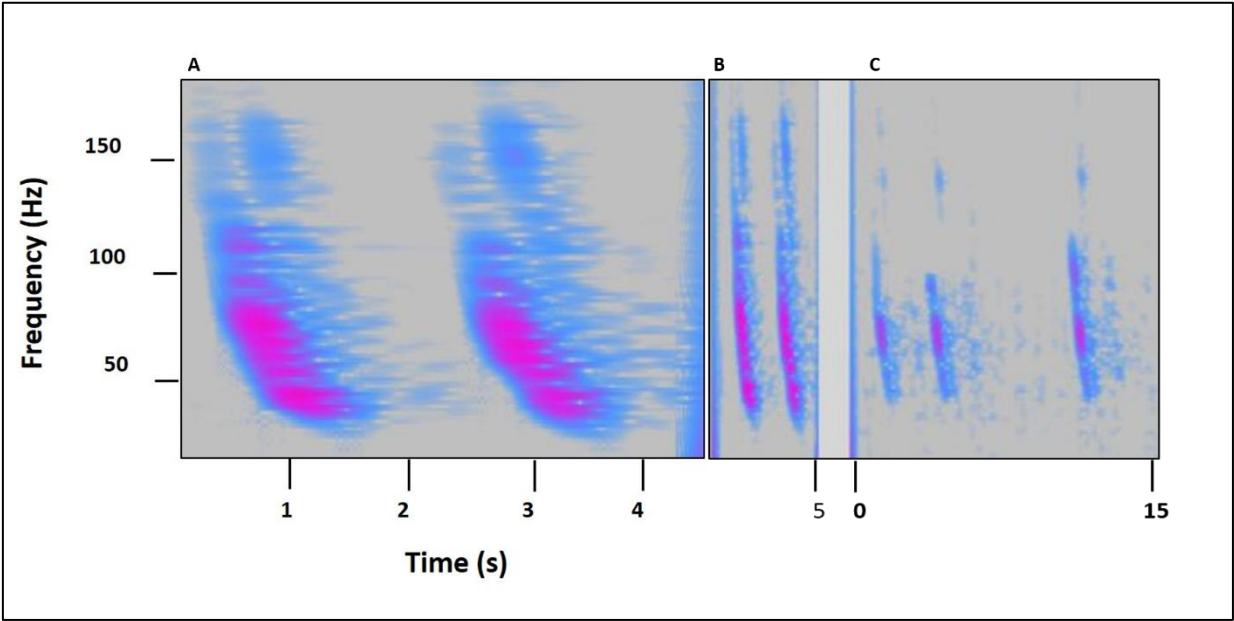
195   Figure 03. Spectrogram of sei whale vocalization recorded with the hydrophone (32768

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

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

198   15 seconds.

199

200

201 Table 2. Comparison of the frequency and timing of recorded calls of sei whales in the

202 present study with studies in other areas. Values are mean value ± standard deviation.

203 ND = no data (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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205   4. Discussion

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

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

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

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

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

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

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

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

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

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

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

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

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

219   1972). Minke whales in the North Atlantic produce long pulse trains (Mellinger *et al*.,

220   2000), these were not recorded in this area, fin and minke whales downsweep are

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

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

223   frequency of blue whales is higher than that in our results and downsweep had been

224   accompanied by the Southeast Pacific signal type 2 (SEP2) (Saddler *et al*., 2017),

225   supporting our results, that our records are really from sei whales. In addition, sei whale

226   vocalizations described here show very similar characteristics to those described off

227   Azores Islands by Romagosa *et al.* (2015), off New England by Baumgartner *et al*. (2008)

228   and off Hawaii by Rankin and Barlow (2007). In these areas, sei whale vocalizations are

229 characterized by low frequency downsweeps. However, sei whales sweeps recorded off

230 Nova Scotia by Thompson (1979) and Knowlton et al. (1991) or in Antarctic waters by

231 McDonald (2005), Gedamke and Robinson (2010) are different from our recording and

232 are characterize by higher frequencies.

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

234 44 Hz and 39-21 Hz with durations of 1.0 s and 1.3 s, respectively. In the present study,

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

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

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

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

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

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

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

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

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

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

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

246 Pacific waters.

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

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

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

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

251 2008, Newhall *et al*., 2012, Romagosa *et al*., 2015).

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

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

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

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

256 populations, suggesting that different sei whale populations produce different

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

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

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

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

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

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

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

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

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

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

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

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

269 2018). However, low frequency sei whale downsweeps may have a different function

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

285 biologically important signals and impede the communications between individuals

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

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

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

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

290 unfavorable conservation status which require international agreements for their

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

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

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

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

295 hypotheses and improve our understanding of this species.

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