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Clicks of wild Burmeister's porpoises (*Phocoena spinipinnis*) in Tierra del Fuego, Argentina

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The Burmeister's porpoise, *Phocoena spinipinnis*, is one of the seven species of Phocoenidae described to date (Committee on Taxonomy 2016). Endemic to South America, it inhabits coastal waters from North Peru (05°01'S) on the Pacific coast to South Brazil (28°48'S) on the Atlantic coast, with Cape Horn (56°S) being the southernmost limit of its distribution (Brownell and Praderi 1982, 1984; Goodall *et al.* 1995a; Brownell and Clapham 1999; Reyes and Van Waerebeek 1995; Molina-Schiller *et al.* 2005). Although the species is mainly coastal (Goodall *et al.* 1995b), it has been recorded occasionally in offshore waters (Goodall *et al.* 1995b, Brownell and Clapham 1999) and is frequently found in bays, narrow fjords, and river mouths (Aguayo 1975, Goodall *et al.* 1995b).

In Tierra del Fuego, Argentina, the occurrence of these porpoises was reported (by stranding and sightings) both, on the Atlantic coast and in the Beagle Channel.

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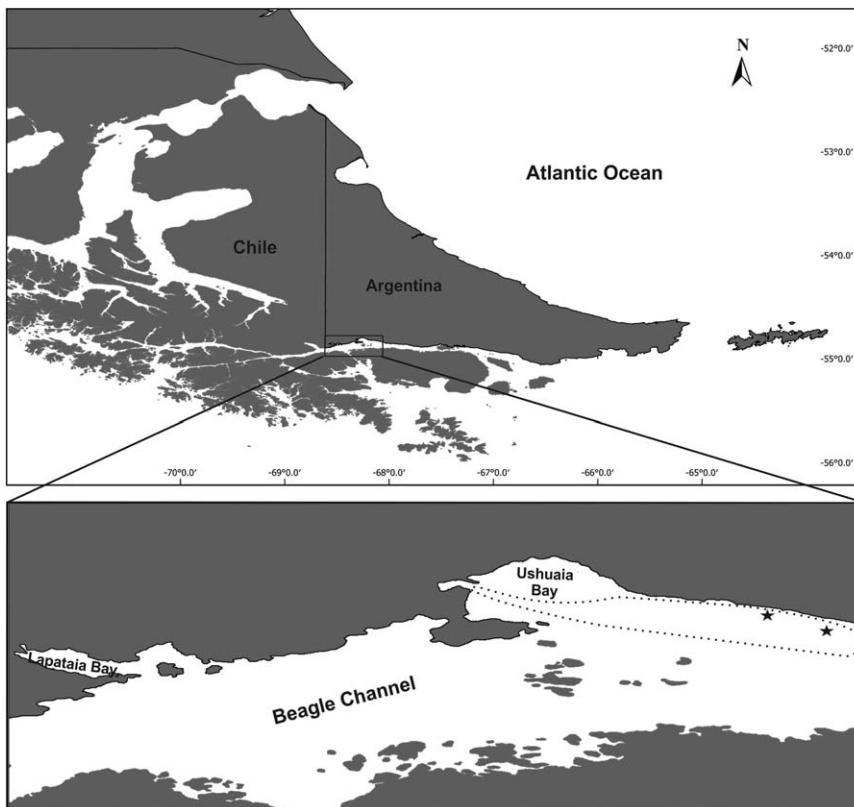


Figure 1. Map depicting Tierra del Fuego and zoomed in the Beagle Channel. The two black stars represent the two sites in which Burmeister's porpoises were recorded. Dashed line indicates search area.

In Lapataia and Ushuaia bays (Fig. 1) several sightings have been recorded year-round since the 1990s, indicating a resident group in the Beagle Channel (Goodall *et al.* 1995b, Tezanos Pintos *et al.* 2000). Although very common in this area, rough weather precludes their sightings (Beaufort scale ≥ 2). Their undisturbed swimming behavior, the long, fast, and erratic submersions, and the low dorsal fin make it difficult to see them especially in poor weather conditions (Goodall *et al.* 1995b, Tezanos Pintos *et al.* 2000).

During the last decade, passive acoustics has become a powerful tool to detect and monitor cetaceans (Moore *et al.* 2006, Mellinger *et al.* 2007, Gallus *et al.* 2012, Jaramillo-Legorreta *et al.* 2016). Acoustic data can be obtained using dropped and/or towed hydrophones, as well as autonomous recording packages. With the latter it is possible to continue recording at night or in poor weather. In addition, this method often offers a larger detection range compared to visual surveys (Akamatsu *et al.* 2001, Barlow and Taylor 2005). The advantages become even more important in species that are difficult to spot or are critically endangered (Rojas-Bracho *et al.* 2006; Rayment *et al.* 2009, 2011; Gallus *et al.* 2012; Jaramillo-Legorreta *et al.* 2016). The fact that Burmeister's porpoise is listed as "Data Deficient" by the

IUCN due to the lack of information about population sizes and trends (Hammond *et al.* 2012) makes it an important species to be monitored by passive acoustics to determine its conservation status. In this context, the goal of this study is to characterize the clicks of wild Burmeister's porpoises recorded in a resident population in the Beagle Channel, Argentina.

Sounds of some species of phocoenids such as Indo-Pacific finless porpoise, *Neophocaena phocaenoides* (Kamminga *et al.* 1986, Li *et al.* 2007), Dall's porpoise, *Phocoenoides dalli* (Basset *et al.* 2009, Kyhn *et al.* 2013), harbor porpoise, *Phocoena phocoena* (Villadsgaard *et al.* 2007, Kyhn *et al.* 2013), and vaquita, *Phocoena sinus* (Silber 1991) have been described in the wild previously. The acoustic signals of all these species consisted of narrow band high-frequency (NBHF) clicks. These clicks are normally defined by a peak frequency over 120 kHz with no spectral energy below 100 kHz, long durations with a high number of oscillations and a half-power (-3 dB) bandwidth around 15 kHz (Madsen *et al.* 2005, Kyhn *et al.* 2010). Other species known to produce such clicks include members of the genus *Cephalorhynchus* and two species of the genus *Lagenorhynchus* (*australis* and *cruciger*) (Kyhn *et al.* 2009, 2010; Götz *et al.* 2010; Morisaka *et al.* 2011; Reyes Reyes *et al.* 2015), the pygmy sperm whale, *Kogia breviceps* (Madsen *et al.* 2005), and the franciscana, *Pontoporia blainvillei* (Melcón *et al.* 2012). However, no information on sounds produced by Burmeister's porpoise is available to date.

Acoustic recordings of Burmeister's porpoises were made on 2–3 January 2017 in the Beagle Channel, Tierra del Fuego, Argentina (Fig. 1). The recording device consisted of an omnidirectional hydrophone Reson TC-4033 (Teledyne RESON Inc., Thousand Oaks, CA; <http://www.teledyne-reson.com/product/tc-4033/>), and a custom-built preamplifier. All components were embedded in a polyurethane tube filled with mineral oil, which matches the acoustic impedance of the sensors with that of seawater. Signals were digitized with a resolution of 16-bits and 500 kHz sample rate using an Avisoft Ultrasound-Gate USB 116 (Avisoft Bioacoustics e.K., Glienicke/Nordbahn, Germany). Field work was done with a semirigid boat and each time the animals were sighted, the engine was turned off and the hydrophone deployed into the water to a maximum depth of 10 m. Recordings were made under calm sea state (Beaufort scale <2), and at depths between 50 m and 70 m. No other cetaceans were sighted nor acoustically detected at any time during the field work.

Spectrograms and waveforms of the sound files were visually scanned using the Matlab-based (Mathworks, Natick, MA) custom software Triton (Wiggins and Hildebrand 2007), and the occurrence of click trains was logged. The inverse of the transfer function of the hydrophone and preamplifier was applied to correct the received levels according to the sensitivity. After manual inspection of other types of vocalizations, the presence of click trains were logged and then a semiautomatic detector was used to detect and extract NBHF clicks with signal-to-noise ratio (SNR) equal or higher than 20 dB as described in Reyes Reyes *et al.* 2015. Less than 1% of the detections were false positives, *i.e.*, were classified as a NBHF click but the signal was not actually a click. The spectral characteristics of clicks were quantified for the 300 μ s following the start of each click by calculating a 256-point fast Fourier transform (FFT), rectangular window, and a fourth-order Butterworth band-pass filter between 20 kHz to eliminate the low frequency noise and 240 kHz. For each click, the following parameters were calculated according to Au (1993): peak frequency, centroid frequency (defined as the frequency dividing the spectrum in two halves of equal energy), -10 dB bandwidth (defined as the bandwidth at 10 dB points below the maximum intensity), -3 dB bandwidth (defined as the

bandwidth at 3 dB points below the maximum intensity), $Q_{-3\text{dB}}$ (defined as the centroid frequency divided by the -3 dB bandwidth), and 10 dB duration (defined as time differences between the end points that were 10 dB lower than the peak amplitude of the envelope of the pulse waveform). The signal envelope was generated by taking the absolute value of the waveform after applying the Hilbert transform function (Au 1993, Madsen and Wahlberg 2007). Since the signals had all their energy above 100 kHz, a bandpass filter between 100 kHz and 240 kHz was used to calculate the centroid frequency. Interclick interval (ICI) was calculated as the difference between the start time of a click and the start time of the previous one. Because of the skewed distribution of the data, the median of each parameter with the quartile deviation (QD, defined as the difference between percentile 75th and 25th divided by two) and percentiles 10th (P10) and 90th (P90) are reported within the text as median \pm QD [P10 P90]. However, for comparison purposes, the mean \pm standard deviation and the range are reported in Tables 1 and 2. All analyses and signal processing were performed with custom-written scripts in Matlab.

Vocalizations from Burmeister's porpoises were recorded on two days. On the first day of recordings, porpoises were observed four times (three sightings of single individuals, and one of a group of four individuals), whereas on the second day only one group of five animals was sighted. A total of 163 min of acoustic recordings was obtained, out of which 35 min contained click trains (Fig. 2) produced by the porpoises.

Manual inspection of the time series and spectrograms did not provide any indication of other acoustic signals in the frequency range recorded other than NBHF clicks in presence of Burmeister's porpoises. A total of 481 clicks were extracted and analyzed in this study. The time series of a representative click and median spectrum of all the analyzed clicks is depicted in Figure 3. Clicks were NBHF with a median -3 dB and -10 dB bandwidth of 8 ± 0 [6 10] kHz and 14 ± 4 [10 21] kHz, respectively, and a 10 dB duration of 133 ± 2 [131 162] μs . The signals had a median centroid frequency at 144 ± 5 [138 157] kHz, and peak frequency at 135 ± 2 [133 164] kHz, with a subdominant peak frequency around 170–180 kHz. The median $Q_{-3\text{dB}}$ was 21 ± 2 [16 28].

Clicks were emitted with a median ICI of 51 ± 26 [34 114] ms (Fig. 4). Also, trains of burst pulses consisting of series of NBHF clicks with very short ICIs (<5 ms) were recorded. Given the very low SNR, these burst pulses were excluded from further analysis.

The present study represents the first published characterization of sounds produced by Burmeister's porpoises. This species produces NBHF clicks as all the other members of the Phocoenidae family, the exception being the spectacled porpoise (*Phocoena dioptrica*), whose acoustic repertoire remains unknown. Predation pressure from killer whales (*Orcinus orca*) is considered one of the main factors that has driven convergent evolution of NBHF clicks in porpoises, some small coastal dolphins and the pygmy sperm whale (Madsen *et al.* 2005, Morisaka and Connor 2007). These signals have no energy below 100 kHz, which is the upper limit of audition of killer whales (Szymanski *et al.* 1999, Branstetter *et al.* 2017). Except for the species of the genus *Neophocaena*, which produce clicks with lower peak frequency and lower $Q_{-3\text{dB}}$ value, the remaining species of porpoises produce signals rather similar (Table 1). However, slight differences can be found among different species or even between different populations of the same species related to habitat (Kyhn *et al.* 2009) or character displacement in sympatric species (Kyhn *et al.* 2013). Kyhn *et al.* (2013) compared click parameters for Dall's porpoises in British Columbia, and two

Table 1. Descriptive statistics of NBHF clicks from Burmeister's porpoises analyzed in this study, compared to clicks previously described from other porpoises. Values are given as mean \pm SD and [range].

Species	<i>P. spinipinnis</i> (British Columbia) ^a	<i>P. phocaena</i> (Denmark)	<i>P. sinus</i> ^c	<i>P. dalli</i> ^a	<i>N. a. asiatoorientalis</i> (Yangtze River) ^d	<i>N. a. samameri</i>
Peak frequency (kHz)	138 \pm 11 [129–186]	137 \pm 6 [112–145] ^a	133 \pm 4 [128–139]	137 \pm 4 [119–143]	125 \pm 7 [87–145]	121 \pm 4 [113–131] ^d
Centroid frequency (kHz)	146 \pm 8 [134–178]	136 \pm 3 [126–144] ^a	—	137 \pm 3 [121–147]	—	—
–3 dB bandwidth (kHz)	8 \pm 2 [6–27]	17 \pm 5 [5–36] ^a	17 \pm 5 [11–28] ^c	11 \pm 5 [3–23]	20 \pm 4 [9–42]	18 \pm 3 [11–25] ^d
Q _{–3dB}	21 \pm 5 [6–34]	9 \pm 3 [3–30] ^a	—	15 \pm 8 [6–45]	7 \pm 2 [3–13]	7 \pm 1 [5–11] ^d
10 dB duration (μ s)	144 \pm 64 [40–286]	54 \pm 8 [35–98] ^a	136 \pm 41 [79–193]*	104 \pm 37 [53–251]	—	[40–80] ^c
ICI (ms)	66 \pm 39 [26–238]	[30 –200] ^b	103 \pm 23 [19–144]	—	—	—

*Represents 20 dB duration.

^aFrom Khyn *et al.* (2013).

^bFrom Villadsgaard *et al.* (2007).

^cSilber (1991). It is unknown how the bandwidth and duration were measured.

^dFrom Li *et al.* (2007).

^eFrom Kamminga *et al.* (1986). It is unknown how the duration was measured.

Table 2. Descriptive statistics of clicks from NBHF species distributed in the south coast of Argentina and Chile. Values are given in the format: mean \pm SD [range].

Species	<i>P. spinipectus</i>	<i>C. commersoni</i> ^{a,b}	<i>L. australis</i> ^{b,c}	<i>L. cruceger</i> ^d	<i>C. entropia</i> ^e
<i>n</i>	481	3,180	2,101	58	83
Peak frequency (kHz)	138 \pm 11 [129–186]	137 \pm 14 [116–208]	154 \pm 36 [110–241]	126 \pm 2 [122–131]	127 \pm 4
Centroid frequency (kHz)	146 \pm 8 [134–178]	143 \pm 10 [130–188]	146 \pm 15 [122–192]	129 \pm 3 [124–132]	126 \pm 2
–3 dB bandwidth (kHz)	8 \pm 2 [6–27]	7 \pm 3 [3–26]	9 \pm 4 [2–27]	15 \pm 4 [9–34]	18 \pm 5
–10 dB bandwidth (kHz)	9 \pm 6 [1–25]	23 \pm 8 [5–50]	21 \pm 11 [5–82]	17 \pm 4 [12–25]	8 \pm 3
Q_{-3dB}	21 \pm 5 [6–34]	12 \pm 5 [4–48]	18 \pm 7 [5–68]	13 \pm 2 [9–18]	34 \pm 8
10 dB duration (μ s)	144 \pm 64 [40–286]	95 \pm 48 [10–290]	57 \pm 33 [8–196]	115 \pm 24 [79–176]	83 \pm 30*

*Represents 20 dB duration.

^aFrom data published in Reyes Reyes *et al.* (2015) (left).

^bKyhn *et al.* (2010) (right).

^cMarino *et al.*, unpublished data (left).

^dKyhn *et al.* (2009).

^eGötz *et al.* (2010) (*20 dB duration).

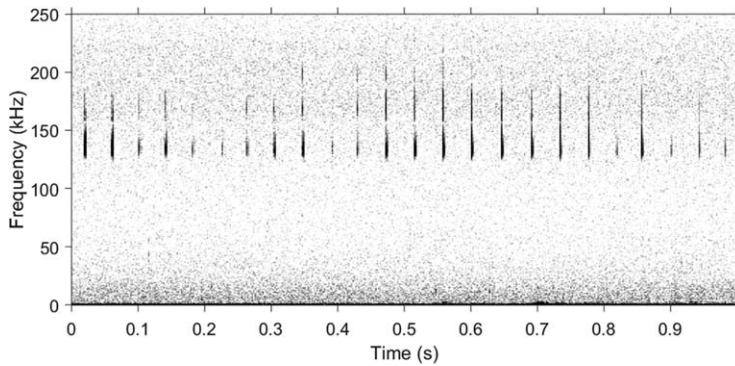


Figure 2. Spectrogram of a representative click train of a Burmeister's porpoise swimming freely in the Beagle Channel (1,024-point FFT, 0% overlap, 0.5 kHz frequency resolution, 0.002 s time resolution).

populations of harbor porpoises, one from British Columbia, and the other from Denmark. They found acoustic differences between the two sympatric NBHF species sharing the same habitat in British Columbia, and also acoustic differences between the clicks of the same NBHF species recorded in two different habitats.

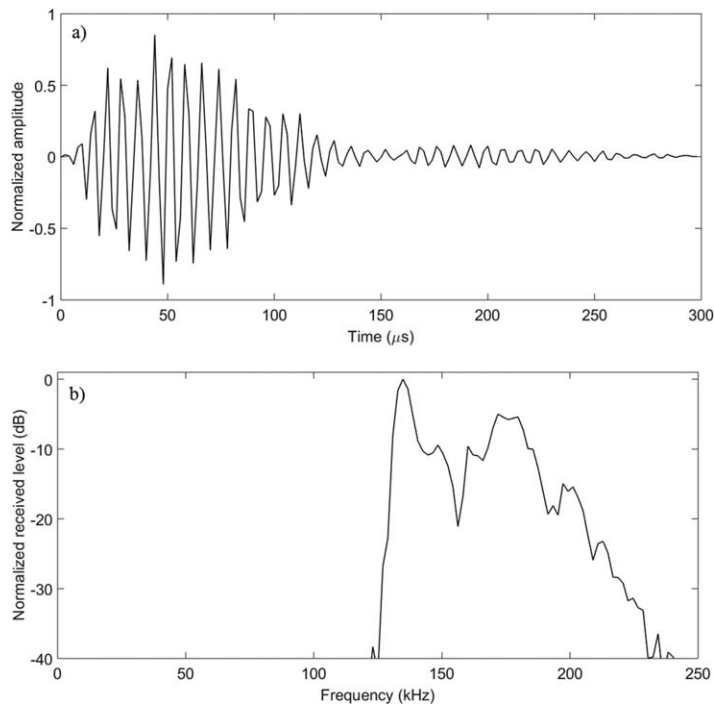


Figure 3. (a) Normalized time series of a representative click. (b) Normalized median spectrum of all clicks analyzed (20–240 kHz bandpass filter, 256-point FFT, 500 kHz sampling frequency, rectangular window, 2 kHz frequency resolution).

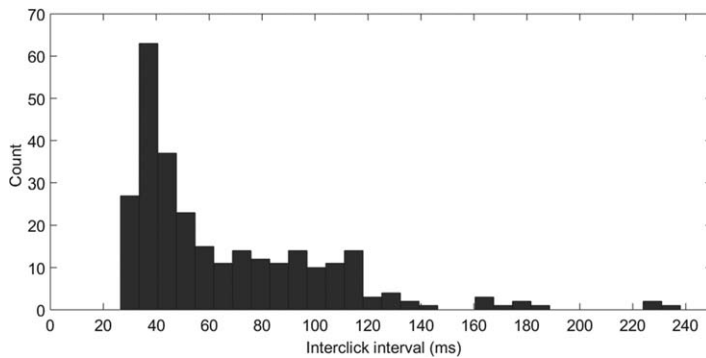


Figure 4. Histogram of interclick interval (ms) of 282 clicks recorded from Burmeister's porpoises in the Beagle Channel. Clicks were emitted with a median ICI of 51 ± 26 ms.

Table 1 shows that Burmeister's, Dall's, vaquita, and harbor porpoises all produce clicks with similar peak frequencies. Centroid frequency of Burmeister's porpoises' clicks was more similar to that of harbor porpoises in British Columbia with respect to the other species of porpoises (Table 1). They also share similar -3 dB bandwidth and $Q_{-3\text{dB}}$ values. As occurs in British Columbia with marine mammal-eating killer whales, in the Beagle Channel killer whales have been registered feeding on marine mammals (Goodall *et al.* 2007), thus Burmeister's porpoises might also obtain acoustic crypsis by producing NBHF clicks that cannot be heard by killer whales.

Because of uncertainties in the position of the animals relative to the hydrophone, it was not possible to estimate source levels of the clicks. The use of a single hydrophone restrained distinction between on- and off-axis clicks. NBHF clicks are highly directional signals and suffer distortions in the temporal and spectral domain as the angle with respect to the animal's head increases (Au 1993). Thus, as in this study clicks from different angles were pulled together for the analysis, this could explain the higher ranges observed in the parameters estimated for Burmeister's porpoises' clicks and higher duration with comparison to other species of porpoises (Table 1).

A secondary peak at high frequencies had been reported before for captive Commerson's dolphins, *Cephalorhynchus commersonii*, and finless porpoises (Kamminga and Wiersma 1982, Kamminga *et al.* 1986), and wild Commerson's dolphins in Santa Cruz province, Argentina (Reyes Reyes *et al.* 2015). For wild Commerson's dolphins, the authors described three clusters of clicks based on their peak frequency and -3 dB bandwidth. One of the clusters comprised a small proportion of clicks which were described with a median peak frequency at 173 kHz. In this study, we also observed that a few clicks of Burmeister's porpoises had the peak frequency higher than 160 kHz (Fig. 5).

More recordings with a higher SNR would be necessary to characterize temporal and spectral parameters of burst pulses produced by the species, as well as to analyze whether this species produces different sounds under different behavioral contexts.

Given the average wind speed within the Beagle Channel of about 30 km/h (Balestrini *et al.* 1998) and the cryptic behavior of this species, passive acoustic monitoring is potentially useful not only to improve the knowledge of its occurrence in

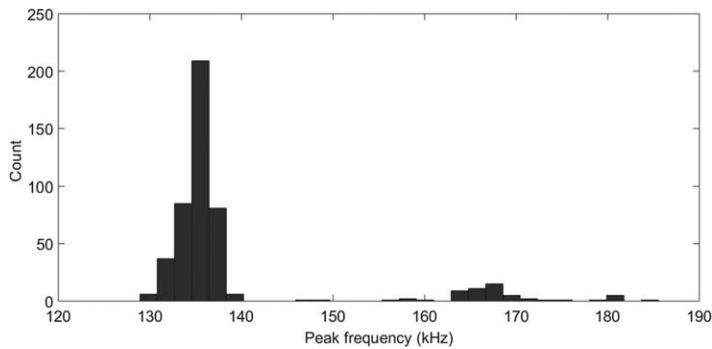


Figure 5. Histogram of peak frequencies of 481 clicks recorded from Burmeister's porpoises in the Beagle Channel. Median peak frequency was at 135 ± 2 kHz, with a few clicks showing peak frequencies higher than 160 kHz.

the area but also to assess abundance estimates in different populations of South America. Many NBHF species can be found along the Southern coast of Argentina and Chile, such as Commerson's dolphins, Chilean dolphins, *Cephalorhynchus eutropia*, Peale's dolphins, *Lagenorhynchus australis*, hourglass dolphins, *L. cruciger*, and Burmeister's porpoises (Aguayo-Lobo *et al.* 1998; Goodall *et al.* 2008; Dellabianca *et al.* 2012, 2016). The spectacled porpoise is also distributed in these areas (Goodall 2008, Goodall *et al.* 2008) and it is expected to produce NBHF clicks as every other species of porpoises. This poses a big challenge given the similarities found between the sounds produced by these species (Table 2). Most of the advantages offered by passive acoustics are diminished if the discrimination of their acoustic signals is not accurately achieved. Some authors observed that slight differences can be found among the centroid frequencies in clicks produced by Peale's and Commerson's dolphins (Kyhn *et al.* 2010) and between Dall's porpoises, British Columbia harbor porpoises, and Danish harbor porpoises (Kyhn *et al.* 2009). This criterion allowed the classification of these NBHF species with a high level of confidence. As shown in Table 2 and stated by Kyhn and colleagues (2009, 2010), although NBHF clicks are highly stereotyped, small differences between source parameters can be used to classify acoustic signals of the mentioned species. However, further research is needed to provide a more detailed characterization of the signals and establish ground knowledge for future application of passive acoustic monitoring of sympatric NBHF species. Incorporating other parameters as well as implementing dataloggers with sufficient frequency resolution could serve to resolve small differences among these signals. However, an appropriate characterization of the acoustic signals is the first step to applying passive acoustic methods to increase the knowledge about Burmeister's porpoises and their conservation status.

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LITERATURE CITED

- Aguayo, A. 1975. Progress report on small cetacean research in Chile. *Journal of the Fisheries Board of Canada* 32:1123–1143.
- Aguayo-Lobo, A., D. Torres and J. Acevedo. 1998. Los mamíferos marinos de Chile: I. Cetacea [Marine mammals of Chile: I. Cetacea]. *Serie Científica INACH* 48:19–159.
- Akamatsu, T., D. Wang, K. Wang and Z. Wei. 2001. Comparison between visual and passive acoustic detection of finless porpoises in the Yangtze River, China. *Journal of the Acoustical Society of America* 109:1723–1727.
- Au, W. W. L. 1993. *The sonar of dolphins*. Springer-Verlag, New York, NY.
- Balestrini, C., G. Manzella and G. A. Lovrich. 1998. Simulación de corrientes en el Canal Beagle y Bahía Ushuaia, mediante un modelo bidimensional, [Simulation of currents within the Beagle Channel and Ushuaia Bay, through a two-dimensional model]. *Servicio de Hidrografía Naval, Departamento de Oceanografía, Informe Técnico* 98. 58 pp.
- Bassett, H. R., S. Baumann, G. S. Campbell, S. M. Wiggins and J. A. Hildebrand. 2009. Dall's porpoise (*Phocoenoides dalli*) echolocation click spectral structure. *Journal of the Acoustical Society of America* 125:2677.
- Barlow, J., and B. L. Taylor 2005. Estimates of sperm whale abundance in the Northeastern temperate Pacific from a combined acoustic and visual survey. *Marine Mammal Science* 21:429–445.
- Branstetter, B. K., J. St. Leger, D. Acton, J. Stewart, D. Houser, J. J. Finneran and K. Jenkins. 2017. Killer whale (*Orcinus orca*) behavioral audiograms. *Journal of the Acoustical Society of America* 141:2387–2398.
- Brownell, R. L., Jr., and R. Praderi. 1984. *Phocoena spinipinnis*. *Mammalian Species* 217:1–4.
- Brownell, R. L., Jr., and P. J. Clapham. 1999. Burmeister's porpoise *Phocoena spinipinnis*, Burmeister 1865. Pages 393–410 in S. H. Ridgway and R. Harrison, eds. *Handbook of marine mammals*. Volume 5. The second book of dolphins and the porpoises. Academic Press, London, U.K.
- Committee on Taxonomy. 2016. List of marine mammal species and subspecies. Society for Marine Mammalogy. Available at <http://www.marinemammalscience.org>, consulted on 7 July 2017.
- Dellabianca, N., G. Scioscia, A. Schiavini and A. Raya Rey. 2012. Occurrence of hourglass dolphin (*Lagenorhynchus cruciger*) and habitat characteristics along the Patagonian Shelf and the Atlantic Ocean sector of the Southern Ocean. *Polar Biology* 35:1921–1927.
- Dellabianca, N. A., G. J. Pierce, A. Raya Rey, *et al.* 2016. Spatial models of abundance and habitat preferences of Commerson's and Peale's dolphin in southern Patagonian waters. *PLOS ONE* 11(10):e0163441.
- Gallus, A., M. Dähne, U. K. Verfuß, S. Bräger, S. Adler, U. Siebert and H. Benke. 2012. Use of static passive acoustic monitoring to assess the status of the 'Critically Endangered' Baltic harbour porpoise in German waters. *Endangered Species Research* 18: 265–278.
- Goodall, R. N. P. 2008. Spectacled porpoise *Phocoena dioptrica*. Pages 1158–1161 in W. F. Perrin, B. Würsig and J. G. M. Thewissen, eds. *Encyclopedia of marine mammals*. Academic Press, San Diego, CA.
- Goodall, R. N. P., K. S. Norris, G. Harris, J. A. Oporto and H. P. Castello. 1995a. Notes on the biology of the Burmeister's porpoise, *Phocoena spinipinnis*, off southern South America. *Report of the International Whaling Commission (Special Issue 16)*:317–347.
- Goodall, R. N. P., B. Würsig, M. Würsig, G. Harris and K. S. Norris. 1995b. Sightings of Burmeister's porpoise, *Phocoena spinipinnis*, off southern South America. *Report of the International Whaling Commission (Special Issue 16)*:297–316.
- Goodall, R. N. P., C. C. Boy and A. C. M. Schiavini. 2007. Historical and modern records of cetacean self-stranding to escape from killer whale. Paper SC/59/SM17 presented to the IWC Scientific Committee, 2007. 19 pp.
- Goodall, R. N. P., N. Dellabianca, C. C. Boy, L. G. Benegas, L. E. Pimper and L. Ricciardelli. 2008. Review of small cetaceans stranded or incidentally captured on the

- coasts of Tierra del Fuego, Argentina, over 33 years. Paper SC/60/SM21 presented to the IWC Scientific Committee, 2008. 13 pp.
- Götz, T., R. Antunes and S. Heinrich. 2010. Echolocation clicks of free-ranging Chilean dolphins (*Cephalorhynchus eutropia*). *Journal of the Acoustical Society of America* 128: 563–566.
- Hammond, P. S., G. Bearzi, A. Bjørge, *et al.* 2012. *Phocoena spinipinnis*. The IUCN Red List of Threatened Species 2012: e.T17029A17117957.
- Jaramillo-Legorreta, A., G Cardenas-Hinojosa, E. Nieto-Garcia, *et al.* 2016. Passive acoustic monitoring of the decline of Mexico's critically endangered vaquita. *Conservation Biology* 31:183–191.
- Kamminga, C., and H. Wiersma. 1982. Investigations on cetacean sonar. V. The true nature of the sonar sound of *Cephalorhynchus commersonii*. *Aquatic Mammals* 9:95–104.
- Kamminga, C., T. Kataoka and F. J. Engelsma. 1986. Investigations on cetacean sonar. Underwater sounds of *Neophocaena phocaenoides* of the Japanese coastal population. *Aquatic Mammals* 12:52–60.
- Kyhn, L. A., J. Tougaard, F. Jensen, *et al.* 2009. Feeding at a high pitch: Source parameters of narrow band, high-frequency clicks from echolocating off-shore hourglass dolphins and coastal Hector's dolphins. *Journal of the Acoustical Society of America* 125:1783–1791.
- Kyhn, L. A., F. H. Jensen, K. Beedholm, J. Tougaard, M. Hansen and P. T. Madsen. 2010. Echolocation in sympatric Peale's dolphins (*Lagenorhynchus australis*) and Commerson's dolphins (*Cephalorhynchus commersonii*) producing narrow-band high-frequency clicks. *Journal of Experimental Biology* 213:1940–1949.
- Kyhn, L. A., J. Tougaard, K. Beedholm, F. H. Jensen, E. Ashe, R. Williams and P. T. Madsen. 2013. Clicking in a killer whale habitat: Narrow-band, high-frequency biosonar clicks of harbour porpoise (*Phocoena phocoena*) and Dall's porpoise (*Phocoenoides dalli*). *PLOS ONE* 8(5):e63763.
- Li, S., D. Wang, K. Wang, T. Akamatsu, M. Ma and J. Han. 2007. Echolocation click sounds from wild inshore finless porpoise (*Neophocaena phocaenoides sunameri*) with comparisons to the sonar of riverine *N. p. asiaorientalis*. *Journal of the Acoustical Society of America* 121:3938–3946.
- Madsen, P. T., and M. Wahlberg. 2007. Recording and quantification of ultrasonic echolocation clicks from free-ranging toothed whales. *Deep-Sea Research Part I: Oceanographic Research Papers* 54:1421–1444.
- Madsen, P. T., D. A. Carder, K. Bedholm and S. H. Ridgway. 2005. Porpoise clicks from a sperm whale nose—convergent evolution of 130 kHz pulses in toothed whale sonars? *Bioacoustics* 15:195–206.
- Melcón, M. L., M. Failla and M. A. Iníiguez. 2012. Echolocation behavior of franciscana dolphins (*Pontoporia blainvillei*) in the wild. *Journal of the Acoustical Society of America* 131:EL448–EL453.
- Mellinger, D. K., K. M. Stafford, S. E. Moore, R. P. Dziak and H. Matsumoto. 2007. An overview of fixed passive acoustic observation methods for cetaceans. *Oceanography* 20: 36–45.
- Molina-Schiller, D., S. A. Rosales and T. R. O. de Freitas. 2005. Oceanographic conditions off Coastal South America in relation to the distribution of Burmeister's porpoise, *Phocoena spinipinnis*. *Latin American Journal of Aquatic Mammals* 4:141–156.
- Moore, S. E., K. M. Stafford, D. Mellinger and J. A. Hildebrand. 2006. Listening for large whales in the offshore waters of Alaska. *BioScience* 56:49–55.
- Morisaka, T., and R. C. Connor. 2007. Predation by killer whales (*Orcinus orca*) and the evolution of whistle loss and narrow-band high frequency clicks in odontocetes. *Journal of Evolutionary Biology* 20:1439–1458.
- Morisaka, T., L. Karczmarski, T. Akamatsu, M. Sakai, S. Dawson and M. Thornton. 2011. Echolocation signals of Heaviside's dolphins (*Cephalorhynchus heavisidii*). *Journal of the Acoustical Society of America* 129:449–457.

- Rayment, W., S. Dawson and E. Slooten. 2009. Trialling an automated passive acoustic detector (T-POD) with Hector's dolphins (*Cephalorhynchus bectori*). *Journal of the Marine Biological Association of the United Kingdom* 89:1015–1022.
- Rayment, W., S. Dawson, S. Scali and L. Slooten. 2011. Listening for a needle in a haystack: Passive acoustic detection of dolphins at very low densities. *Endangered Species Research* 14:149–156.
- Reyes, J. C., and K. van Waerebeek. 1995. Aspects of the biology of Burmeister's porpoise from Peru. Report of the International Whaling Commission (Special Issue 16):349–364.
- Reyes Reyes, M. V., M. A. Iníguez, M. Hevia, J. A. Hildebrand and M. L. Melcón. 2015. Description and clustering of echolocation signals of Commerson's dolphins (*Cephalorhynchus commersonii*) in Bahía San Julián, Argentina, *Journal of the Acoustical Society of America* 138:2046–2053.
- Rojas-Bracho, L., R. R. Reeves and A. Jaramillo-Legorreta. 2006. Conservation of the vaquita *Phocoena sinus*. *Mammal Review* 36:179–216.
- Silber, G. 1991. Acoustic signal of the vaquita (*Phocoena sinus*). *Aquatic Mammals* 17:130–133.
- Szymanski, M., D. Bain, K. Kiehl, S. Pennington, S. Wong and K. R. Henry. 1999. Killer whale (*Orcinus orca*) hearing: Auditory brainstem response and behavioral audiograms. *Journal of the Acoustical Society of America* 106:1134–1141.
- Tezanos Pinto, G., C. Gasparrou, M. Iníguez and R. N. P. Goodall. 2000. Observaciones preliminares de Marsopas espinosas (*Phocoena spinipinnis*) en el Canal Beagle (Tierra del Fuego, Argentina), [Preliminary observations of Burmeister's porpoises (*Phocoena spinipinnis*) in the Beagle Channel (Tierra del Fuego, Argentina)], III Congreso SOLAMAC and IX Reunión de Trabajo de Especialistas en Mamíferos Acuáticos de América del Sur. [Proceedings of the IX Conferences on Specialists on Aquatic Mammals from South America and III SOLAMAC Congress], Buenos Aires, Argentina. Abstract available at https://www.researchgate.net/profile/Gabriela_Tezanos-Pinto.
- Villadsgaard, A., M. Wahlberg and J. Tougaard. 2007. Echolocation signals of wild harbour porpoises, *Phocoena phocoena*. *Journal of Experimental Biology* 210:56–64.
- Wiggins, S. M., and J. A. Hildebrand. 2007. High-frequency acoustic recording package (HARP) for broad-band, long-term marine mammal monitoring. Pages 551–557 in *International Symposium of Submarine Cables and Related Technologies 2007 IEEE*, Tokyo, Japan.

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