Aquatic Mammals 2025, *51*(1), 96-104, DOI https://doi.org/10.1578/AM.51.1.2025.96

Short Note

Whistle Characteristics of the Rough-Toothed Dolphin (*Steno bredanensis*) in the Canary Islands

Ambrosine L. Clark, Francesca Fusar Poli, and Vidal Martín

Society for the Study of the Cetacean in the Canary Archipelago (SECAC), Lanzarote, Canary Islands, Spain
E-mail: ambrosine.clark@gmail.com

Dolphins exhibit a complex array of vocal behaviours critical for their survival and social interaction within their habitats (Wang et al., 1995; Janik & Slater, 2000). Vocal communication of dolphins is broadly categorised into clicks, burst pulse sounds, and frequency-modulated whistles (Ryabov, 2016). Each type serves a distinct functional purpose, ranging from echolocation to complex social communications (Jones et al., 2020). Whistles are frequency-modulated tonal sounds that vary in pitch over time and are used for communication among dolphins, particularly for social coordination and identification of individuals (Janik, 2000; Quick & Janik, 2008; Papale et al., 2017). They play a vital role in the dolphins' acoustic communication as they convey a wide range of information, including individual identity (through signature whistles), emotional state, and group cohesion (May-Collado & Wartzok, 2008; van Ginkel et al., 2018). These vocalisations are integral to the social fabric of dolphin communities, facilitating complex interactions and behaviours (Janik et al., 2006; Ryabov, 2016). With their variations in frequency, duration, and inflection patterns, whistles suggest a complex and nuanced communication system. Such variability emphasizes the importance of whistle characteristics in understanding dolphin acoustic communication and social structure. The ability of dolphins to adapt their vocalisations in response to environmental changes, including noise levels and the presence of other species, shows the adaptive nature of their communication (Kremers et al., 2016).

Rough-toothed dolphins (*Steno bredanensis*) in particular are known to have wide acoustic plasticity and produce vocalisations such as whistles, broad-band clicks, and burst pulses (Watkins et al., 1987; Oswald et al., 2003; Baumann-Pickering et al., 2010; Seabra de Lima et al., 2012). The study of vocal behaviour in *Steno bredanensis*, especially their use of whistles, can reveal the complexity and adaptability of odontocete acoustic communication. These vocalisations are integral to navigating, foraging, and maintaining social cohesion in challenging aquatic environments (as seen in other delphinid species; e.g., Jones et al., 2020). By delving into the specifics of these sounds, their functions, and how they vary under different environmental stimuli, we can gain invaluable insights into the ecological adaptations and social lives of these marine mammals, demonstrating the critical role of acoustic communication in their survival (Notarbartolo di Sciara & Gordon, 1997; Laiolo, 2010; Teixeira et al., 2019).

Although *Steno bredanensis* were globally classified as of "Least Concern" in 2019 by the International Union for Conservation of Nature, data regarding their distribution, ecology, or acoustic behaviour remain scarce (Rankin et al., 2015; Caruso et al., 2019; Kiszka et al., 2019). *Steno bredanensis* are distributed throughout the deep oceanic waters of tropical and subtropical regions, and in warm temperate waters worldwide (Miyazaki & Perrin, 1994; Kerem et al., 2016) as well as in shallow coastal waters (e.g., Brazil; West et al., 2011; Jefferson, 2018). *Steno bredanensis* have been found in groups of 10 to 50 individuals (Baird et al., 2008; West et al., 2011), but the size and group composition of this species are unknown for most regions worldwide (Kiszka et al., 2019).

Despite the abundance of research on dolphin vocalisations, many research gaps still exist regarding the acoustic behaviour of *Steno bredanensis*. Due to the elusive nature of this species and the small group sizes generally observed, Rankin et al. (2015) suggested using passive acoustic methods as a way to improve the detection of this species. Only a few studies have characterized *Steno bredanensis* whistles over the past decades, focusing mainly on pods found in the West Atlantic Ocean (Busnel & Dziedzic, 1966; Seabra de Lima et al., 2012), in the Pacific Ocean (Oswald et al., 2003, 2007), and in the Mediterranean Sea (Caruso et al., 2019). Seabra de Lima et al. (2012) provided a foundational characterization of *Steno bredanensis* whistles off the Rio de Janeiro coast. This study marks a significant step in understanding the acoustic diversity within this species in the South Atlantic Ocean. Furthermore, Oswald et al. (2003, 2007) have contributed to the body of knowledge on *Steno bredanensis* by focusing on their acoustic presence and behaviour in different oceanic regions. Their work underscores the importance of acoustic research in understanding the social and ecological dynamics of these cetaceans. Caruso et al. (2019) expanded the geographical scope of whistle research by documenting *Steno bredanensis* acoustic data in the Mediterranean Sea. This study suggests a need for continuous monitoring to evaluate their conservation status in the Mediterranean and enhances our comprehension of their acoustic communication in relatively understudied regions (Caruso et al., 2019).

To the authors' knowledge, this is the first account of acoustic recordings of *Steno bredanensis* in this geographical region of the Canary Islands archipelagos. Herein, we present an acoustic characterization and a detailed comparison to other populations in the Pacific Ocean and in the Mediterranean Sea. Overall, this study aimed to contribute to and expand on current knowledge of the acoustic behaviour of *Steno bredanensis*. By identifying the main vocalisation characteristics and comparing them to those found in previous studies, the authors are working towards understanding if the population of *Steno bredanensis* in the Canary Islands is similar to those observed in other parts of the world (e.g., South Atlantic Ocean, Pacific Ocean, Mediterranean Sea). Our hypothesis was that better insight into the distribution and ecology of *Steno bredanensis* will be possible if the vocalisations of this study group are similar to those found in other studies.

Study Area

This research was conducted in the Canary Archipelago (from 29º 24' 40" to 27º 58' 16" N and from 13º 19' 54" to 18º 09' 38" W), an oceanic volcanic archipelago located in the African continental edge. It consists of eight islands and various islets comprised of the eastern (La Graciosa, Lanzarote, and Fuerteventura), central (Gran Canaria and Tenerife), and western (La Gomera, La Palma, and El Hierro) islands. The Canary Islands are a Spanish autonomous region with a total surface area of 7,273 km^2, a coastline of approximately 1,581 km, and an Exclusive Economic Zone (EEZ) of approximately 494,192 km^2 (Figure 1). The bathymetry surrounding the islands is defined by steep slopes, with depths reaching up to 1 km along the coast (Canales & Dañobeitia, 1998).

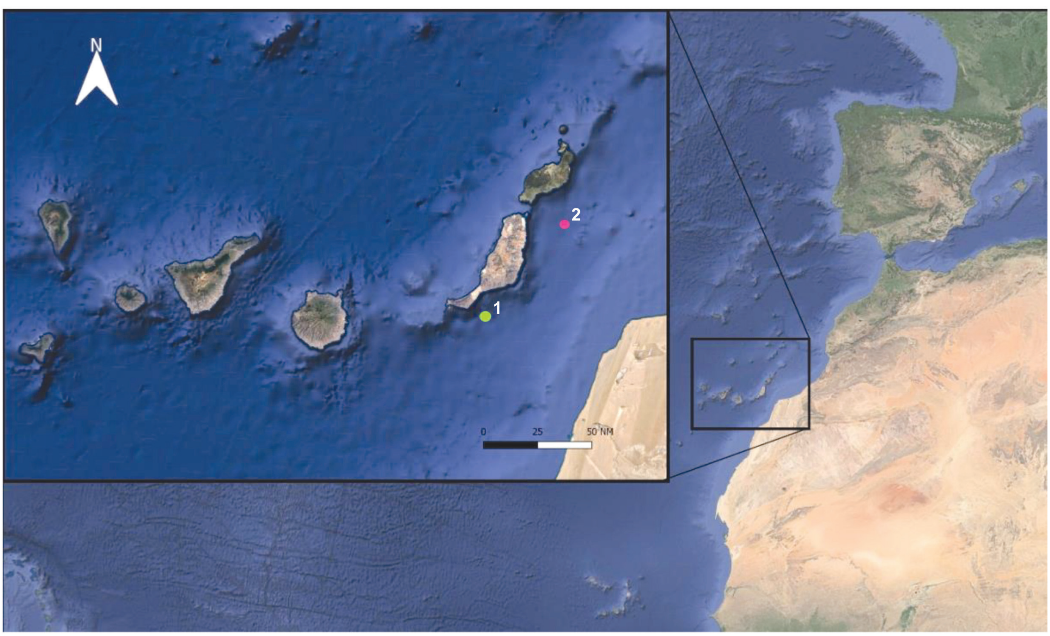


Figure 1. Map of the study area in the eastern Canary Islands, situated in the northeastern Atlantic Ocean. The recordings were taken off the East Coast of the Canary Archipelago. Point 1 represents the data collection location from 20 January 2012, while point 2 represents the data collection location from 12 September 2012. For more details, see Papale et al. (2017).

Data Collection

Acoustic records of *Steno bredanensis* were obtained from dedicated surveys conducted in 2012 in the marine area east and south of Lanzarote-Fuerteventura (LIC-ESZZ15002). This area is a Marine Protected Area (MPA) of the Natura 2000 Network of the European Union (Directive 92/43/EEC of 21 May 1992). This study was part of a multi-species study conducted by the Society for the Study of Cetacean in the Canary Archipelago (SECAC). A total of 60 individuals were observed on 20 January 2012, while 30 individuals were found on 12 September 2012. Following the definition provided by Daura-Jorge et al. (2005), a group was identified as a cluster of dolphins visibly connected, allowing for an accurate count of the individuals observed. Although behavioural data are generally used in acoustical studies, such data were not gathered during the collection of these recordings. Therefore, only acoustical data are presented in this short note.

A total of 85 min of recordings were obtained during this study, with 21 min recorded on 20 January and 51 min recorded on 12 September 2012. Acoustic data collection occurred when *Steno bredanensis* were visually identified to be the only species present to avoid considering vocalisations emitted by other delphinid species (such as the Atlantic spotted dolphin [*Stenella frontalis*]; see Papale et al., 2017). A towed hydrophone system with four elements was used to collect the acoustic data. Two medium-frequency Benthos hydrophones (Benthos, Falmouth, MA, USA; sensitivity: 201 dBv; frequency response at 1 Hz to 15 kHz of ±1.5 dB [ref. 1 µPa ± 1 dB]) were separated 3 m from each other and were connected to a pair of broadband preamplifiers (HP/02; Magrec, Devon, UK). Two spherical ceramic hydrophones (25 cm apart) were positioned in between the Benthos hydrophones (with high-frequency preamplifiers with a 2 kHz high-pass filter; sensitivity: -161 dBv at 20°C [front element], -158 dBv at 20ºC [rear element]; frequency response ~2 to 150 kHz). Sounds were digitalised at a sampling rate of 92 kHz. The towed hydrophone system was connected to a laptop utilising *PAMGUARD*, Version 1.11.01, and was used to monitor the recordings *in situ*. Time, group size, and GPS positions were recorded throughout the survey. For more detailed specifications regarding survey methodology, see Papale et al. (2017).

Data Analysis

The acoustic data were analysed using the software *Raven Pro*, Version 1.6.4 (2022; Cornell Lab of Ornithology, Ithaca, NY, USA). Recordings were taken in WAV format (16 bits per sample), and the spectrogram window was set at 512 Discrete Fourier Transform (DFT), window type Hann with a 50% overlap.

Whistles were visually identified and classified using contour types similar to those categorised by Azevedo & Van Sluys (2005) as stepped (the whistle had multiple plateaus), constant (the start and end frequency were the same: ±0.5 Hz), ascending (rising in frequency), ascending–plateau (first rising in frequency and then reaching a plateau), descending (decreasing in frequency), ascending–descending (first rising in frequency and then decreasing in frequency), descending–ascending (first decreasing in frequency and then rising in frequency), and mixed (all other types of whistles) (Figure 2).

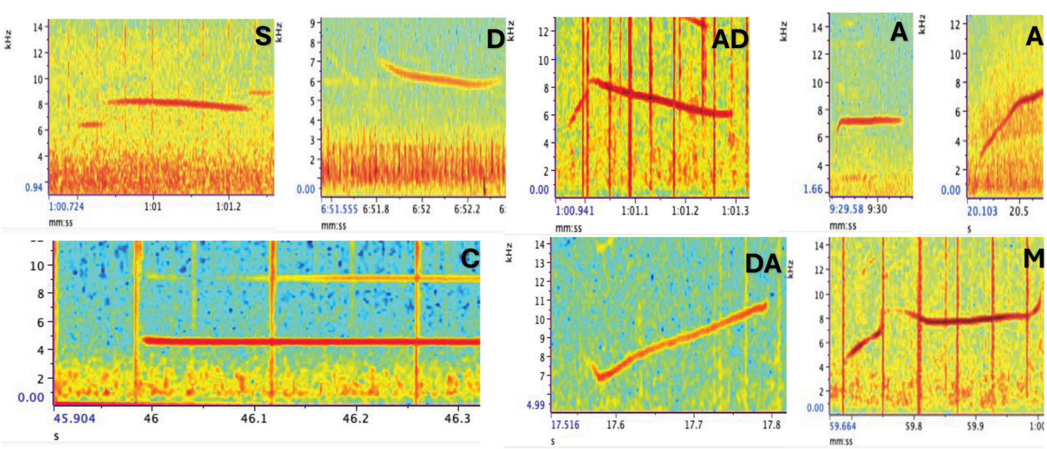


Figure 2. Categories of shapes used to classify rough-toothed dolphin (*Steno bredanensis*) whistles: stepped (S), mixed (M), descending–ascending (DA), descending (D), constant (C), ascending–descending (AD), ascending (A), and ascending–plateau (AP). The X axes represent time (ms), while the Y axes represent frequency (kHz).

Seven acoustic parameters from essential components of each whistle were measured: mean duration (milliseconds [ms]), start and end frequency (kHz), minimum and maximum frequency (kHz), delta frequency (*Raven Pro* defines delta frequency as the difference between maximum and minimum frequency and describes the bandwidth or frequency range of the whistle in kHz), and the number of inflection points (described as points where the whistle contour changed from descending to ascending or vice versa). The number of inflection points were manually counted. The parameters chosen were consistent with those used in other studies (Oswald et al., 2003, 2007; Azevedo & Van Sluys, 2005; Seabra de Lima et al., 2012). Whistles were selected for analysis only if there were no overlaps with other whistles or engine noise. Those which had unclear start and end points or for which the acoustic parameters could not be measured clearly were excluded from the analysis. Whistle harmonics were noted, but only the fundamental contour was counted in the analysis.

Statistical Analysis

Descriptive statistics were performed and included the mean, standard deviation, coefficient of variation, and minimum and maximum values for all acoustic parameters measured. All analyses and graphs were undertaken with *R studio*, Version 1.4.1106 (R Core Team, 2020). Prior to analysis, data were tested for normality using a Shapiro test, and significance was considered with $p < 0.05$. Although results showed the data were non-normally distributed, the lack of raw data from other studies justified the use of a two-sided t test to perform a simple descriptive analysis using summary data (Lumley et al., 2002; Fagerland, 2012). The values obtained for each whistle parameter in this study were therefore compared to the ones reported by Oswald et al. (2003, 2007), Seabra de Lima et al. (2012), and Caruso et al. (2019) by using a two-sided t test. These studies were chosen as they used similar parameters that could be quantitatively compared to those used in this study.

Photo-identification data showed that the groups observed on 20 January and on 12 September 2012 were different. Data from both dates were pooled together for analysis (due to the larger number of recordings obtained on 12 September) to ensure a better analysis of the acoustic behaviour of *Steno bredanensis*. After excluding all whistles that did not meet the acoustic quality criteria described above, a total of 396 whistles were selected for the analysis. Stepped ($n = 126$; 31.82%), mixed ($n = 75$; 18.94%), and ascending–plateau ($n = 45$; 11.36%) whistles were the most common (Figure 3). The mean frequency ranged between 0.47 to 9.7 kHz, while the mean minimum frequency was 5.2 kHz (SD = 1.30 kHz) and the mean maximum frequency was 8.1 kHz (SD = 2.1 kHz). While 73% of whistles had a mean frequency below 4 kHz, only 0.5% of whistles had a high frequency above 12 kHz. On average, the end frequency (mean = 7.57 kHz; SD = 2.40) of *Steno bredanensis* whistles was higher than the start frequency (mean = 6.06 kHz; SD = 4.34).

Whistle duration was on average 430 ± 230 ms, and 26.6% of whistles lasted less than 600 ms. The mean number of inflection points found in these whistles was 1.45 ± 1.1, with 84% of whistles having less than three inflection points and 22.9% having zero inflection points. Descriptive statistics of all measured parameters are shown in Table 1, where whistles were combined in their respective shape categories. This was done to provide extensive information on the whistle structure of *Steno bredanensis* as done by Azevedo & Van Sluys (2005), Seabra de Lima et al. (2012), and Caruso et al. (2019).

The mean, start, and end frequency values of this study were similar to those found by Seabra de Lima et al. (2012). The only values that were significantly different were the minimum frequency and the maximum frequency ($p < 0.05$). The start, end, minimum, and maximum frequency values for

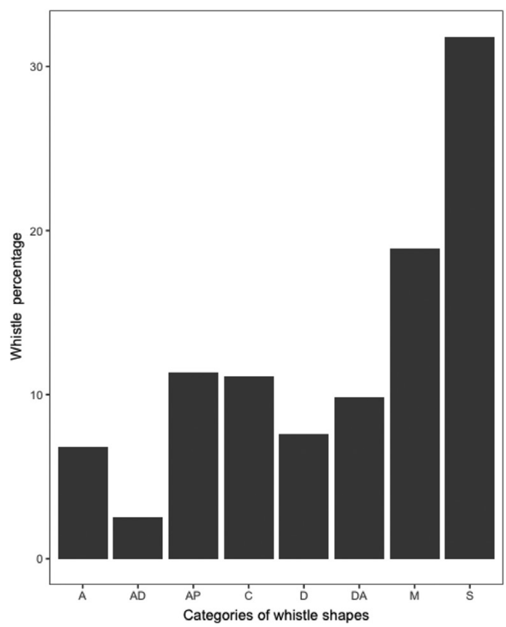


Figure 3. Categories of whistle shapes found in this study. Eight main contour types were identified: (1) ascending (A), (2) ascending–descending (AD), (3) ascending–plateau (AP), (4) constant (C), (5) descending (D), (6) descending–ascending (DA), (7) mixed (M), and (8) stepped (S).

Table 1. Descriptive statistics (mean, standard deviation, coefficient of variation, and minimum and maximum values) of the seven acoustic parameter values measured for each of the eight categories of *Steno bredanensis* whistles (S, M, AP, C, DA, D, A, and AD; $N = 396$). The duration was measured in milliseconds (ms) and the frequency in kilohertz (kHz).

Acoustic parameters	Stepped (S)	Mixed (M)	Ascending–plateau (AP)	Constant (C)	Descending–ascending (DA)	Descending (D)	Ascending (A)	Ascending–descending (AD)
Mean duration (ms)	390 ± 196 0.50 61/125	420 ± 200 0.47 57/926	460 ± 200 0.44 130/970	530 ± 220 0.41 70/100	380 ± 230 0.61 70/780	390 ± 240 0.60 70/930	400 ± 230 0.58 80/920	730 ± 410 0.56 170/1,490
Min. freq. (kHz)	5.28 ± 1.01 0.19 3.22/8.24	5.18 ± 1.17 0.22 2.57/9.93	4.65 ± 1.28 0.27 2.68/8.83	4.30 ± 1.53 0.35 2.82/7.46	6.04 ± 1.29 0.21 3.62/9.28	5.7 ± 1.25 0.22 3.11/8.00	5.85 ± 1.34 0.22 3.63/7.64	5.37 ± 1.20 0.22 2.70/6.79
Max. freq. (kHz)	6.99 ± 1.34 0.19 4.40/1.16	6.87 ± 1.25 0.18 3.37/9.93	6.42 ± 1.56 0.24 3.37/11.06	4.70 ± 1.56 0.33 3.00/7.87	6.72 ± 1.56 0.23 3.93/10.50	6.35 ± 1.38 0.21 3.56/8.81	7.19 ± 1.53 0.21 4.50/10.68	7.10 ± 1.02 0.14 4.87/8.62
Delta freq. (kHz)	3.75 ± 1.37 0.36 9.23/6.84	3.51 ± 2.10 0.59 0.85/9.78	2.82 ± 1.24 0.44 0.88/ 6.44	0.81 ± 0.18 0.22 0.47/1.58	2.74 ± 1.87 0.68 0.94/9.67	1.45 ± 0.74 0.51 0.58/3.19	3.00 ± 1.98 0.66 0.79/7.73	2.42 ± 1.28 0.53 0.98/5.14
Start freq. (kHz)	5.97 ± 1.61 0.26 3.05/1.02	6.59 ± 8.21 0.12 2.69/7.52	5.50 ± 5.93 0.10 2.61/4.35	4.56 ± 1.58 0.34 2.96/8.04	7.33 ± 1.71 0.23 3.89/14.44	6.88 ± 1.53 0.22 3.69/9.77	5.91 ± 1.42 0.24 3.61/7.83	5.46 ± 1.31 0.24 2.70/7.17
End freq. (kHz)	8.36 ± 2.07 0.24 3.97/1.39	8.13 ± 2.38 0.29 1.10/13.20	7.14 ± 1.56 0.21 3.24/11.25	4.57 ± 1.58 0.34 2.96/8.04	8.44 ± 2.82 0.33 4.27/15.92	5.95 ± 1.15 0.19 3.33/8.06	8.84 ± 1.85 0.20 5.07/13.26	6.76 ± 1.23 0.18 4.80/9.09
Number of inflection points	2.12 ± 0.94 0.44 0/5	2.42 ± 0.91 0.37 0/5	1.11 ± 0.310 0.28 1/2	0	1.25 ± 0.54 0.43 0/2	0	0.444 ± 0.64 144.10 0/2	1.2 ± 0.42 35.13 1/2

Table 2. Means and standard deviations of *Steno bredanensis* whistles described by this study ($N = 396$) and by other studies—Oswald et al. (2003, 2007) in the Pacific Ocean, Seabra de Lima et al. (2012) in the South Atlantic Ocean, and Caruso et al. (2019) in the Mediterranean Sea—that presented similar acoustic parameters. A two-sided t test was performed (Moore & McCabe, 1999) to compare each parameter with those found in this study. The numbers in bold represent significant differences ($p < 0.05$), while the asterisk represents data not reported by the study.

Acoustic parameters	Present study, 2023 (Atlantic Ocean)	Oswald et al., 2003 (Pacific Ocean)	Oswald et al., 2007 (Pacific Ocean)	Seabra de Lima et al., 2012 (South Atlantic Ocean)	Caruso et al., 2019 (Mediterranean Sea)
Start freq. (kHz)	6.07 ± 4.34	**6.8 ± 2.9**	**7.41 ± 3.15**	6.56 ± 1.7	*
End freq. (kHz)	7.57 ± 2.40	**8.5 ± 3.1**	**8.33 ± 2.95**	7.4 ± 1.72	*
Low freq. (kHz)	5.23 ± 1.30	**6.3 ± 2.5**	**6.46 ± 2.33**	**6.08 ± 1.46**	5.1 ± 0.9
Max. freq. (kHz)	6.59 ± 1.57	**9.1 ± 3.00**	**9.53 ± 2.97**	**7.96 ± 1.57**	**8.8 ± 1.4**
Delta freq. (kHz)	2.91 ± 1.78	2.8 ± 2.1	*	1.89 ± 1.42	**3.6 ± 1**
Inflection points	1.45 ± 1.13	1.3 ± 2.8	**2.56 ± 3.0**	0.36 ± 0.73	*
Mean duration (ms)	431 ± 227	**600 ± 400**	640 ± 360	347 ± 236	**734 ± 193**
Number of whistles	396	68	192	340	7

Steno bredanensis whistles recorded in the Canary Islands were significantly lower than those reported by Oswald et al. (2003, 2007; Table 2). In the present study, the respective frequency values were higher (Table 2). Although Caruso et al. (2019) only reported half of the whistle parameters, the maximum frequency, number of inflection points, and duration of whistles were, on average, significantly higher than those found in this study.

This study presents the first results on the acoustic behaviour of *Steno bredanensis* in the Canary Archipelago. The means of most whistle frequencies reported in this study occurred in a similar frequency range to those found in other studies (between 2 and 13 kHz; e.g., Evans, 1967; Watkins et al., 1987; Seabra de Lima et al., 2012). However, specific whistle parameters, such as minimum/maximum frequency, mean frequency, and duration, also differed from those observed in other studies as the values reported herein were often lower. In contrast, the number of inflection points found in this study was higher, with most whistles having more than two inflection points. Interestingly, 10 whistles with a frequency above 12 kHz were found in this dataset, despite whistles above 12 kHz being uncommon for *Steno bredanensis* (Oswald et al., 2003, 2007; Seabra de Lima et al., 2012; Caruso et al., 2019).

The recorded whistles showed comparable spectral characteristics to other studies (Seabra de Lima et al., 2012; Rankin et al., 2015; Caruso et al., 2019; see Annexes 1a-1c). While the majority of whistle shapes observed were identical to those found in other regions (i.e., South Atlantic Ocean and Mediterranean Sea), this study found a prevalence in stepped whistles. Many of these often started with a long and steep upsweep and ended with a more gradual downsweep; the majority showed clear steps and breaks (Figure 2). Statistical results found that the occurrence and shape of stepped whistles were comparable to those found in the Mediterranean Sea (Rankin et al., 2015; Caruso et al., 2019), proving that this whistle characteristic may not be a singularity of the geographical region. However, the studies by Rankin et al. (2015) and Caruso et al. (2019) did not give an extensive description of the whistle shapes used to categorise their results as they mainly focused on four types of stepped whistles (see Annexes 1b & 1c). Therefore, most of the comparisons for other whistle types were with those from Seabra de Lima et al. (2012). While stepped, mixed, and ascending–plateau were the most common shapes found in our study, constant and ascending were the ones most observed by Seabra de Lima et al. (2012) (see Annexe 1a). Furthermore, some whistles categorised as descending–ascending and mixed were observed for the first time in this study, supporting the hypothesis that whistle types are an adaptation to certain habitats or populations (Jefferson, 2018; Albertson et al., 2022). Studies have shown that dolphin vocalisations can give specific information on species communication, distribution, and behaviour (Herzing & Johnson, 2015), while their whistle repertoire can present distinctive characteristics and adaptations to both habitats and population types (McCowan et al., 2002; Gannier & West, 2005).

Overall, *Steno bredanensis* exhibit a varied repertoire of whistles that are simple in their structure yet similar to those found in other regions worldwide (i.e., South Atlantic Ocean, Pacific Ocean, Mediterranean Sea). The differences observed could be explained by a genetic drift between populations that occurred through geographical isolation and that has led to characteristic adaptations of each population to their own habitat as observed in other species of dolphins (Wang et al., 1995; Azevedo & Van Sluys, 2005). Although further analyses are required to confirm this, some studies have supported the geographical isolation hypothesis (Papale et al., 2014; Moron et al., 2019; Luís et al., 2021). This study has shown that the *Steno bredanensis* whistles recorded in the Canary Islands archipelagos resemble those emitted by populations in the Mediterranean but differ from those in the Pacific and South Atlantic Oceans. Less than 10 studies have researched the acoustic behaviour of *Steno bredanensis*, and most of them used a limited number of recordings for their analysis. Research has shown that the abundance of *Steno bredanensis* could be underestimated when based on visual observations during boat surveys but that using passive acoustic monitoring to detect the animals could bring more precise estimates (Rankin et al., 2008). Furthermore, acoustic signals provide crucial information on population structure and phenotypic diversity, proving to be an effective tool in delphinid conservation (Papale et al., 2021; Paitach et al., 2022). This highlights the need for extensive research on *Steno bredanensis* as the assessment of their conservation status appears deficient due to the lack of long-term studies. By investigating the acoustic behaviour of this understudied species in the Canary Islands archipelagos, our study aimed to contribute to the knowledge gaps surrounding the ecology of *Steno bredanensis*.

Acknowledgments

We gratefully acknowledge Mónica-Pérez-Gil, Enrique Pérez-Gil, Antonella Servidio, Nuria Varo, Cristina Lorenzo, Marisa Tejedor, Leire Ruiz, Saioa Talavera, Bernd Braderlau, Silvana Neves, and Arquímedes Bermúdez for assistance during field work. The field work was co-funded by the Canary Government (Consejería de Transición Ecológica, Lucha contra el Cambio Climático y Planificación

Territorial), the Spanish Government (Fundación Biodiversidad and Ministerio para la Transición Ecológica y el Reto Demográfico MITECO), Project BIOCETCAN, and the EU programme LIFE+ INDEMARES (LIFE07/NAT/E/00732). This research was carried out under the administrative authorisation of MITECO. We thank Dr Louise Roberts for her help in revising our work. We are grateful to the reviewers for their constructive comments that helped to improve this manuscript.

Literature Cited

Albertson, G. R., Alexander, A., Archer, F. I., Caballero, S., Martien, K. K., Hemery, L. G., Baird, R. W., Oremus, M., Poole, M. M., & Duffield, D. A. (2022). Worldwide phylogeography of rough-toothed dolphins (*Steno bredanensis*) provides evidence for subspecies delimitation. *Marine Mammal Science*, *38*(4), 1371-1397. https://doi.org/10.1111/mms.12933

Azevedo, A. F., & Van Sluys, M. (2005). Whistles of tucuxi dolphins (*Sotalia fluviatilis*) in Brazil: Comparisons among populations. *The Journal of the Acoustical Society of America*, *117*(3), 1456-1464. https://doi.org/10.1121/1.1859232

Baird, R. W., Webster, D. L., Mahaffy, S. D., McSweeney, D. J., Schorr, G. S., & Ligon, A. D. (2008). Site fidelity and association patterns in a deep-water dolphin: Rough-toothed dolphins (*Steno bredanensis*) in the Hawaiian Archipelago. *Marine Mammal Science*, *24*(3), 535-553. https://doi.org/10.1111/j.1748-7692.2008.00201.x

Baumann-Pickering, S., Wiggins, S. M., Hildebrand, J. A., Roch, M. A., & Schnitzler, H-U. (2010). Discriminating features of echolocation clicks of melon-headed whales (*Peponocephala electra*), bottlenose dolphins (*Tursiops truncatus*), and Gray's spinner dolphins (*Stenella longirostris longirostris*). *The Journal of the Acoustical Society of America*, *128*(4), 2212-2224. https://doi.org/10.1121/1.3479549

Busnel, R., & Dziedzic, A. (1966). Acoustic physiologique—Caracteristiques physiques de certains signaux acoustiques due Delphinide *Steno bredanensis* LESSON [Physiological acoustics—Physical characteristics of some acoustic signals due to Delphinidae *Steno bredanensis* LESSON]. *Comptes Rendus de l'Académie des Sciences*, *262*, 143.

Canales, J., & Dañobeitia, J. J. (1998). The Canary Islands swell: A coherence analysis of bathymetry and gravity. *Geophysical Journal International*, *132*(3), 479-488.

Caruso, F., Sciacca, V., Parisi, I., Viola, S., de Vincenzi, G., Bocconcelli, A., Mooney, T. A., Sayigh, L., Li, S., & Filiciotto, F. (2019). Acoustic recordings of rough-toothed dolphin (*Steno bredanensis*) offshore eastern Sicily (Mediterranean Sea). *The Journal of the Acoustical Society of America*, *146*(3), EL286-EL292. https://doi.org/10.1046/j.1365-246X.1998.00448.x

Daura-Jorge, F. G., Wedekin, L. L., Piacentini, V. D. Q., & Simões-Lopes, P. C. (2005). Seasonal and daily patterns of group size, cohesion and activity of the estuarine dolphin, *Sotalia guianensis* (P.J. van Bénéden) (Cetacea, Delphinidae), in southern Brazil. *Revista Brasileira de Zoologia*, *22*(4), 1014-1021. https://doi.org/10.1590/S0101-81752005000400029

Evans, W. E. (1967). Vocalization among marine animals. In W. N. Tavolga (Ed.), *Marine bioacoustics: Proceedings of the Second Symposium on Marine Bioacoustics* (Vol. 2, pp. 159-186). Pergamon.

Fagerland, M. W. (2012). t-tests, non-parametric tests, and large studies—A paradox of statistical practice? *BMC Medical Research Methodology*, *12*, 78. https://doi.org/10.1186/1471-2288-12-78

Gannier, A., & West, K. (2005). Distribution of the rough-toothed dolphin (*Steno bredanensis*) around the Windward Islands (French Polynesia). *Pacific Science*, *59*(1), 17-24. https://doi.org/10.1353/psc.2005.0007

Herzing, D. L., & Johnson, C. M. (2015). *Dolphin communication and cognition: Past, present, and future*. MIT Press. https://doi.org/10.7551/mitpress/9939.001.0001

Janik, V. M. (2000). Whistle matching in wild bottlenose dolphins (*Tursiops truncatus*). *Science*, *289*(5483), 1355-1357. https://doi.org/10.1126/science.289.5483.1355

Janik, V. M., & Slater, P. J. B. (1998). Context-specific use suggests that bottlenose dolphin signature whistles are cohesion calls. *Animal Behaviour*, *56*(4), 829-838. https://doi.org/10.1006/anbe.1998.0881

Janik, V. M., Sayigh, L. S., & Wells, R. S. (2006). Signature whistle shape conveys identity information to bottlenose dolphins. *Proceedings of the National Academy of Sciences*, *103*(21), 8293-8297. https://doi.org/10.1073/pnas.0509918103

Jefferson, T. A. (2018). Rough-toothed dolphin: *Steno bredanensis*. In B. Würsig, J. G. M. Thewissen, & K. M. Kovacs (Eds.), *Encyclopedia of marine mammals* (3rd ed., pp. 838-840). Elsevier. https://doi.org/10.1016/B978-0-12-804327-1.00223-5

Jones, B., Zapetis, M., Samuelson, M. M., & Ridgway, S. (2020). Sounds produced by bottlenose dolphins (*Tursiops*): A review of the defining characteristics and acoustic criteria of the dolphin vocal repertoire. *Bioacoustics*, *29*(4), 399-440. https://doi.org/10.1080/09524622.2019.1613265

Kerem, D., Goffman, O., Elasar, M., Hadar, N., Scheinin, A., & Lewis, T. (2016). The rough-toothed dolphin, *Steno bredanensis*, in the eastern Mediterranean Sea: A relict population? *Advances in Marine Biology*, *75*, 233-258. https://doi.org/10.1016/bs.amb.2016.07.005

Kiszka, J. J., Baird, R. W., & Braulik, G. (2019). *Steno bredanensis*, rough-toothed dolphin. In International Union for Conservation of Nature (Ed.), *IUCN red list of threatened species*. IUCN. https://doi.org/e.T20738A50376703

Kremers, D., Célérier, A., Schaal, B., Campagna, S., Trabalon, M., Böye, M., Hausberger, M., & Lemasson, A. (2016). Sensory perception in cetaceans: Part I—Current knowledge about dolphin senses as a representative species. *Frontiers in Ecology and Evolution*, *4*, 49. https://doi.org/10.3389/fevo.2016.00049

Laiolo, P. (2010). The emerging significance of bioacoustics in animal species conservation. *Biological Conservation*, *143*(7), 1635-1645. https://doi.org/10.1016/j.biocon.2010.03.025

Lammers, M. O., Au, W. W. L., & Herzing, D. L. (2003). The broadband social acoustic signaling behavior of spinner and spotted dolphins. *The Journal of the Acoustical Society of America*, *114*(3), 1629-1639. https://doi.org/10.1121/1.1596173

Luís, A. R., May-Collado, L. J., Rako-Gospić, N., Gridley, T., Papale, E., Azevedo, A., Silva, M. A., Buscaino, G., Herzing, D., & dos Santos, M. E. (2021). Vocal universals and geographic variations in the acoustic repertoire of the common bottlenose dolphin. *Scientific Reports*, *11*(1), 11847. https://doi.org/10.1038/s41598-021-90710-9

Lumley, T., Diehr, P., Emerson, S., & Chen, L. (2002). The importance of the normality assumption in large public health data sets. *Annual Review of Public Health*, *23*(1), 151-169.

May-Collado, L. J., & Wartzok, D. (2008). A comparison of bottlenose dolphin whistles in the Atlantic Ocean: Factors promoting whistle variation. *Journal of Mammalogy*, *89*(5), 1229-1240. https://doi.org/10.1644/07-MAMM-A-310.1

McCowan, B., Doyle, L. R., & Hanser, S. F. (2002). Using information theory to assess the diversity, complexity, and development of communicative repertoires. *Journal of Comparative Psychology*, *116*(2), 166-172. https://doi.org/10.1037/0735-7036.116.2.166

Miyazaki, N., & Perrin, W. F. (1994). Rough-toothed dolphin *Steno bredanensis* (Lesson, 1828). In S. H. Ridgway (Ed.), *Handbook of marine mammals* (pp. 1-21). Academic Press.

Moore, D. S., McCabe, G. P., & Craig, B. A. (1999). *Introduction to the practice of statistics* (Vol. 4). W. H. Freeman.

Moron, J. R., Lopes, N. P., Reis, S. S., Mamede, N., Reis, S. S., Toledo, G., Corso, G., Sousa-Lima, R. S., & Andriolo, A. (2019). Whistle variability of Guiana dolphins in South America: Latitudinal variation or acoustic adaptation? *Marine Mammal Science*, *35*(3), 843-874. https://doi.org/10.1111/mms.12572

Notarbartolo di Sciara, G., & Gordon, J. (1997). Bioacoustics: A tool for the conservation of cetaceans in the Mediterranean Sea. *Marine and Freshwater Behaviour and Physiology*, *30*(2), 125-146. https://doi.org/10.1080/10236249709379020

Oswald, J. N., Barlow, J., & Norris, T. F. (2003). Acoustic identification of nine delphinid species in the Eastern Tropical Pacific Ocean. *Marine Mammal Science*, *19*(1), 20-37. https://doi.org/10.1111/j.1748-7692.2003.tb01090.x

Oswald, J. N., Rankin, S., Barlow, J., & Lammers, M. O. (2007). A tool for real-time acoustic species identification of delphinid whistles. *The Journal of the Acoustical Society of America*, *122*(1), 587-595. https://doi.org/10.1121/1.2743157

Paitach, R. L., Melcón, M., Andriolo, A., & Cremer, M. J. (2022). Acoustic repertoire and bioacoustics applications. In P. C. Simões-Lopes & M. J. Cremer (Eds.), *The franciscana dolphin: On the edge of survival* (pp. 175-200). Elsevier. https://doi.org/10.1016/B978-0-323-90974-7.00001-X

Papale, E., Perez-Gil, M., Castrillon, J., Perez-Gil, E., Ruiz, L., Servidio, A., Tejedor, M., Giacoma, C., & Martín, V. (2017). Context specificity of Atlantic spotted dolphin acoustic signals in the Canary Islands. *Ethology Ecology & Evolution*, *29*(4), 311-329. https://doi.org/10.1080/03949370.2016.1171256

Papale, E. B., Azzolin, M. A., Cascão, I., Gannier, A., Lammers, M. O., Martín, V. M., Oswald, J. N., Pérez-Gil, M., Prieto, R., & Silva, M. A. (2021). Dolphin whistles can be useful tools in identifying units of conservation. *BMC Zoology*, *6*(1), 22. https://doi.org/10.1186/s40850-021-00085-7

Papale, E., Azzolin, M., Cascão, I., Gannier, A., Lammers, M. O., Martín, V. M., Oswald, J., Perez-Gil, M., Prieto, R., Silva, M. A., & Giacoma, C. (2014). Acoustic divergence between bottlenose dolphin whistles from the Central–Eastern North Atlantic and Mediterranean Sea. *Acta Ethologica*, *17*, 155-165. https://doi.org/10.1007/s10211-013-0172-2

Quick, N. J., & Janik, V. M. (2008). Whistle rates of wild bottlenose dolphins (*Tursiops truncatus*): Influences of group size and behavior. *Journal of Comparative Psychology*, *122*(3), 305-311. https://doi.org/10.1037/0735-7036.122.3.305

R Core Team. (2020). R*: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org

Rankin, S., Barlow, J., & Oswald, J. N. (2008). *An assessment of the accuracy and precision of localization of a stationary sound source using a two-element towed hydrophone array* (NOAA Technical Memorandum 3549). U.S. Department of Commerce, National Oceanic and Atmospheric Administration. https://repository.library.noaa.gov/view/noaa/3549

Rankin, S., Oswald, J. N., Simonis, A. E., & Barlow, J. (2015). Vocalizations of the rough-toothed dolphin, *Steno bredanensis*, in the Pacific Ocean. *Marine Mammal Science*, *31*(4), 1538-1548. https://doi.org/10.1111/mms.12226

Ryabov, V. A. (2016). The study of acoustic signals and the supposed spoken language of the dolphins. *St. Petersburg Polytechnical University Journal: Physics and Mathematics*, *2*(3), 231-239. https://doi.org/10.1016/j.spjpm.2016.08.004

Seabra de Lima, I. M., de Andrade, L. G., Ramos de Carvalho, R., Lailson-Brito, J., & Azevedo, A. F. (2012). Characteristics of whistles from rough-toothed dolphins (*Steno bredanensis*) in Rio de Janeiro coast, southeastern Brazil. *The Journal of the Acoustical Society of America*, *131*(5), 4173-4181. https://doi.org/10.1121/1.3701878

Teixeira, D., Maron, M., & van Rensburg, B. J. (2019). Bioacoustic monitoring of animal vocal behavior for conservation. *Conservation Science and Practice*, *1*(8), e72. https://doi.org/10.1111/csp2.72

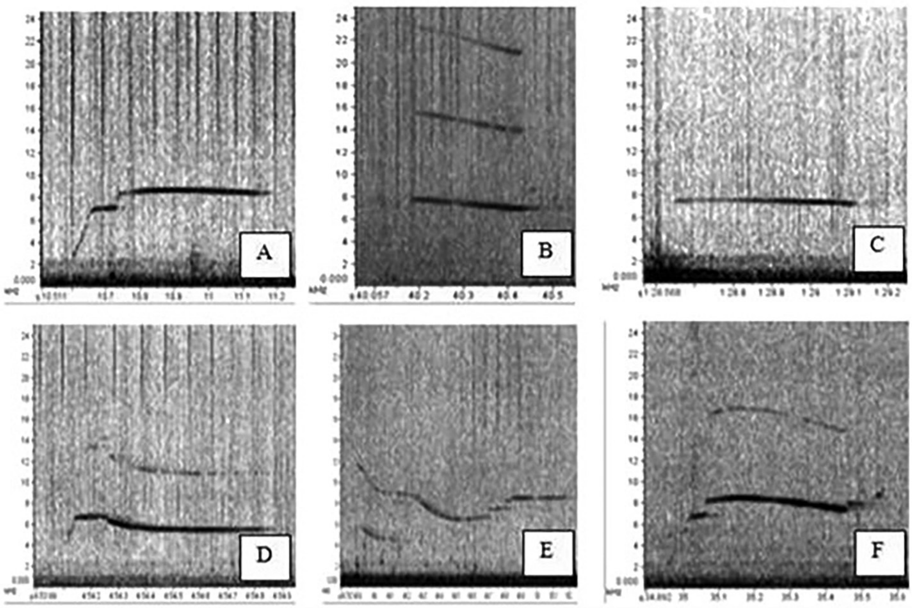
van Ginkel, C., Becker, D. M., Gowans, S., & Simard, P. (2018). Whistling in a noisy ocean: Bottlenose dolphins adjust whistle frequencies in response to real-time ambient noise levels. *Bioacoustics*, *27*(4), 391-405. https://doi.org/10.1080/09524622.2017.1359670

Wang, D., Würsig, B., & Evans, W. E. (1995). Whistles of bottlenose dolphins: Comparisons among populations. *Aquatic Mammals*, *21*(1), 65-77.

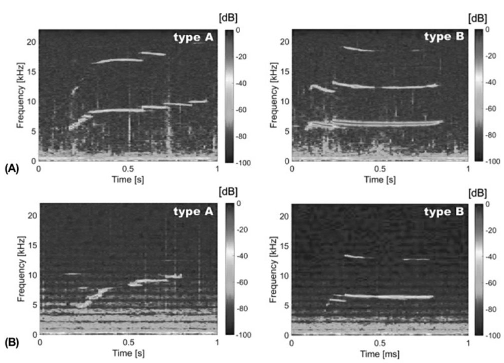
Watkins, W. A., Tyack, P., Moore, K. E., & Notarbartolo di Sciara, G. (1987). *Steno bredanensis* in the Mediterranean Sea. *Marine Mammal Science*, *3*(1), 78-82. https://doi.org/10.1111/j.1748-7692.1987.tb00152.x

West, K. L., Mead, J. G., & White, W. (2011). *Steno bredanensis* (Cetacea: Delphinidae). *Mammalian Species*, *43*(886), 177-189. https://doi.org/10.1644/886.1

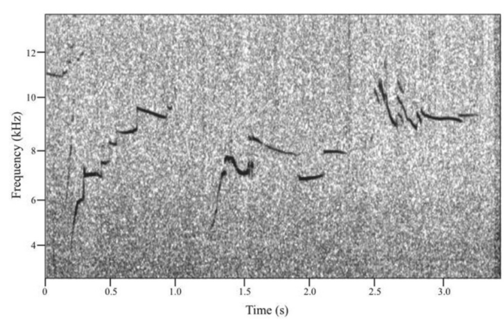
Annexes



Annexe 1a. Categories of contour in which rough-toothed dolphin (*Steno bredanensis*) whistles were classified: ascending (A), descending (B), constant (C), ascending–descending, (D), descending–ascending (E), and multi (F). X axis = ¼ time (ms); Y axis = ¼ frequency (kHz). (Figure from Seabra de Lima et al., 2012)



Annexe 1b. (A) Spectrograms (nfft = 1,024; overlap = 50; Hann window) of the two whistle categories produced by *Steno bredanensis* (Type A and Type B); and (B) same categories of whistles recorded by Watkins et al. (1985). (Figure from Caruso et al., 2019)



Annexe 1c. Spectrogram of whistles produced by *Steno bredanensis* (44.1 kHz sample rate; 1,024 FFT, Hann window). (Figure from Rankin et al., 2015)