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First acoustic description of Risso's dolphin (*Grampus griseus*) whistles in Mexican waters

Raul Rio[1, 2, *], and Hiram Rosales Nanduca[3]

[1]Laboratory of Observational and Bioacoustics Technologies Applied to Biodiversity (TecBio), Department of Veterinary Medicine, Federal University of Juiz de Fora, Brazil
[2]Ocean Sound (Som de Oceano), Nongovernmental Organization (NGO), Santos, Brazil
[3]Departamento Académico de Ingeniería en Pesquerías, Universidad Autónoma de Baja California Sur, La Paz, Mexico

Odontocetes produce a diversity of sounds that are often classified into two broad categories: echolocation clicks, which are used for navigation and prey localization, and whistles and burst pulses used in communication (May-Collado & Wartzok, 2008; Baumann-Pickering et al., 2015; Jones et al., 2020; Rio, 2023a). Among communicative sounds, whistles are the most studied and are primarily used in the context of group cohesion and coordination of activities (Janik & Slater, 1998; Janik, 1999; May-Collado & Wartzok, 2009; May-Collado, 2010; Rio, 2023b; Rio et al., 2024).

Although odontocetes have the impressive ability to both emit and perceive sounds, some aspects of their vocal repertoire remain poorly studied (Corkeron & Van Parijs, 2001). Among the least studied members of the Globicephalinae is the Risso's dolphin (*Grampus griseus*). Despite their broad distribution, little information exists about the geographical, environmental, and behavioral factors shaping their vocal repertoire. Most studies about their acoustic behavior have focused on describing their echolocation clicks (Philips et al., 2003; Soldevilla et al., 2008, 2011, 2017; Arranz et al., 2016; Smith et al., 2016; Frasier et al., 2017; Cohen et al., 2022), only a handful of studies describe the acoustic features of their communicative signals (*e.g.*, Rendell et al., 1999; Corkeron & Van Parijs, 2001; Gannier et al., 2010; Favaro et al., 2016; Carlucci et al., 2024). This study provides the first description of Risso's dolphin whistles in Mexican waters of the North Pacific Ocean to contribute to the acoustic knowledge of this species.

The acoustic data herein were opportunistically collected during one encounter of a Risso's dolphin group with approximately 200 individuals, including calves and juveniles, on 26 July 2022, from 10:30h to 12:00h near La Ventana, southeastern La Paz City, Baja California Sur, Mexico (24°05'35" N, 109°42'34" W - Fig. 1). The dolphins were observed in a large but dispersed group, with several subgroups of 6 and 30 individuals, traveling slowly in south direction. In some of the subgroups, the individuals breathed and moved in a synchronized manner.

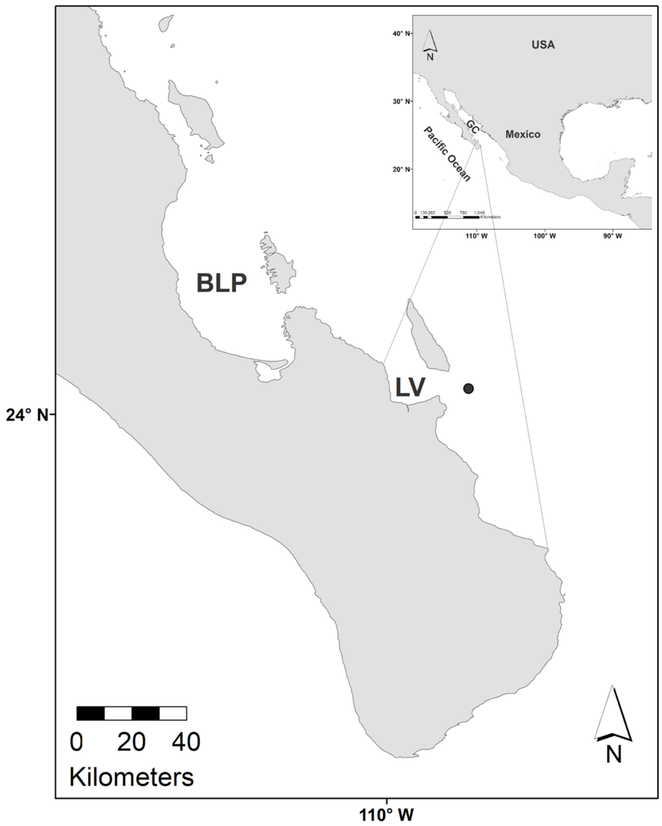

Figure 1. Location of sighting and vocal recordings (black dot) of a free-ranging Risso's dolphin (*Grampus griseus*) group carried out on 26 July, 2022, near the town of La Ventana (LV), southeast of Bahía de La Paz (BLP) in the Gulf of California (GC), Mexico.

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Figure 2. A pair of Risso's dolphin (*Grampus griseus*) sighted on 26 July 2022, in the Gulf of California, Mexico, in the North Pacific Ocean.

Recordings were conducted using an SQ26-08 hydrophone (frequency ranging from 20 Hz to 50 kHz, and effective sensitivity = 169 dB, re 1 V/μPa; Cetacean Research Technology, Golden, CO) deployed from the boat ("panga" of 8 m length with an outboard engine of 250 Hp) and placed 5 m underwater. The hydrophone was connected to a Zoom H1n digital recorder and used a sampling rate of 48 kHz and 16-bit resolution. Recordings were made with the boat engine off. When the hydrophone was used, the closest dolphin subgroup was approximately 50 m away. When the boat stopped and the engine was turned off, the dolphins did not change their course and passed close to the boat without showing interest in the boat or swimming around it. The identity of the species was based on continuous visual observation (Fig. 2). The sea was calm with light wind conditions (Beaufort 1) and 20 cm waves, partly cloudy, and with good visibility (approximately 10 km). Since no other cetaceans were observed at the assessed location, and the identification of the species, we are confident the recorded sounds belong to Risso's dolphins.

Only whistles with a clear and dark contour from start to end and a signal-to-noise ratio (SNR) above 4 dB were manually selected for analysis. Repeated whistle units, known as possible signature whistles (Janik & Slater, 1998), were not considered to avoid overestimating the most repeated whistle contours. Spectrograms of each recording were created in Raven Pro 1.6.1 (Cornell Laboratory of Ornithology, Ithaca, USA) at 1,024 Fast Fourier Transform size (FFT), Hanning window, and 50% overlap.

Whistles were categorized into six whistle contour types based on the pattern of modulation (ascending or descendant) and the number of changes in modulation direction (inflection points) (Rio et al., 2024). The following categories were used: upsweeps (Type I), downsweeps (Type II), inverted U-shapes (or convex) (Type III), U-shapes (or concave) (Type IV), wavering sinusoidal (or sine) (Type V), and Flat (Type VI).

The following standard acoustic features were manually extracted from selection boxes framing the whistles: Start (StaF), end (EndF), minimum (MinF) and maximum (MaxF) frequency, bandwidth (BanF) (also known as delta frequency), duration (Dur), and the number of changes in modulation direction (InfP). The means and standard deviations were calculated for all whistle acoustic features. All statistical analyses were performed in GraphPad 8 (GraphPad Software Inc., San Diego, USA).

One hundred eighty-four whistles were manually selected for analyses from the 17.9-min whistle time registers. However, 64.13% (118/184) of them were issued in a bout pattern and classified as stereotyped whistles (STW); consequently, their copies were not selected for the analysis (exclusion criteria). On the other hand, 35.87% (66/184) of recorded whistles met all inclusion criteria and were extracted and analyzed.

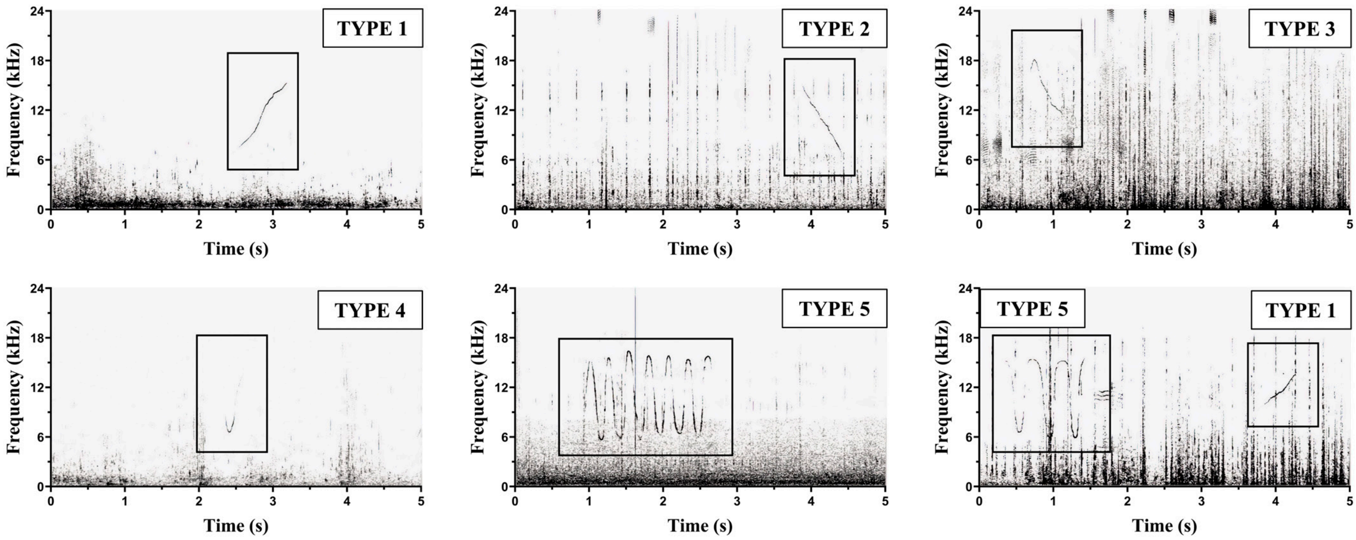

Figure 3. Examples of whistle (black highlighted box) spectrograms and their respective modulation categories, based on emissions by Risso's dolphins (*Grampus griseus*) living in Mexican Pacific waters, Gulf of California. Frequency (kHz) is on the y-axis, ranging from 0 to 24 kHz. Time (s) is on the x-axis, representing 5 s. Scaling was the same for all items. Spectrogram settings: fast Fourier transform size = 1024; Hanning window; overlap = 50%. The numerical information type at the top of each whistle spectrogram represents its classification based on the adopted categories: Upsweeps (Type I); Downsweeps (Type II); Inverted U-shapes (or convex) (Type III); U-shapes (or concave) (Type IV); and Wavering sinusoidal whistles (or sine) (Type V).

Figure 3 shows examples of whistle contours recorded in this study. The analyzed whistles were not evenly distributed among contour types. Sine and convex whistle contours (33.33% and 30.30%, respectively) prevailed in the acoustic repertoire of Risso's dolphins and were followed by upsweep and downsweep whistle contours (22.73% and 3.03%, respectively). Concave whistle contours were the least common, representing only 3.03% of all recorded contour types. No flat whistles were observed.

Table 1 shows the mean and standard deviation for all analyzed whistles compared to other studies. The recorded frequency parameters showed similar mean StaF and EndF values (12.24 ± 4.41 kHz and 12.34 ± 4.61 kHz, respectively). Mean BanF and MinF values were also similar to each other and presented values close to 9 kHz (8.43 ± 2.34 kHz for MinF and 9.53 ± 3.07 kHz for BanF). The mean MaxF was 17.96 ± 2.43 kHz - values ranged from 12.20 kHz to 24.00 kHz. The fundamental frequencies of some whistle contours were "cut off" by the upper-frequency limit of the recordings (24 kHz), suggesting we did not capture the full extent of their frequency range. The mean whistle duration (Dur) was 0.67 ± 0.34 s and ranged from 0.20 to 1.76s. Frequency modulation is measured here as the number of inflection points (InfP), which ranges from 0 to 13 inflection points in a single contour.

Odontocetes evolved unique capabilities, including broadband hearing, high-frequency sensitivity, fast neurophysiological responses, and short temporal resolutions, because they adapted to the aquatic environment (Mooney et al., 2006). Although knowledge of cetaceans' acoustic features is mandatory for one's understanding of their ecology, a statement made more than half a century ago about knowledge of bioacoustics seems contemporary: "Sounds emitted by cosmopolitan Risso's dolphins have only briefly been mentioned in the ever-growing literature on cetacean vocalizations" (Caldwell et al., 1969, p. 252). Overall, there are just four studies describing complete acoustic parameters results for this species' whistle repertoire (Rendell et al., 1999; Gannier et al., 2010; Favaro et al., 2016; Carlucci et al., 2024); all carried out in the Mediterranean Sea (Gannier et al., 2010; Carlucci et al., 2024) and the Atlantic Ocean (Rendell et al., 1999; Favaro et al., 2016). Corkeron & Van Parijs (2001) described vocalizations of eastern Australian Risso's dolphins in the South Pacific Ocean. However, their results corresponded to five different STW contour types and combined tonal sounds and explosive pulse, among other vocalization types. Other studies have focused on different acoustic aspects, like mixed-species associations (Viana et al., 2022) or corresponded to a captive individual stranded during venipuncture (Caldwell et al., 1969). Our study described complete acoustic parameter results for Risso's dolphins in Mexican waters. At first glance, a larger number of whistles could be expected, given the size of the group encountered. However, the relatively low number of whistles analyzed [higher than Favaro et al. (2016) and Carlucci et al. (2024)] was primarily due to the high number of copies of single contour types (SWT). The highly stereotyped and repetitive nature of some whistle contours suggests the possible occurrence of signature whistles (Caldwell et al., 1969; Favaro et al., 2016; Carlucci et al., 2024) or common group distinctive call types, which reduced our acoustic analysis to nearly one-third of the recorded whistles. Similarly, a study carried out in the Mediterranean Sea from April 2019 to September 2022, based on 41 sightings of Risso's dolphins and 5.20 h of acoustic recordings, resulted in more than 150 recorded whistles, but only 36 could be used for analysis due to the high number of repetitions of the same contour (Carlucci et al., 2024). Furthermore, Risso's dolphins rarely emit narrowband frequency-modulated whistles for communication (Carlucci et al., 2024).

Most of the measured acoustic and temporal variables recorded in this study showed mean values similar to those available in other studies conducted with the same species (Rendell et al., 1999; Corkeron & Van Parijs, 2001; Favaro et al., 2016), except for maximum frequency (MaxF) and bandwidth (BandF) results (Table 1). Our MaxF mean value was higher than all others reported in previous studies, with almost 3 kHz above the highest value to date (Favaro et al., 2016). Moreover, the whistle signal spectrum contour of some fundamental frequencies observed in the present study was "cut off" by the upper-frequency limit adopted for the recordings (sample rate 48 kHz). This finding suggests that Risso's dolphins would emit frequency whistles higher than 24 kHz. The highest whistle frequency previously recorded for this species was 22 kHz, on the coast of Newcastle, Australia (Corkeron & Van Parijs, 2001) - these data were limited by a sample rate recording system equal to 44 kHz. The most recent study on this topic collected at a sampling frequency of between 192 and 300 kHz and recorded a MaxF mean equal to 13.05 kHz for Risso's dolphins in the Gulf of Taranto, Northern Ionian Sea, central Mediterranean Sea (Carlucci et al., 2024).

Table 1. Descriptive analyses (Mean ± Standard Deviation) of frequency (kHz) and temporal parameters recorded for Risso's dolphins' whistles for this study compared to previous ones.

Location	*n*	Start (StaF)	End (EndF)	Minimum (MinF)	Maximum (MaxF)	Bandwidth (BanF)	Duration (s) (Dur)	Inflection (n) (InfP)
Gulf of California, the North Pacific Ocean (this study)	66	12.24 ± 4.41	12.34 ± 4.61	8.43 ± 2.34	17.96 ± 2.43	9.53 ± 3.07	0.67 ± 0.34	1.47 ± 2.01
Gulf of Taranto, Mediterranean Sea (Carlucci et al., 2024)	36	9.47 ± 4.28	9.98 ± 3.50	7.17 ± 2.24	13.05 ± 3.90	5.87 ± 2.85	0.70 ± 0.31	1.08 ± 1.34
Canary Archipelago, the North Atlantic Ocean (Favaro et al., 2016)	62	11.46 ± 2.78	12.81 ± 4.31	10.09 ± 2.48	15.21 ± 3.93	5.11 ± 2.98	0.51 ± 0.22	1.00 ± 2.00
Western Mediterranean Sea (Gannier et al., 2010)	158	11.75 ± 3.93	11.88 ± 3.52	8.29 ± 2.03	14.65 ± 3.27	6.37 ± 3.24	0.65 ± 0.36	-
Azores, the North Atlantic Ocean (Rendell et al., 1999)	82	8.24 ± 3.37	13.41 ± 4.80	6.63 ± 2.15	13.41 ± 5.36	6.79 ± 5.69	0.53 ± 0.39	1.20 ± 1.31
Stornoway, the North Atlantic Ocean (Rendell et al., 1999)	1.182	12.37 ± 2.63	10.65 ± 3.12	8.98 ± 2.68	13.44 ± 2.40	4.46 ± 2.26	0.53 ± 0.25	1.38 ± 1.33

Despite evidence in the present study, it is necessary to conduct further research to clarify and broaden knowledge on the upper-frequency limit of tonal sounds emitted by Risso's dolphins.

Based on similar mean values available in three previous studies [5.87 kHz (Carlucci et al., 2024), 6.37 kHz (Gannier et al., 2010), and 6.79 kHz (Rendell et al., 1999)], the current literature suggests that this delphinid species would produce a repertoire with relatively narrow frequency range (BandF). The present results added new limits to this knowledge by recording a mean BanF value equal to 9.53 ± 3.07 kHz, which represents more than one-third of the previously reported means (Rendell et al., 1999; Gannier et al., 2010; Carlucci et al., 2024). The present study was also the first to classify Risso's dolphins' whistles into category types based on their overall contour. Although new machine learning methods offer a better and more exhaustive approach, the simplicity of the adopted method facilitates its adoption and allows future comparisons between different populations and environmental contexts (Rio et al., 2024).

Our data represent the baseline acoustic recording and characterization of whistles emitted by the Risso's dolphin in Mexican waters, filling a gap in the tonal sound repertoire of this species in the North Pacific Ocean. In the future, our data can further contribute to developing acoustic identification software (frequency whistles higher than 24 kHz), the progress of passive acoustic monitoring methods, and the best understanding of potential factors involved in this delphinid's micro and macro-geographic acoustic variations.

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