JASA LETTER TO THE EDITOR

Acoustic recording of false killer whale (*Pseudorca crassidens*) from Mexico (L)

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ABSTRACT:

This study collected acoustic information on false killer whales (*Pseudorca crassidens*) in Mexican waters, close to Roca Partida Island, Revillagigedo Archipelago. In total, 321 whistles were collected after we found a group with at least ten individuals. The high prevalence of ascending contour types [upsweep (type I): 42.99%] contradicted the idea that false killer whales mostly produce constant whistles. Lack of well-established reproducibility criteria for whistle type categorization among studies may have generated results different from those expected for signal modulation. Future acoustic and ecological studies should be conducted to help clarify these findings and expand the limited knowledge about this species. © *2023 Acoustical Society of America*. https://doi.org/10.1121/10.0017726

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I. INTRODUCTION

False killer whales (*Pseudorca crassidens*) are highly social delphinids found in the world's tropical and semi-tropical waters, mostly in offshore and deep waters, where they mainly feed on fish and squid (Baumann-Pickering *et al.*, 2015).

The diversity and complexity of odontocete vocalizations are a remarkable feature of this group, and these vocalizations are traditionally fit into categories of broadband echolocation clicks, broadband burst pulses, and frequency-modulated narrowband whistles. Pulsed vocal signals, such as clicks, burst pulses, and "buzzes," are known to have echolocation and social functions (Baumann-Pickering *et al.*, 2015), whereas whistles presumably play some sort of communication/social cohesion role (Thode *et al.*, 2016). False killer whales produce whistles, echolocation clicks, and burst pulses (McCullough *et al.*, 2021); oftentimes, their whistle spectrograms resemble those produced by other odontocete species (Murray *et al.*, 1998). However, they tend to present lower frequency, which is less frequency-modulated than most delphinid whistles (Barkley *et al.*, 2019).

The vocal repertoire of both captive individuals (Murray *et al.*, 1998; Yuen *et al.*, 2005; Madsen *et al.*, 2013) and free-living populations has been registered and analyzed since the first sound emitted by *P. crassidens* was recorded (Schevill and Watkins, 1962). The most important acoustic recordings of them were made in continental shelf waters (Weir *et al.*, 2013), mainly in oceanic habitats, such as Hawaii (Thode *et al.*, 2016; Barkley *et al.*, 2019) and international waters (Oswald *et al.*, 2003). Nevertheless, if one takes into consideration all studies available in the literature about this topic, knowledge about this species' vocalizations remains limited. The present study introduces the first baseline acoustic recording of false killer whales in Mexican waters, contributing to global knowledge on this delphinid's acoustic repertoire.

II. MATERIALS AND METHODS

A. Study site and data collection

Revillagigedo Archipelago (18° 50′ 0″ N, 112° 50′ 0″ W) comprises four islands (Rio *et al.*, 2022), namely, San Benedicto Island, Socorro Island, Clarión Island, and Roca Partida Island (Fig. 1), where these animals were registered and data about them were collected. It belongs to a submarine mountain ridge located in Eastern Pacific Ocean, in Mexico's Economic Exclusive Zone.

A group of at least ten false killer whale individuals was first sighted on January 3, 2021, from an inflatable boat during a bioacoustics expedition (Rio *et al.*, 2022). The daytime visual confirmation of *P. crassidens* resulted from the underwater footage of a subgroup of four individuals and from photographs of them taken during the practice of snorkeling.

All data were collected from a liveaboard vessel (33.5 m in length, 7.5 m in width, capacity: 30 people), with engines off, anchored at a permitted area around Roca Partida Island (Research Permission for Collection of Biodiversity Data: N. SGPA/DGVS/00823/20). The recording of the species was considered continuous while it was possible to visualize records of whistles and pulsed sounds in the spectrogram [duration (Dur): 98.3 min]. Part of this period was in sync with the visual confirmation of the species; therefore, all signs of this period are attributed to the identified species.

Underwater recordings were made with hydrophone system BuninTech H0220 (final sensitivity gain of 52 dB, by GainBox: −152 dB re 1 V/μPa ± 3 dB; frequency band: 5 Hz–80 kHz) placed 5 m underwater and connected to a Tascam DR-100MKIII digital recorder by a 10-m cable. Recordings were made at a sample rate of 96 kHz and 24-bit

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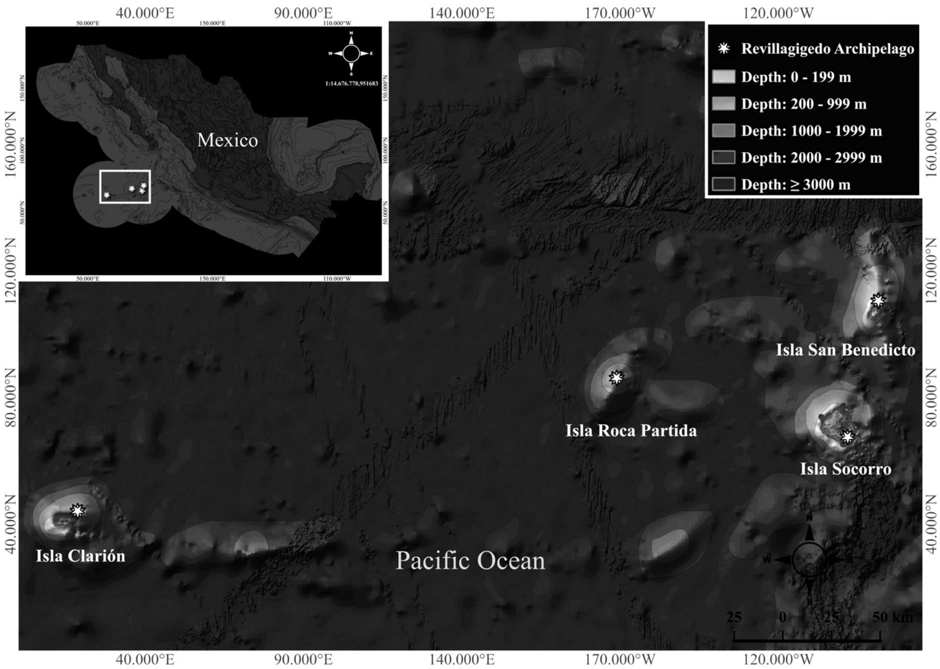

FIG. 1. Map of the study site in the Revillagigedo Archipelago islands, Mexico, Eastern Pacific Ocean; bathymetry and landform data of the four islands forming the archipelago: San Benedicto Island, Socorro Island, Roca Partida Island, and Clarión Island. Acoustic recordings of sounds produced by a group of false killer whales (*P. crassidens*) were obtained in a site close to Roca Partida Island.

resolution. All acoustic data were recorded in 5-min recording files as time-stamped wav files.

B. Acoustic and statistical analysis

All whistles with good signal-to-noise (SNR) ratio and complete, clear spectral contours were first visually and aurally identified; then they were manually selected for analysis purposes. Spectrograms were plotted in the spectrogram view of Raven Pro 1.6.1 at 1024 fast Fourier transform (FFT) size, Hanning window, and 50% overlap.

The term "whistle type" was used to ascribe all whistles of a particular frequency modulation pattern or contour to predetermined categories based on human visual evaluations. The whistles were classified into six categories, according to the contour (Azevedo *et al.*, 2007); they took into consideration the presence or lack of modulations, the modulation direction (ascendant or descendent), and the number of changes in direction (inflexion points). Flat whistles were taken as relatively constant signals without inflection points; they changed less than 1 kHz throughout more than 90% of their Dur. Only the overall whistle contour was taken into account in the present study, rather than the minor contour classifications or subcategories, which take into consideration small variations at the beginning or at the end of a whistle. The following categories were used: upsweeps (type I); downsweeps (type II); inverted U-shapes (or ascending-descending) (type III); U-shapes (or descending-ascending) (type IV), wavering sinusoidal whistles (type V); and flat (type VI).

The main and classical acoustic parameters of all analyzed whistles were measured to feature this species' acoustic repertoire. Start (StaF), end (EndF), minimum (MinF), and maximum (MaxF) frequency, bandwidth (BanF), Dur, and number of inflection points (InfP) (change from positive to negative aspect or vice versa) were the extracted spectral and temporal parameters.

All parameters were manually extracted through selection boxes in Raven Pro 1.6.1 software. Selection box boundaries were used to extract BanF, MinF, MaxF, and Dur, whereas StaF, EndF, and InfP were additionally marked to properly represent their value. Qualitative visual analysis was used to categorize whistle types.

Descriptive statistical analysis was applied to all frequency and temporal parameters. Emission rate was calculated by dividing the number of whistles by the number of minutes of recorded whistle time. The recorded whistle time was defined as the time interval between the first and last acoustic signal (clicks or whistles), either with or without visual confirmation. All statistical analyses were performed in GraphPad 8 at 95% significance level.

III. RESULTS

In total, 321 whistles were extracted from the 98.3-min recorded whistle time, which led to an emission rate of 3.27 whistles/min. Temporal and spectral parameters of the analyzed whistles are displayed in Table I. The descriptive analysis has shown mean whistle Dur of 0.56 ± 0.25 s [mean ± standard deviation (SD)]—values ranged from 0.16 to 2.17 s.

Frequency parameters recorded for whistles' acoustic repertoire have shown mean MinF and MaxF of 5.36 ± 1.45 kHz and 8.60 ± 1.55 kHz, respectively. The highest recorded frequency was 12.95 kHz, and the lowest one was 2.69 kHz. Mean BanF was 3.24 ± 1.41 kHz, whereas StaF (6.30 ± 1.87 kHz) and EndF (7.82 ± 1.98 kHz) recorded the most similar mean values.

Based on the whistle modulation type analyses, approximately 42.99% (138/321) of emitted whistles were of the ascending contour type (type I). Overall, all other whistle

TABLE I. Descriptive analyses [mean ± standard deviation (SD); minimum (Min) and maximum (Max) values; coefficient of variation (CV)] of frequency (kHz) and temporal (s) parameters recorded for whistles ($n = 321$) emitted by false killer whales (*P. crassidens*) close to Roca Partida Island, Revillagigedo Archipelago, Pacific Ocean, Mexico.

	StaF	EndF	MinF	MaxF	BanF	Dur
Mean ± SD	6.30 ± 1.87	7.82 ± 1.98	5.36 ± 1.45	8.60 ± 1.55	3.24 ± 1.41	0.56 ± 0.25
Min	2.69	2.85	2.69	4.41	0.68	0.16
Max	12.32	12.95	11.03	12.95	7.29	2.17
CV (%)	29.64	25.30	27.12	18.02	43.39	44.42

types presented proportions similar to each other; the simple flat structure (type VI) was the least prevalent contour [9.35% (30/321)]—it was followed by type II [10.59% (34/321)], type IV [12.46% (40/321)], type III [12.77% (41/321)], and type V [11.84% (38/321)], respectively. Figure 2 shows examples of whistle spectrograms and their respective adopted modulation categories.

IV. DISCUSSION

Featuring a given species' vocal repertoire is critical for the subsequent analysis of signal functionality, geographical variation, social relevance, and transmission. Bioacoustics efforts to study *P. crassidens* are, somehow, complicated due to inherent challenges associated with the assessed animals, since they mostly live in deep ocean waters; consequently, scientific acoustic knowledge about them remains scarce. Accordingly, the present study is the first to collect acoustic information about false killer whales (*P. crassidens*) distributed in Mexican oceanic waters, close to Roca Partida Island, Revillagigedo Archipelago.

Overall, based on the available literature, false killer whales often produce relatively short-Dur, little-modulation and low-frequency whistles (4–10 kHz) (Murray *et al.*, 1998; Oswald *et al.*, 2003; Weir *et al.*, 2013; Thode *et al.*, 2016) at similar mean StatF-EndF and MinF-MaxF values. These values, in turn, show markedly narrow frequency range—sometimes, they only reach 1.1 kHz (Weir *et al.*, 2013).

When it comes to spectral modulation, this species is known to mostly vocalize flat whistles (Weir *et al.*, 2013; Thode *et al.*, 2016). These particular bioacoustic features, on the one hand, favor acoustic identification between delphinid species; on the other hand, they impair the identification of intraspecific variations. False killer whale whistles can be properly species-classified based on the highest correct classification in comparison to other dolphin species (Oswald *et al.*, 2007; McCullough *et al.*, 2021); however, their time-frequency whistle measurements have failed to accurately classify encounters of three genetically differentiated false killer whale populations in Hawaii (Barkley *et al.*, 2019).

Despite BanF data, mean values recorded for frequency parameters and for the temporal production of whistles recorded for Mexican oceanic false killer whales were consistent with those found in few studies that have also shown full descriptive results (Oswald *et al.*, 2003; Oswald *et al.*, 2007; Weir *et al.*, 2013).

Oceanic studies conducted by Oswald *et al.* (2003) and Oswald *et al.* (2007) presented similar results, regardless of whether they were conducted with samples comprising 69 (Oswald *et al.*, 2003) or 340 whistles (Oswald *et al.*,

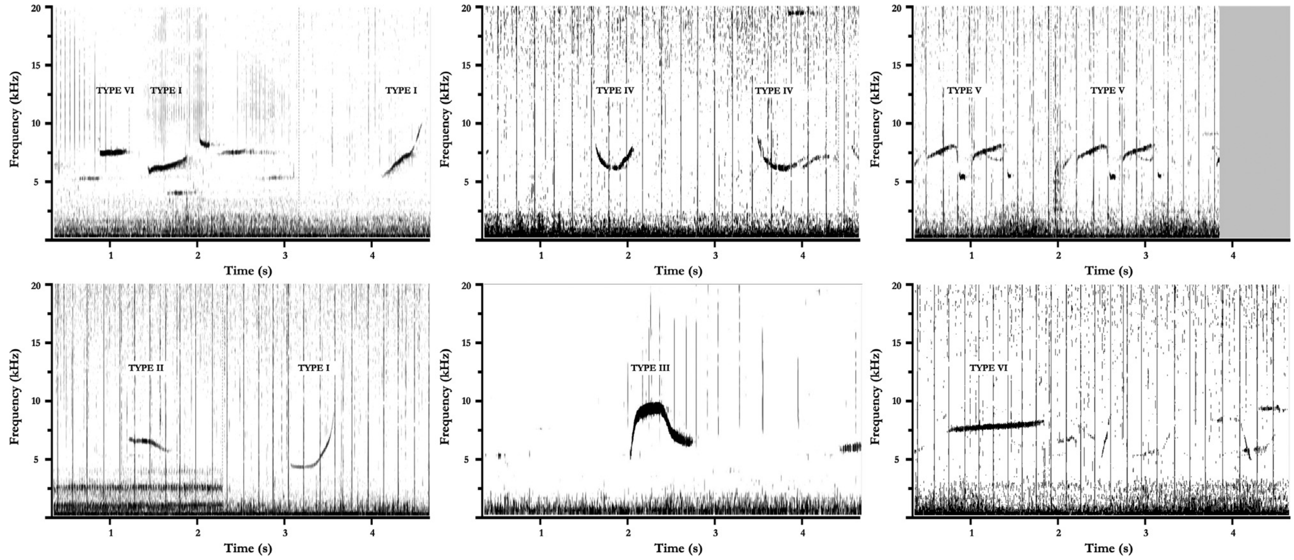

FIG. 2. Examples of whistle spectrograms and their respective adopted modulation categories emitted by false killer whales (*P. crassidens*) close to Roca Partida Island, Revillagigedo Archipelago, Pacific Ocean, Mexico. Frequency (kHz) is on the y axis, and it ranges from 0 to 20 kHz. Time (s) is on the x axis, and it represents 5 s. Scaling was the same for all items. Spectrogram settings: FFT size = 1024; Hanning window; overlap = 50%. Numerical information type at the top of each whistle represents its classification based on the adopted categories: upsweeps (type I); downsweeps (type II); inverted U-shapes (or ascending-descending) (type III); U-shapes (or descending-ascending) (type IV); wavering sinusoidal whistles (type V); and flat (type VI).

2007). These values were always below the mean values recorded herein for all assessed acoustic parameters. Sometimes, there were minimum differences in StaF [Oswald *et al.* (2003), StaF 5.20 kHz; Oswald *et al.* (2007), StaF 5.77 kHz; our results, StaF 6.30 kHz] and MinF [Oswald *et al.* (2003), MinF 4.70 kHz; Oswald *et al.* (2007), MinF 5.28 kHz; our results, MinF 5.36 kHz], and sometimes, there was greater difference in them but always similarity to each other, for example, mean MaxF [Oswald *et al.* (2007), mean MaxF 6.95 kHz; our results, MaxF 8.60 kHz] and EndF [Oswald *et al.* (2003), mean EndF 5.80 kHz; Oswald *et al.* (2007), mean EndF 6.27 kHz; our results, EndF 7.82 kHz]. On the other hand, parameters presenting the most discrepant mean results (MaxF and EndF), in comparison to results by Oswald *et al.* (2003) and Oswald *et al.* (2007), were the most similar to results observed by Weir *et al.* (2013), who recorded false killer whales ($n = 20$ whistles) in continental shelf waters in Gabon and Côte d'Ivoire.

Mean duration result (0.56 s) recorded in the current study was higher than that of previously documented oceanic [0.4 s (Oswald *et al.*, 2003) and 0.44 s (Oswald *et al.*, 2007)] and neritic [0.32 s (Weir *et al.*, 2013)] encounters. Thus, the lowest and the highest temporal differences were observed in a study that used a sample size similar to the present one (Oswald *et al.*, 2007) ($n = 340$ whistles) and in the study that recorded the smallest whistle sample (Weir *et al.*, 2013) ($n = 20$ whistles), respectively. Small sample sizes reduce the possibility of observing less frequent events that, after all, reduce the amplitude of the observed results.

The current mean BanF (mean 3.24 ± 1.41 kHz) represented more than twice the means reported in the literature [Oswald *et al.* (2003), mean BanF 1.40 ± 1.3 kHz; Weir *et al.* (2013), mean BanF 1.10 ± 0.72 kHz]. According to Weir *et al.* (2013), their results were comparable to those observed by Oswald *et al.* (2003); small sample sizes preclude any meaningful discussion about vocalizations produced by false killer whales. Furthermore, the only study capable of providing acoustic parameter values of BanF comparable to the present ones did not reveal its mean data (Oswald *et al.*, 2007).

Whistle modulation analysis [type I: 42.99% (138/321)] results contradicted the idea that false killer whales mostly produce constant whistles (Murray *et al.*, 1998; Oswald *et al.*, 2003; Weir *et al.*, 2013; Thode *et al.*, 2016). Lack of well-established reproducibility criteria for whistle type categorization among studies may have generated results different from those expected for signal modulation. These findings would explain why our results presented mean values for acoustic parameters similar to those found in the literature, but with clear and unprecedented prevalence of ascending whistles. Although false killer whale whistles may seem visually flat in the spectrogram, they oftentimes show subtle slope; however, when they are carefully analyzed, they can be categorized as type I. This finding clearly showed increased prevalence of upsweep contours (type I) that, consequently, reduced values recorded for flat whistles (type VI).

Finally, it is important to take into consideration that our acoustic results could be influenced by many factors, such as habitat, genetic or cultural drift, group size, group composition, and behavior (Murray *et al.*, 1998; May-Collado and Wartzok, 2008). However, these factors were not controlled herein.

Bioacoustics emissions can be used as a tool in both evolutionary studies and applied ecology or species conservation studies (Laiolo, 2010). In the future, attempts to categorize the whistle types of false killer whales and other studies focused on acoustic monitoring based on environmental and behavioral context will help broaden bioacoustics knowledge about this species and contribute to their conservation.

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