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Acoustic recordings of rough-toothed dolphin (*Steno bredanensis*) offshore Eastern Sicily (Mediterranean Sea)

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Abstract: Rough-toothed dolphin's abundance and distribution is largely unknown worldwide and evaluation of its conservation status in the Mediterranean Sea is necessary. A rough-toothed dolphin was sighted offshore Eastern Sicily (Mediterranean Sea) in July 2017 and acoustic data were acquired in the same area of Watkins, Tyack, Moore, and Notarbartolo di Sciara [(**1987**). Mar. Mamm. Sci. **3**, 78–82]. An automatic detection algorithm was developed to identify the echolocation clicks recorded within both datasets and a recurrent inter-click interval value was identified during the new encounter. Distinctive whistle classes were also identified with similar contour shapes within both datasets.

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1. Introduction

The rough-toothed dolphin (*Steno bredanensis*) is the only species in the genus *Steno*. It has only recently been included among the cetaceans regularly noted in the Mediterranean Sea, as a result of sightings mainly reported in its eastern basin, although the sub-population is likely of Atlantic origin (Kerem *et al.*, 2016). Little is currently known regarding the species' Mediterranean distribution, ecology and potential management needs (Notarbartolo di Sciara and Birkun, 2010).

Globally, rough-toothed dolphins inhabit warm-temperate, tropical, and subtropical deep waters close to steep volcanic islands (Jefferson *et al.*, 2015; Miyazaki and Perrin, 1994; West *et al.*, 2011). They are often described as solitary or in groups of 10–50 individuals (Baird *et al.*, 2008; West *et al.*, 2011), however, groups with more than 100 animals have been observed (Watkins *et al.*, 1987). Animals are usually found 2–5 km from shore in areas with an average depth of 500–2000 m (Baird *et al.*, 2008; Gannier and West, 2005; Oremus *et al.*, 2012; West *et al.*, 2011). Rough-toothed dolphins have been reported to form mixed schools with different species within the family *Delphinidae*, such as Risso's dolphin (*Grampus griseus*) in the Mediterranean Sea (Ryan *et al.*, 2014), and also with humpback whales (*Megaptera novaeangliae*) (West *et al.*, 2011). The size and status of most populations are poorly known for most regions of the world (West *et al.*, 2011).

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The acoustic behavior of this species is poorly understood. The few data that are available, primarily from the Pacific Ocean, suggest that rough-toothed dolphins produce broadband echolocation clicks from 10 to 90 kHz (Oswald *et al.*, 2003) and short-duration whistles (ca. 0.5 s) with an average frequency range from 2.5 to 10 kHz (de Lima *et al.*, 2012; Rankin *et al.*, 2015).

In the Mediterranean Sea, the status of rough-toothed dolphins changed from "occasional" to "possibly regular" after an unexpected sighting offshore Eastern Sicily in September 1985 (Watkins *et al.*, 1987). Previously, only uncertain sightings of this species had been reported in the Ionian Sea and the Sicily Channel (Di Natale and Mangano, 1981; Cagnolaro *et al.*, 1983). Watkins *et al.* (1987) reported a large aggregation—approximately 160 animals—offshore Cape Passero (Ionian Sea). After 1987, sightings were documented only in the Eastern Ionian Sea and Levantine Basin (see Kerem *et al.*, 2016 for a complete review), except for one case in the Central Ionian Sea. In this last observation an acoustic recording in which vocalizations of rough-toothed dolphin were identified was acquired by International Fund for Animal Welfare (IFAW) on 14 September 2003 between Italy and Greece (Boisseau *et al.*, 2010). Table 1 reports the few sighting and stranding events in Central and Western Ionian Sea from 1985 (Watkins *et al.*, 1987) until this work. Still, very little research has been conducted to improve scientific knowledge about the species' conservation status in the Mediterranean Sea (Kerem *et al.*, 2016).

Here, we present results from an opportunistic survey conducted in July 2017, as part of an oceanographic cruise in Western Ionian Sea. A rough-toothed dolphin was sighted southeast of Sicily coast, offshore Cape Passero (Table 1; Fig. 1) and acoustic recordings were made. About thirty years after the last documented sighting of rough-toothed dolphins offshore Eastern Sicily (Watkins *et al.*, 1987), this study aims at posing new attention to their presence and acoustic behavior in the area. Recorded vocalizations were analyzed to investigate patterns in echolocation signals (regular clicks) and contour shapes of social sounds (whistles). A comparison with the dataset recorded by Watkins *et al.* (1987) was also performed in order to improve potential passive acoustic monitoring (PAM) activities in the study area.

2. Materials and methods

The survey region was located in the Western Ionian Sea. Topography of the area is characterized by a short continental shelf with a rapid slope into very deep waters (ca. 2000 m; Fig. 1). This is a data-poor zone with respect to marine mammal ecology and conservation biology (Caruso *et al.*, 2015; Caruso *et al.*, 2017; Sciacca *et al.*, 2015), with few regular visual and acoustic boat-based surveys. The cruise was focused over the slope and submarine canyons. Visual and acoustic observations of cetaceans were made over 16 days at sea. During a transit of 1225 km aboard a 54-ft catamaran, 623 km were surveyed by four trained observers when meteorological conditions were sufficient to detect cetaceans by visual monitoring (Beaufort Sea state <3), at a speed of approximately 7–12 km/h. Observers were located on a platform at ca. 6 m above sea level. They regularly scanned the 360° view around the boat by naked-eye and with 7×50 binoculars. Track data were recorded continuously using Locus Map Free App for Android (Asamm Software, Prague, CZ). Associated geographical information (meteorological conditions, acoustical stations, sighting descriptions) was also recorded using the same app. During a sighting, animal(s) were approached to identify species, count number of individuals, describe behavioral context and enable recordings of acoustic data. A total of 52 sightings, 34 occurred on-effort, were noted during the survey. The number of sightings included 27 of striped dolphin occurrences, 5 sightings of Cuvier's beaked whales, 1 of sperm whales and 1 sighting of the rough-toothed dolphin.

Acoustic data were obtained using an AS-1 hydrophone (linear frequency range: 1 Hz to 100 kHz ± 2 dB; receiving sensitivity: −208 dB re 1 V/μPa) with PA-4 preamplifier, from Aquarian Audio (Aquarian Audio & Scientific, AFAB Enterprises, WA, United States) and a 16-bit a Behringer U-PHORIA USB acquisition board (Behringer GmbH,

Table 1. Available records of rough-toothed dolphin sightings (SI), stranding (ST), and acoustic recordings (R) since 1985 in Central and Western Ionian Sea. Coordinates, location, and number of individuals (n) are reported for each event.

Year	Record	Lat	Long	Location	Type	n
1985	Watkins *et al.* (1987)	35°28′26″ N	15°53′04″ E	SE Cape Passero	SI + R	∼160
2002	Cagnolaro *et al.* (2015); Banca Dati Spiaggiamenti (2018)	36°45′36″ N	14°38′24″ E	Donnalucata (Sicily)	ST	6
2003	Boisseau *et al.* (2010)	38°29′40″ N	18°47′25″ E	Central Ionian Sea	SI + R	8
2017	Caruso *et al.* (present work)	36°35′80″ N	15°32′35″ E	E Cape Passero	SI + R	1

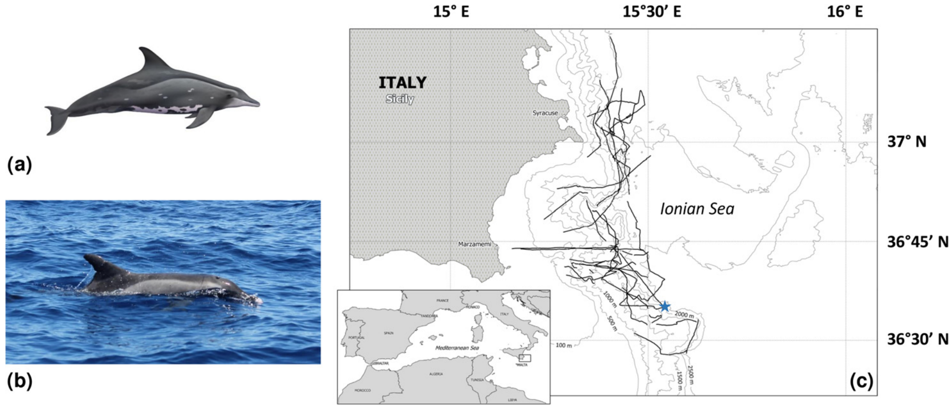

Fig. 1. (Color online) (a) Graphic representation of rough-toothed dolphin (NOAA Fisheries, 2019). (b) Picture of the animal sighted offshore Eastern Sicily in July 2017. (c) Map of the monitoring area. Black lines show transects when meteorological conditions were sufficient to detect cetaceans by visual monitoring. The star symbol indicates the rough-toothed dolphin sighting location (36°35′80″ N, 15°32′35″ E).

Kirchardt, DE) sampled at 44.1 kHz sampling rate. The board was connected to a laptop computer. The software SEAPRO (Pavan, 2017) was interfaced to the hardware device for real-time spectrogram visualization and acquisition of the recordings. A 37.14 min long acoustic recording was acquired during the 2017 sighting.

The dataset from Watkins *et al.* (1987), retrieved from the Watkins Marine Mammal Sound Database (WHOI Marine Mammal Center, 2019; Sayigh *et al.*, 2016), consisted of a 14.22 min long recordings acquired using an array of Ithaco 602M108 hydrophones, Ithaco 450 amplifiers and WHOI/PEMTEK tape recorders with a sampling frequency of 192 kHz. Hereafter, the two datasets will be referred to as "2017" and "1985."

2.1 Click analysis

An automatic click detector was *ad-hoc* developed in MATLAB (The MathWorks, Inc., MA, United States) in order to analyze the inter-click interval (ICI) of the recorded echolocation clicks. The algorithm initially applied a finite impulse response high-pass filter at 6000 Hz to the original signal in order to exclude low frequency background noise. A Hilbert transform was performed and the 99th percentile of the resulting energy envelope signal (h) was calculated. The function *findpeaks* was then applied to the Energy envelope. This function searched for peaks higher than $2*h$ and for a distance between consecutive peaks of at least 0.1 ms. This value was selected as a reliable minimum distance for the detector to discriminate among different clicks when searching for energy peaks (Rankin *et al.*, 2015). Hence, the algorithm identified target clicks when isolated peaks were present with high signal-to-noise ratio (value at least three times higher than the 20th percentile of the background noise measured within a window of 1 ms). Once click events were selected, the click detector extracted the original signal lasting about 4 ms around each peak (1 ms before and 3 ms after). Reference time for each click was marked as "detection time."

An expert PAM operator confirmed the results by looking at both the waveform of the clicks extracted and the spectrogram (Fig. 2) of each audio file. The inter-click interval (ICI) was measured as the time between two consecutive click "detection times" for 2017 and 1985 datasets. Attributing *a priori* functional characterization to click series may be often considered incautious (Rankin *et al.*, 2015), thus distribution of the ICI values was studied in order to identify the occurrence of stable temporal patterns in the recorded series of clicks. In order to compare the distribution of the ICI values from the two datasets, we performed a Kolmogorov-Smirnov test for equal distributions, p (same distance) < 0.001. Following Frasier *et al.* (2017), we defined the most frequently observed ICI during period of clicking as the "modal ICI." Events were defined as "click trains" when the ICI value decreased rapidly from about 100 ms to less than 1 ms within a sequence of clicks (Rankin *et al.*, 2015).

2.2 Whistle analysis

In order to assess the presence of rough-toothed dolphin whistles in the recordings, expert operators visually analyzed all acquired data through spectrogram visualization and listening (FFT size 1024 points, overlap 50%, Hanning Window), by using RX5 (iZotope, Cambridge, MA) audio editor software, following Parisi *et al.* (2017). Total duration, minimum frequency (Fmin), maximum frequency (Fmax), and frequency range (FR, expressed as difference between Fmin and Fmax) were measured for both datasets (2017 and 1985). For the 1985 dataset, acoustic data were acquired during sighting of a large number of rough-toothed dolphins (>100 animals), with numerous whistles recorded simultaneously.

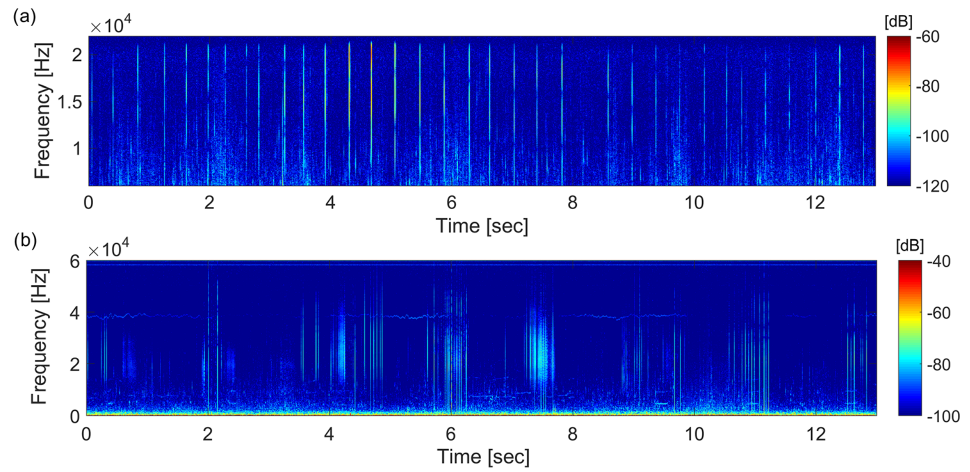

Fig. 2. (Color online) Typical detected click series. Spectrograms of a 13 s section from (a) 2017 dataset (nfft = 2048; overlap = 50; Hann window) and (b) 1985 dataset (nfft = 4096; overlap = 50; Hann window).

Therefore, it was not possible to measure time and spectral features for all the recorded whistles due to overlapping of their contour shapes. Nevertheless, the acoustic parameters of specific categories of whistles were also reported for the 1985 dataset.

3. Results

A solitary traveling rough-toothed dolphin was sighted at the described location [Table 1, Fig. 1(c)] and 1740 echolocation clicks were detected during the encounter. Because only one animal was sighted, we expect all clicks and their sequences to be emitted by solely that animal. In the 1985 dataset, the detector revealed about 7664 echolocation clicks associated to the simultaneous emission by several animals, as described by Watkins *et al.* (1987). An example of the typical click series detected in the two datasets is shown in Fig. 2.

The variation of ICI values over recording time was measured for both the 2017 and the 1985 datasets (Fig. 3). ICI values from both datasets followed a non-parametric distribution (Shapiro-Wilk test, p-value <0.001). In order to compare the two distributions, we randomly selected a subsample of 1733 ICI values from the largest dataset (1985) before testing for equal distributions. The two samples were significantly different following Kolmogorov-Smirnov test (N: 1733, D: 0.74, p-value <0.001). In 2017 dataset, a modal ICI of 400 ms was measured and it highlighted the occurrence of a stable interval among clicks [Figs. 3(a1) and 3(a2)]. In addition, most of ICI values were higher than 100 ms, as indicative of a series of echolocation clicks, with only few click trains of shorter ICIs. These shorter ICIs ranged from ca. 0.7 to 15 ms. Click trains occurred indeed only three times, covering 0.03% of recording time. In 1985 dataset, the distribution of ICIs shows that most of the recorded clicks ($>$ 90%) were found at intervals shorter than 100 ms, with a clear predominance of click trains [Figs. 3(b1) and 3(b2)].

A total of seven whistles were recorded in 2017 and the main signal parameters were measured. The mean duration of whistle vocalizations was 734 ± 193 ms (mean

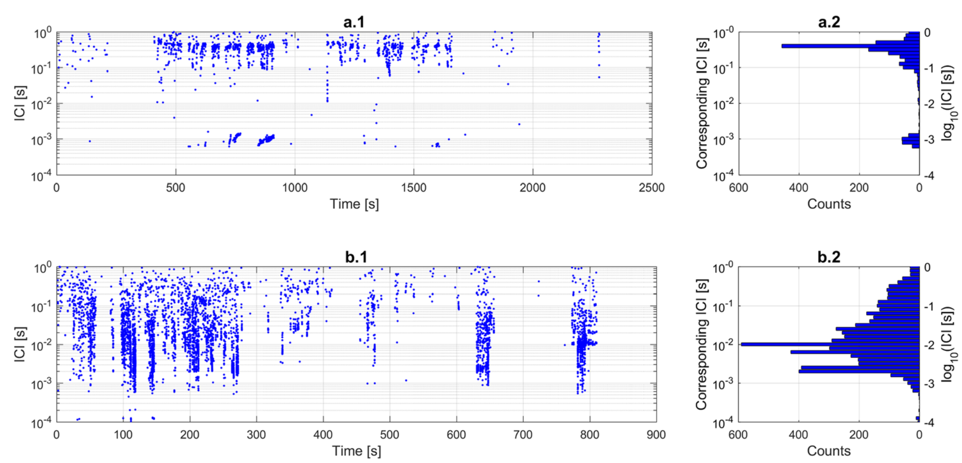

Fig. 3. (Color online) Inter-click interval (ICI) of detected clicks. (a1) and (b1), respectively, show ICI variation over recording time for 2017 and 1985 datasets (log scale). (a2) and (b2) show the frequency distribution of $\log_{10}$ ICI values binned between −4 and 0 in 0.1 increments, corresponding to ICI values between 10^{-4} and 1 s.

± SD), frequency range was 3.6 ± 1 kHz (mean ± SD), with a minimum frequency of 5.1 ± 0.9 kHz (mean ± SD) and maximum frequency of 8.8 ± 1.4 kHz (mean ± SD). Two main whistle categories were identified [Fig. 4(a)]. The first category included four upsweep fragmented whistles (type A). The second category (type B) was characterized by a short-fragmented part, followed by a long concave part. Subsequently, we examined the 1985 dataset to recognize clear contour shapes of the observed whistle categories. In total, 282 tonal sounds were identified, and it was possible to identify the types A and B [Fig. 4(b)] in, respectively, 68 (24.1%) and 21 (7.4%) whistles. In Table 2, we report the values (Mean ± SD) of duration, frequency range, minimum, and maximum frequencies for whistle types A and B within both datasets (2017 and 1985). Considering the low number of whistles recorded in 2017 ($n = 7$), statistical comparison between the two datasets was not performed.

4. Discussion

This study presents the results of acoustic recordings of a rough toothed dolphin in the same Mediterranean area noted in 1985 recordings (Watkins *et al.*, 1987). Data analyses were focused on the characterization of the signal features useful for future PAM activities in the study area. This rare recording of a long sequence of regular clicks, with few bursts, allowed us to measure the statistical mode as representative of a stable interval between clicks (2017 dataset). The occurrence of modal ICIs has been recently found to be a significant parameter in the automatic classification of clicks from different delphinid species over big data series (Frasier *et al.*, 2017).

However, ICIs can be challenging to measure with groups of odontocetes because overlapping click trains will make individual ICIs uncertain and difficult to obtain. While the 2017 data is perhaps limited in overall duration, number of animals encountered and sampling frequency of the acquisition system, the analysis of stable ICI provided important and new information for potential future classification methods. Moreover, few whistles were recorded in 2017, but the comparison performed with the 1985 dataset allowed us to extend the available data in the study area and to investigate the presence of recurrent acoustic cues in the vocal repertoire of Mediterranean rough toothed dolphin.

In general, the recorded whistles (types A and B) showed similar spectral characteristics described in other areas for different rough-toothed dolphin populations (Rankin *et al.*, 2015; Kerem *et al.*, 2016). This typical pattern in whistle modulation, consisting of upsweeps as well as downswept-stepped segments, was also observed during the comparison performed with the dataset from Watkins *et al.* (1987). Fragmented upsweeps (type A) were the most represented whistle category within both datasets (2017 and 1985). As proposed by Kerem *et al.* (2016), this distinctive frequency modulation could represent a prevalent component of the social acoustic behavior of Mediterranean rough-toothed dolphin.

With the establishment of the Watkins Marine Mammal Sound Database, we easily retrieved the data acquired in the same study area thirty years earlier. The Watkins

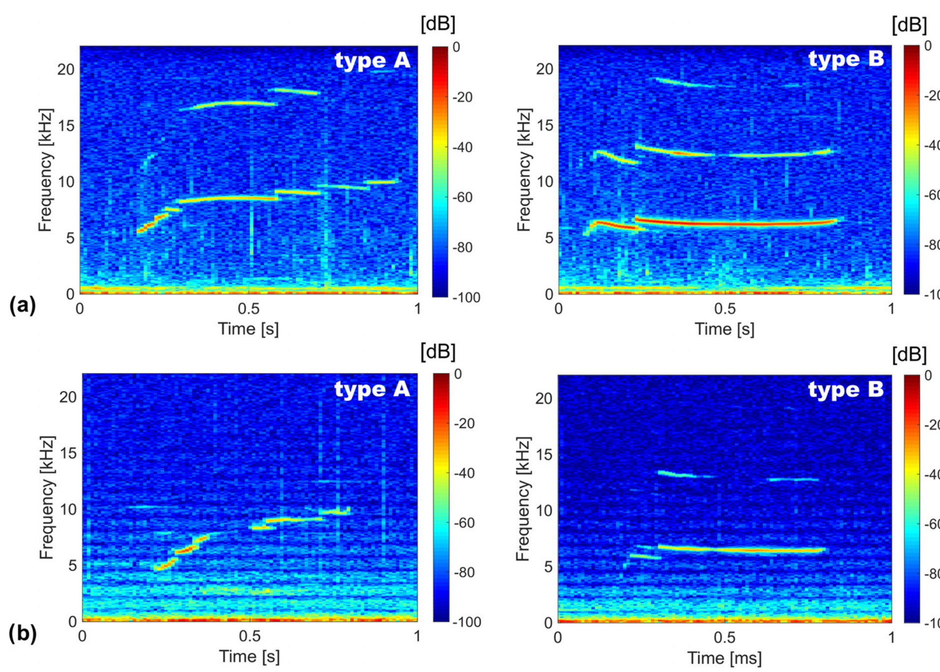

Fig. 4. (Color online) (a) Spectrograms (nfft = 1024; overlap = 50; Hann window) of the two whistle categories (type A and type B). (b) Same categories of whistles recorded by Watkins *et al.* in 1985.

Table 2. Descriptive variables with mean ± SD of the four acoustic parameters (duration, minimum frequency, maximum frequency, frequency range) measured for the two types of whistles identified (type A and type B) within both datasets (2017 and 1985). Numbers in parentheses are the number of whistles analyzed.

	2017		1985	
	Type A ($n = 4$)	Type B ($n = 3$)	Type A ($n = 68$)	Type B ($n = 21$)
Parameters	Mean ± SD		Mean ± SD	
Dur (ms)	692 ± 228	789 ± 26	643 ± 215	603 ± 248
Fmin (kHz)	5.7 ± 0.5	4.5 ± 0.6	4.7 ± 0.9	5.5 ± 0.8
Fmax (kHz)	9.9 ± 0.2	7.4 ± 0.6	8.4 ± 0.9	7.1 ± 0.7
FR (kHz)	4.3 ± 0.7	2.9 ± 0.7	3.7 ± 1	1.6 ± 0.6

database has enormous historical and scientific value. Such type of open source databases represents a fundamental tool for future studies of animal vocalizations, by enabling examination of possible long-term changes in vocal features due to increases in ambient noise levels, as well as geographical and temporal variations. In this work, we highlight the importance of using open source sound databases as scientific reference datasets, going towards the development of increasingly accurate acoustic monitoring and classification systems (Oswald *et al.*, 2007; Roch *et al.*, 2011; Frasier *et al.*, 2017; Leroy *et al.*, 2018; Hildebrand *et al.*, 2019; Simões Amorim *et al.*, 2019). These are urgently needed to perform long-term abundance and population studies on cetacean species, such as the rough-toothed dolphin, for which very little information is still available in the Mediterranean Sea.

5. Conclusions

The International Union for the Conservation of Nature (IUCN) Red List considers the rough-toothed dolphin as a species of "Least Concern," however, their abundance and distribution remain largely unknown worldwide (Hammond *et al.*, 2012). The evaluation of its conservation status in the Mediterranean Sea seems incomplete due to the lack of documented long-term observations. The results provided here offer additional references for the development of increasingly accurate PAM identification algorithms. Particularly, this was the first documented acoustic recording of a single emitting individual of rough-toothed dolphin in the Mediterranean Sea. Previous observations described only acoustic data obtained in presence of groups or large aggregations of rough-toothed dolphins, also observed in association with other species (Kerem *et al.*, 2016). Considering the known habitat preferences of *Steno bredanensis* (West *et al.*, 2011), this sighting strengthens the hypothesis that Eastern Sicily may represent an important area for the population that seems to prefer the eastern Mediterranean basin (Kerem *et al.*, 2016).

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