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ACOUSTIC STUDY OF DIVING SPERM WHALES DURING A WEEK OF CONTINUOUS MONITORING IN THE WESTERN IONIAN SEA.

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ABSTRACT

Endangered Mediterranean sperm whales (*Physeter macrocephalus*) have been monitored in the Ionian Sea via acoustic observatories since the early 2000s. SMO-OνDE acoustic antenna, deployed in the Gulf of Catania at 2100 m depth (2013-2021), consisted of a tetrahedron of synchronized hydrophones sampling at 192 kHz. Real-time acoustic data analysis saved a 5-minute subset every hour. We report sperm whale detection analysis from February to April 2017 and one additional week of continuous raw data. Sperm whale clicks were detected and tracked in a range of 15 km around the observatory. The species was detected almost daily during all months. Different sound types, including regular clicks, 3+1codas, and creaks were found throughout the continuous week. Diving whales' movements were reconstructed by acoustic tracking. 47 dives were studied, and multiple whale movements were reconstructed. Our results confirm the presence of the species about ten years after the previous study in the area and demonstrate the first simultaneous underwater tracking of communicating sperm whales, even in the presence of large vessels and high noise levels. This study reveals essential information on sperm whale behavior and responses to noise, as required for conservation purposes.

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1. INTRODUCTION

The Mediterranean sperm whale is listed as Endangered by the IUCN red list for threatened species [1]. The sperm whale continuously emits impulsive sounds (i.e. *clicks*) to acoustically map the surrounding environment, to search for food and to communicate with conspecifics during dives. Clicks have a duration of about of 10 - 30 ms, source levels up to 236 dB re 1 µPa (RMS) and they typically have a centroid frequency of 15 kHz, going up to more than 30 kHz [2]. Three main click types were considered in this study:

– Regular clicks: associated with the echolocation (i.e. orientation and predatory activity) of the sperm whale are emitted during deep dives. This category includes long sequences of highly directional clicks, with a stable interval between one click and the next, known as the Inter Click Interval (ICI), varying between 0.5 d and 2 s [3].
– Creaks: associated with the final phase of the echolocation sequence, linked to prey capture during deep dives and reach an ICI as low as 5 milliseconds.
– Codas: stereotyped and repetitive sequences of clicks, lasting 0.5-5 s. Their characteristics vary regionally and with group composition. Codas are considered to be associated with social contexts within units of sperm whales [4]. In the Mediterranean Sea the most common sequence is the "3+1" [4], but by the "2+1" sequence was also recorded in the study area [5].

Sperm whales are common in the Western Ionian Sea, which may represent an important feeding and aggregation site for deep-diving whales [2]. However, the available

information on the ecology and behavior of the sperm whale in the area is not homogenous and the most recent studies employed data collected in 2005-2006 [2,5,6]. Several factors influence the high mortality of this population, and anthropogenic noise is known to cause behavioral and physiological effects in cetaceans. Impulsive noise due to propeller cavitation has been observed to interfere with orientation and acoustic communication in odontocete species [7]. Yet, the extent of the effects caused by ship noise on sperm whales are still largely unknown [8]. This study aims to reveal the occurrence of the species over 3 months in 2017, ten years after the previous study in the same location. Moreover, the study shows the first acoustic tracking of multiple sperm whales emitting codas, even in the presence of large vessels and high noise levels.

2. METHODS

The SMO-OvDE acoustic array was located within the Gulf of Catania (Ionian Sea), at a depth of 2076 m, approximately 25 km offshore Catania. The array consisted of four synchronized broadband hydrophones arranged in a tetrahedral configuration and connected to the onshore laboratories via an electro-optical cable. The signals, sampled at 192 kHz, were saved in 5-minute cycles every hour for subsequent analysis [9]. For this study, acoustic data collected at 5-minute intervals per hour were analyzed for the period spanning February 2nd to April 30th, 2017, complemented by continuous data acquired from February 22nd to February 28th, 2017. Continuous data acquisition was triggered following the detection of sperm whale vocalizations, facilitating a comprehensive and detailed analysis of behavioral patterns. The maximum detection range of sperm whale signals was estimated to be about 12 km around the station under optimal recording conditions [6]. The open-source software "Audacity" was employed for initial acoustic data analysis. Spectrograms were processed with a Fast Fourier Transform (FFT) size of 1024 points, a 50% overlap, and a Hanning window. An expert operator estimated the occurrence of sperm whales' acoustic signals and classified them into "regular clicks" (RC), "codas" (CD), and "creaks" (CR) types. The overall detection rate and the daily rates for each click type were calculated.

Sperm whales movements were then reconstructed acoustically using the localization and tracking technique described in [6]. The noise produced by close vessels in the monitoring area was also studied and the vessel source position was reconstructed by using automatic identification system (AIS) information within a range of 15 km from the observatory. As a case study, we reconstructed the positions of a diving sperm whale, during the passage of a bulk carrier vessel above SMO-OvDE station, over about 60 recording minutes.

3. RESULTS

The daily data analysis showed that in the months of February-March-April 2017, sperm whales were detected on an almost-daily basis (Figure 1)

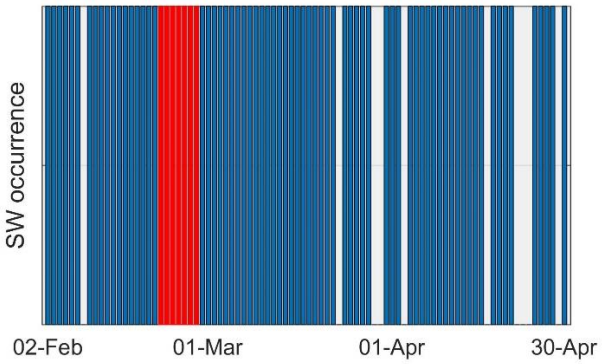

Figure 1. Daily detections of sperm whales between February 2nd and April 30th, 2017. Blue bars indicate SW detection, red bars mark the continuous recording period from February 22nd to 27th, 2017.

The occurrence of sperm whale clicks, click types and number of reconstructed acoustic tracks in all 5-min files available during the week of continuous monitoring is shown in Table 1.

Table 1. Number of 5-min files available (files), files with regular clicks (R), codas (CD), and creaks (CR), and relative percentage of time with sperm whale detections (SW %) for each recording day (Feb 22nd to 28th). The number of reconstructed acoustic tracks (tracks) is also indicated.

Day	Files	SW (%)	R	CD	CR	Tracks
22	102	91.18	93	12	2	5
23	205	99.51	204	63	6	23
24	132	97.73	129	21	2	12
25	129	98.45	129	10	0	0
26	208	58.17	121	2	2	0
27	125	49.00	50	1	0	3
28	300	50.00	1	0	0	30

Figure 2 shows the cumulative detection rate and the distribution of the three click types in the presence of one or more individuals. Results show that when multiple individuals were detected, the number of files containing regular clicks and codas increased. Files containing creaks displayed minimal values, both in the presence of a single individual and of multiple individuals.

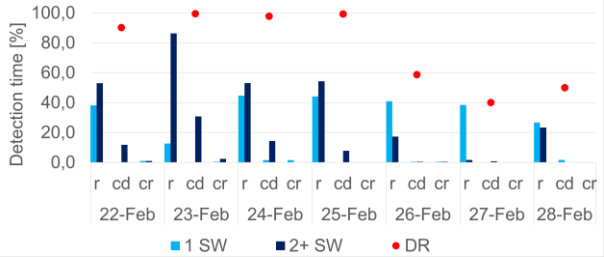

Figure 2. Detection time (%) referred to files containing regular clicks (r), codas (cd), and creaks (cr) produced by either a single sperm whale (1 SW) or multiple individuals (2+ SW) during the continuous monitoring week. Red dots represent the detection rate (DR), i.e. files with detected acoustic signals per day, relative to the availability of acoustic data.

47 acoustic tracks of diving sperm whales were reconstructed during the whole monitoring week. The daily distribution of all detected depths from acoustically tracked sperm whales is shown in Figure 3.

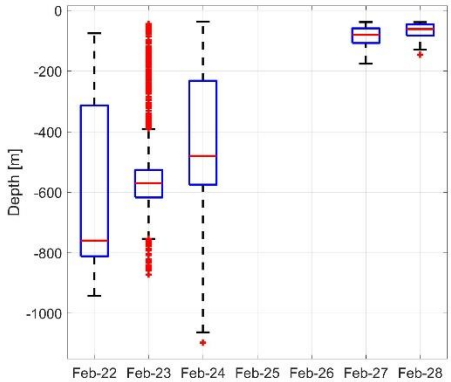

Figure 3. Boxplot showing the daily statistical distribution of the depths (m) from all tracked sperm whales during the continuous monitoring week.

74.5% of the reconstructed acoustic tracks of diving sperm whales occurred in the presence of transiting vessels in the same range of detection. Figure 4 shows the example of an acoustic track of a single sperm whale diving close to a transiting bulk carrier vessel (AIS track), for 60 recording minutes.

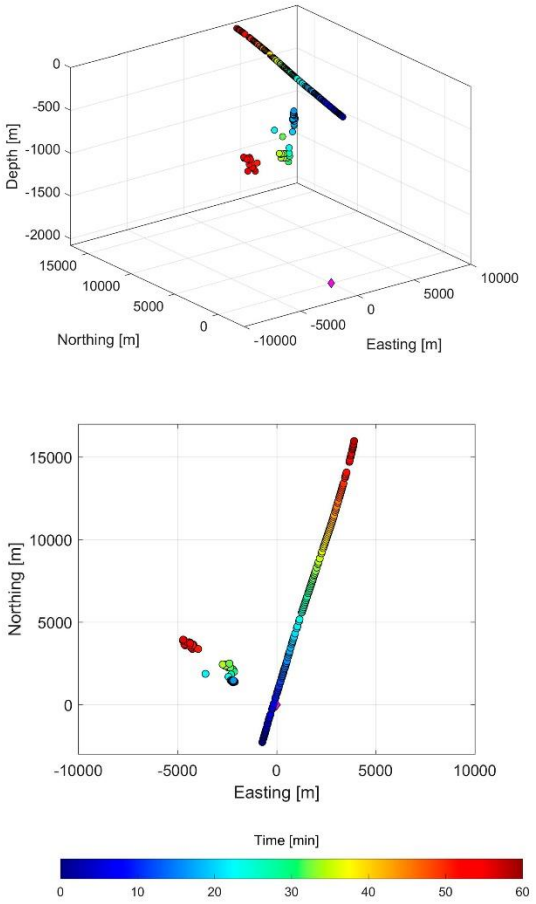

Figure 4. Reconstructed vessel positions (by AIS) and sperm whale acoustic track over 1 h of continuous monitoring. The purple diamond marker indicates the position of the SMO-OvDE observatory.

4. DISCUSSION

Our findings confirm the presence of the species approximately ten years after the previous detection studies conducted in the area [2]. The daily occurrence of sperm

whales in the Gulf of Catania was demonstrated, for the first time, throughout the analyzed period (February–April 2017). The number of files containing sperm whale clicks showed a decreasing trend throughout the whole continuous acoustic monitoring week. February 23rd was the day with the highest percentage of recording time with sperm whale detections (99.5%) and reconstructed acoustic tracks (23). Reconstructed tracks showed that in 60% of the cases the animals detected were diving between 450 and 750 m, reaching a maximum depth slightly higher than 1300 m. Multiple whales were tracked simultaneously on February 22nd, 23rd and 24th and the higher variability in the depth variation on the 23rd is likely related to the detection of 2, and possibly more sperm whales. Concerning the different types of signals, the number of files with regular clicks was significantly higher compared to the other two categories. Considering the nature and main function of regular clicks in echolocation, a predominantly exploratory behavior can be inferred. Finally, codas were always characterized by the "3 + 1" sequence [4,5] and were detected with decreasing frequency throughout the analysis period. The trend in the number of recordings with sperm whale clicks was found to correlate with the number of acoustically active individuals in the area. Specifically, regular clicks and codas were more frequently recorded in the presence of two or more individuals, consistent with the role these signals play in intraspecies communication. In addition, presented results confirm the potential of continuous passive acoustic detection and tracking in assessing the exposure of sperm whales to ship noise.

5. CONCLUSIONS

Extending the study of the reconstructed tracks and integrating information related to the acoustic behavior of the animals will be essential in understanding the ecological significance of observed diving depths. Developed methods will also enable the evaluation of received levels over long-term studies. The system may be essential in assessing the occurrence of behavioral reactions and exposure levels when a vessel approaches. Cabled observatories such as SMO-OvDE offer the opportunity to develop increasingly efficient monitoring methods to address a number of questions concerning the species conservation status and to assess the impact of shipping noise on the Mediterranean sperm whale population.

6. ACKNOWLEDGMENTS

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