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Comparison of acoustic patterns recorded for the sperm whale (*Physeter macrocephalus*) in the Northern Ionian Sea (Central Mediterranean Sea) and in the North-western Levantine Sea (Eastern Mediterranean Sea)

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***Abstract* – Sperm whales *Physeter macrocephalus* show a steady population decline, yet despite their threatened status, there remains a dearth of knowledge in the Mediterranean Sea. The current study reports the preliminary results of sperm whales' acoustic patterns within the Gulf of Taranto and the North-western Levantine Sea. "Regular" clicks were recorded in both regions indicating the presence of foraging grounds. "Codas" were also present in the North-western Levantine. The presence of codas and social units emphasises the importance of the North-western Levantine as potential nursery grounds. Further, inter-click intervals were slightly smaller for the Taranto Gulf while recordings from the North-western Levantine Sea showed similarities with the Mediterranean Sea. Lastly, sperm whales were larger in size in the Taranto Gulf compared to the North-western Levantine Sea. The current results depended on data collected on a single date, therefore further research must be implemented to understand the acoustic patterns of sperm whales.**

I. INTRODUCTION

The sperm whale *Physeter macrocephalus* shows a widespread distribution at Mediterranean scale [1] inhabiting offshore and continental slope waters, where mesopelagic cephalopods are most abundant [2,3]. However, since the 1980s, the Mediterranean subpopulation has shown a steady decline and thus, it has been classified as Endangered by the IUCN Red List [4]. Despite an increase in dedicated survey efforts on sperm whale during last decades, the knowledge of its abundance, spatial-temporal distribution, habitat preferences and behavioural patterns tends to be localized mainly to the western and central Mediterranean Sea, with less than a handful of basin-wide research efforts [5,6,7,8]. In addition, only recently a great effort was carried out to investigate the occurrence and abundance of sperm whales in Eastern Mediterranean Sea [5, 9, 10, 11, 12,13,14]. Despite an increase on research effort, the acoustic patterns of Mediterranean subpopulation of sperm whales have been poorly investigated [15,16,17], which can reveal important information from foraging strategies to population structure and cultural transmissions [18]. Sperm whales do not produce whistles, but instead only use broadband pulses or clicks [19]. Typical known vocalization patterns of sperm whales were "regular" clicks, while codas are occasionally produced. The former is identified as extended sequences of loud clicks produced at regular rates of approximately 0.5-2 clicks per second and they generally take place during the long and deep foraging dives and serve to echolocate the prey [20]. The codas are distinctive and short stereotyped sequences of clicks with a time pattern, produced in the presence of multiple individuals and commonly heard during group aggregation, even if they were occasionally produced at the end of a "regular" click sequence of foraging dives [21]. Social groups of females and juveniles produce higher rates of codas at the surface while they are interacting and it was proposed that codas are linked to some types of communication, likely to be learnt within matrilineal social groups [22] and identifiable for the vocal clans [23, 24]. However, individual or group identification does not appear to be the main function of codas and the most plausible primary function of codas is for the maintenance of social bonds, especially following periods of dispersion or separation, such as following foraging events [25]. Although multiple coda repertoires of sperm whales were recorded in Pacific region, the Mediterranean subpopulation showed little variation of coda repertoire

[15]. The Mediterranean subpopulation dominantly produce 3+1 codas, with a duration ranging from 456 to 1280 ms, and an average duration of 908±176 ms [15]. It is important to note that the 3+1 codas in the Mediterranean are dominantly recorded after foraging dives, while in the Pacific Ocean these are recorded in large socializing groups. Further, males tend to have smaller repertoires than females and the recordings in the Central Mediterranean Sea mainly originated from males leaving the potential for greater variation that previously considered [15]. Therefore, considering the different settings, it is likely that even though codas may have similar structures, social structure of the group will affect the codas function.

There is some evidence of variation from the typical 3+1 coda patterns [15]. Nursery groups in the Mediterranean Sea showed 4-, 5- and 7-click codas [26]. Additionally, some groups recorded in the Eastern Mediterranean Sea demonstrated a different coda type, with 2+1 [27] and 3++1 [28] variations. Despite the existing variations on coda patterns, sperm whale tend to show similar codas within the Mediterranean Sea which raised the possibility of sperm whales displaying an "island habitat" [28]. Island populations contain fewer elements in their vocal repertoires but have more variety within the elements [15].

Nevertheless, the scarce number of comprehensive acoustic studies on sperm whales hinders our understanding of the vocal repertoires of sperm whales in the Mediterranean Sea. Studying the variations in vocalization over time and space through acoustic techniques can produce extensive knowledge of the population structure, cultural and genetic evolution, and the presence of local adaptations [29, 30]. The current case study provides information on the variations in vocal behavior of sperm whales occurring in the Northern Ionian Sea (Central Mediterranean Sea) and in the North-western Levantine Sea (Eastern Mediterranean Sea) , contributing, although preliminarily, to the understanding of whether the vocal repertoire varies between these two areas.

II. MATERIAL AND METHODS

Standardized seasonal boat-based surveys with visual and acoustic survey techniques were carried out to monitor the occurrence of cetaceans in the Gulf of Taranto (Northern Ionian Sea, Central Mediterranean Sea) and along the Turkish coasts of the North-western Levantine Sea (Eastern Mediterranean Sea). While a random line transect design was applied in the Gulf of Taranto between February and December 2019, 22 equally spaced transects were followed seasonally in the North-western Levantine Sea between April 2018 and January 2020. A survey effort of approximately five hours per day was completed, along a 65 km line, covering an area of about 960 km2 in the Gulf of Taranto. 24 hour survey effort for an average of five days per season was conducted in the North-western Levantine Sea, consisting of 644 km of track line in each survey, covering an area of 23,438 km².

In both study areas, observations on board were made with the naked eye and 7 × 50 binoculars. When a visual or acoustic detection took place, the focal group was followed, switching to off-effort [31], to collect information such as photo-identification, geographic coordinates of the sighting, time of first contact, depth (m), group size and behavior. Additionally, environmental and anthropogenic (vessel presence, construction, military sonar and hydrocarbon exploration) noises in the area were logged in the North-western Levantine Sea.

A. Acoustic data collection

In the Gulf of Taranto, data were collected using a pre-amplified omnidirectional hydrophone (Colmar GP0190) with a sensitivity of -175±5 dB re 1V/µPa among 5 and 170 kHz, and a flat response of -171 dB re 1V/µPa under 12 kHz up to 1 kHz. The acoustic data were collected only after the engine switched off, to avoid disturbance and noise, and if possible for the entire duration of the sighting. In the North-western Levantine Sea, a towed hydrophone array was deployed near-continuously during surveys. The hydrophone array (Vanishing Point, UK) consisted of four omni-directional broadband hydrophone elements for high and low frequency monitoring mounted within a streamlined housing and towed on a 200 m strengthened cable. The hydrophone elements were sensitive between 100 Hz and 200 kHz Signals and the hydrophone was amplified and conditioned using a customized hydrophone interface (Magrec HP27) and digitised using a Behringer U-Phoria UMC404HD sound card sampling up to 192 kHz. PAMGuard software ran on a laptop computer making continuous full bandwidth recordings. Additionally, a directional hydrophone was used to localize the sperm whales. In both study area, post-acoustic analyses carried out by PamGuard 2.01.03.

III. RESULTS

In the Gulf of Taranto, during February-December 2019, a total effort of 148 daily surveys was applied accounting for approximately 740 hours of observations and 9600 km covered. A total of 6 visual sightings of sperm whale with a group size ranging from 1 to 5 individuals, occurred in a depth range from 560 and 1050 m in depth (Figure 1). Acoustic data were collected during one sighting. Five possible sperm whales were identified (despite only four being visually confirmed) from 20 recordings lasting 1 hour and 3 minutes recorded on the 17th August 2019. The recordings contained impulsive clicks with well-defined click trains with Inter click interval (ICI) ranging from 0.3 to 1 second. The recorded center frequency has ranged between 8 and 12 kHz and the peak frequency was between 11 to 16 kHz. Peak frequencies are typically recorded in a range 12 to 13.5 kHz (Figure 2). The IPI values received were calculated using the suggested

algorithm [32], suggesting a body length of 9 to 10.5m calculated.

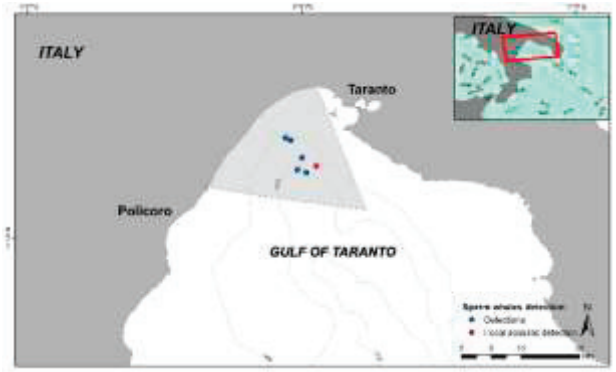

Figure 1. Detected sperm whales within the Gulf of Taranto.

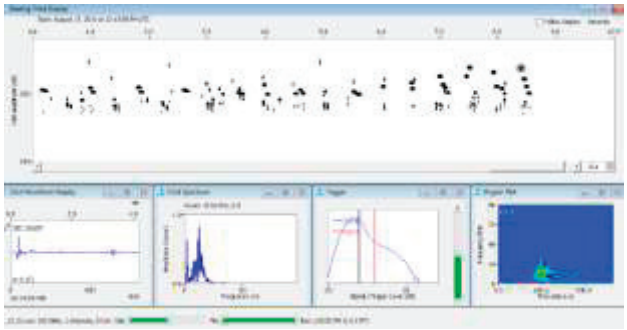

Figure 2. Sample click pattern of a sperm whale recorded on the 17th August 2019 in the Gulf of Taranto.

In the North-western Levantine Sea, a total of 60 days were spent from April 2018 and January 2020, with an effort of approximately 697 hours of observation and covering 4385 km. 23 sightings of sperm whale were detected in waters with depths between 500 and 2500 m, of which only 4 sightings were visually recorded (Figure 3). A total of 13 acoustic recordings of sperm whales making up 1 hour and 29 minutes on July 15th, 2019 were analysed, revealing the possible presence of 4 or more individuals. This date was chosen for the preliminary analysis due to the presence of clearly distinguishable clicks and possible codas. Sperm whale acoustic recordings revealed the presence of "regular clicks" and "codas". Regular clicks showed similar characteristics with inter click interval (ICI) values of around 1 second and peak frequencies ranging from 2 to 13 kHz. During one of these recordings, the animals encountered emitted both regular foraging clicks and possible codas or indistinct click trains. Regular clicks emitted during foraging dives started with an ICI of 1.4 seconds and decreased to 0.65 seconds approximately, before decreasing further. The peak frequency of the click also altered from an emphasis on 2 to 4 kHz signals in bimodal clicks with a lower peak at 7.3 to 9.4 kHz. The lower peak frequency reduced on the more frequent clicks presumably at the target being investigated was approached. While some possible codas followed a pattern of a seven click sequence with varying ICI rates alternating from fast to slow to fast. The recorded codas had a range of ICI and frequencies, but the peak frequency ranged from 12 to 14.4 kHz and centre frequency ranged from 11 to 14 kHz (Figure 4). Inter Pulse Intervals (IPI) suggests body length of 7.8 to 9.3m for four of the whales.

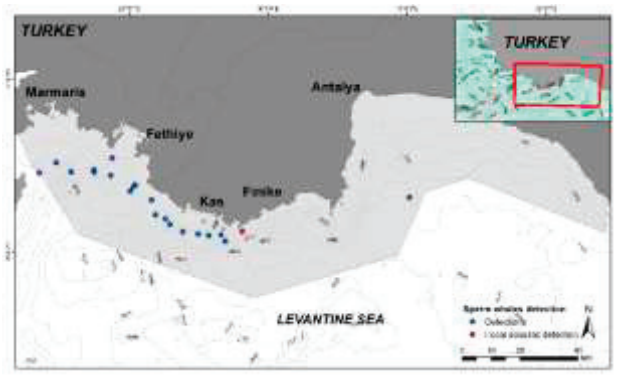

Figure 3. Detected sperm whales within the North-western Levantine Sea survey area.

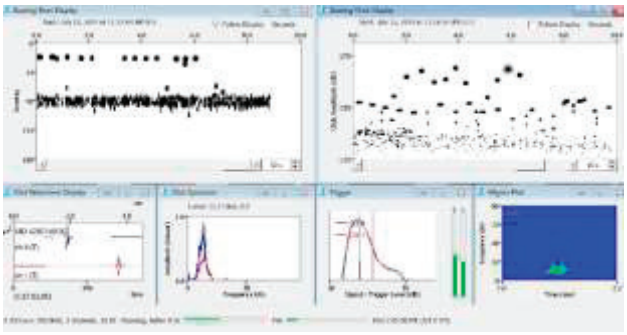

Figure 4. Sample click pattern of a sperm whale recorded on the 15th July 2019 in the North-western Levantine Sea.

IV. DISCUSSION

The comparison of vocalizations of sperm whales recorded in the Gulf of Taranto and North-western Levantine Sea revealed the occurrence of 'regular clicks', indicating both areas hold foraging habitat(s) for sperm whales [18,33]. This hypothesis is supported by the peculiar eco-physiographic features of the Taranto Valley canyon system in the North Ionian Sea and Finike seamounts in the north-western Levantine Sea, both of the location having its energy and biomass exchanges indicating a benthic-pelagic coupling and a rich occurrence of mesopelagic cephalopods [14, 34, 35].

Additionally, in Turkey, the occurrence of coda patterns was indicative of social behaviour [15] thus the area is not only important for the solitary individuals but also for the social, potentially nursery, groups. Hellenic Trench is known to hold one of the most important sperm whale habitats of the Mediterranean Sea with high recording of nursery groups [9,10,11,12]. Therefore, it is highly likely that sperm whales, both the nursery groups and solitary

individuals, share the neighbouring waters. The regular foraging clicks recorded in Turkey appear to be similar to the reported acoustic patterns of sperm whales elsewhere. The Inter Click Interval (ICI) of 1.4 seconds decreasing to 0.6 seconds in Turkey is concurrent with sperm whales within the Mediterranean Sea [33] as well as further afield e.g. waters off Norway [36, 37], the Galapagos [38] the Gulf of Mexico [39], who generally have found click intervals of between 0.5 and 2 seconds.

The ICI ranging from 0.3 to 1 second recorded from sperm whales sighted in the Gulf of Taranto is slightly lower than the aforementioned reported values, but it should be noted click interval changes on approach to prey down to as low as 20 ms [37]. Due to variance of the ICI as a function of proximity to prey or target [33] and depth [37], further acoustic studies are needed to confirm whether the ICI recorded in the Gulf of Taranto could be atypical.

The peak frequencies recorded in both study areas were slightly higher than those recorded in the Galapagos [38] but lower than those recorded in the Bahamas [40] and Norway [41]. The center frequencies were comparable to those recorded in Papua New Guinea [42] but they are lower than central frequency recorded in the Gulf of Mexico [39].

Higher frequency clicks observed following dives, in Turkish water, suffer from higher attenuation suggesting that they are more suited to shorter distance investigation [42]. This demonstrates the ability of animals to modulate or change the signal as the target is approached, changing the frequency of the signal to obtain greater resolution of the target. Echolocation clicks are often produced at intervals that are either similar to or slightly longer than the two - way travel time [43] i.e. the time for the sound to reach the prey and return making it a useful proxy for the distance which the animal is directing its attention [44]. Higher frequency signals with shortened ICIs increase the rate of signal return and therefore return more information on the target as it is approached. Thus, considering with a reasonable approximation that speed of sound in the water (valid for water from 100 m to 800 m depth) is 1510±2 m/s [33], with an ICIs of 1.4 and 0.6 second respectively, recorded in Turkish waters, the maximum prey location distances resulted of 1057 m and 491m, respectively. For the Gulf of Taranto, the same method gave maximum prey location distances ranging from 227 m to 755 m for the 0.3 and 1 second ICIs, respectively. Indeed, the target may be closer but it may be that details of the surrounding environment are still of use in orientation and the tracking and capturing prey [33,45].

Preliminary analysis suggested that the coda patterns observed in Turkey were not similar to the typically observed pattern found in the Mediterranean [15] and did not appear to show the 2+1 nor the 3++1 patterns [27,28] in neighboring Greece. However, more recordings of coda clicks would be required in order to reliably determine coda characteristics and associate them reliably to specific social groups.

Two codas recorded in 1995 by the Italian Navy comprise the only other published data on sperm whale acoustics in the Gulf of Taranto, both of which consisted of the typical 3+1 pattern [15]. The body length in this study calculated based on the whale's IPI gave a length of 13.2m [15] which is considerably larger than the range of 9 to 10.5m calculated in this study.

The results presented here are from the first dedicated cetacean seasonal survey carried out in the Turkish waters of the Eastern Mediterranean Sea [14] and to our knowledge, the first recordings analyzed for their acoustic properties. Similarly, the recordings in the Gulf of Taranto are some of the first recordings analyzed. This preliminary analysis provides the scientific baseline of knowledge on the vocalizations of sperm whales in these understudied areas [5]. In turn, results demonstrate the existence of foraging grounds in both the Gulf of Taranto, already suggested as suitable habitat for this and other cetacean species [46] and the Eastern Levantine Sea, where not only solitary individuals but also social units were encountered Acoustic data collected in each case represents recordings in a single day, of a single year while the life of a sperm whales spans approximately 60 years [47] and therefore, these are very limited snapshots into the lives of sperm whales. There is a clear need for further analyses into the recordings collected but the variation observed between the two study areas, even in the preliminary analyses, emphasizes the need for comprehensive data collection in these understudied areas as well as the value of cross-border collaborations in developing our understanding of the ecology of cetaceans that shows long-movement patterns.

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