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Baseline

Insights into the distribution and ingestion of prey-like plastic fishing lures in Mediterranean rough-toothed dolphins

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ABSTRACT

Rough-toothed dolphins (*Steno bredanensis*) form an isolated subpopulation in the Mediterranean Sea that resides only in the eastern basin. Due to the paucity of records, the conservation threats these dolphins face and their ecology and distribution are poorly understood. While most observations indicate that individuals are found in two isolated clusters in the eastern basin, we hereby present five observations -three visual, one acoustic and one stranding- that possibly extend the range of this subpopulation to the entire offshore waters of the eastern basin. The stomach content remains of the stranded individual revealed a diet based on epipelagic squids and octopods. The stranded dolphin had also consumed seven plastic bags and nine squid-like plastic fishing lures, which had caused a complete gastric blockage and probably led to the stranding. High pollution loads from macroplastics in the Mediterranean Sea may evolve into a new potential threat for this subpopulation.

Routinely occurring in warm tropical and temperate subtropical, oceanic deep waters (Jefferson et al., 2015; West et al., 2011), rough-toothed dolphins (*Steno bredanensis* Lesson, 1828) are also part of the diverse Mediterranean cetofauna (Notarbartolo Di Sciara, 2016) where they can also be encountered in shallow coastal waters (Fig. 1A, Kerem et al., 2012). Although initially treated as an occasional visitor in the Mediterranean Sea, the species is now granted a regular status with its individuals forming an isolated subpopulation of Atlantic origin (Albertson et al., 2022; Kerem et al., 2016). Despite their regular presence, Mediterranean rough-toothed dolphins have eluded even a basic investigation of their ecology and are the least studied and least known regular cetacean species in the Mediterranean Sea (Kerem et al., 2016). Since 1985, the limited number of sightings, strandings and bycaught individuals have been all located east of the Sicilian channel in two seemingly isolated clusters (red points in Fig. 1A): the Levantine Sea with the majority of observations and the Ionian and Libyan Seas with only five observations (see Kerem, 2022; Kerem et al., 2016 for reviews). The limited number of observations might be because when observed from a distance, this species may be readily confused with other more prevalent species in the Mediterranean, such as bottlenose dolphins (*Tursiops truncatus*). This might be the reason why no aerial surveys in the eastern basin have documented the presence of rough-toothed dolphins (ACCOBAMS, 2021).

This apparent lack of data on fine-scale distribution, abundance and ecology for the Mediterranean subpopulation precludes any solid assessment of its conservation status which is currently defined as Near Threatened by the International Union for the Conservation of Nature (Kerem et al., 2021). We hereby report five additional observations of Mediterranean rough-toothed dolphins: namely three sightings, one acoustic detection and one stranding (yellow points in Fig. 1A). While the three sightings have been recently reported (Kerem, 2022; Kerem et al., 2021), we provide some further details on them to shed some light on the distribution and conservation of the species. Towards this direction, our findings from the stranded individual highlight that the fatal ingestion of macroplastics could evolve into a new threat for this isolated, range-restricted and presumably small subpopulation.

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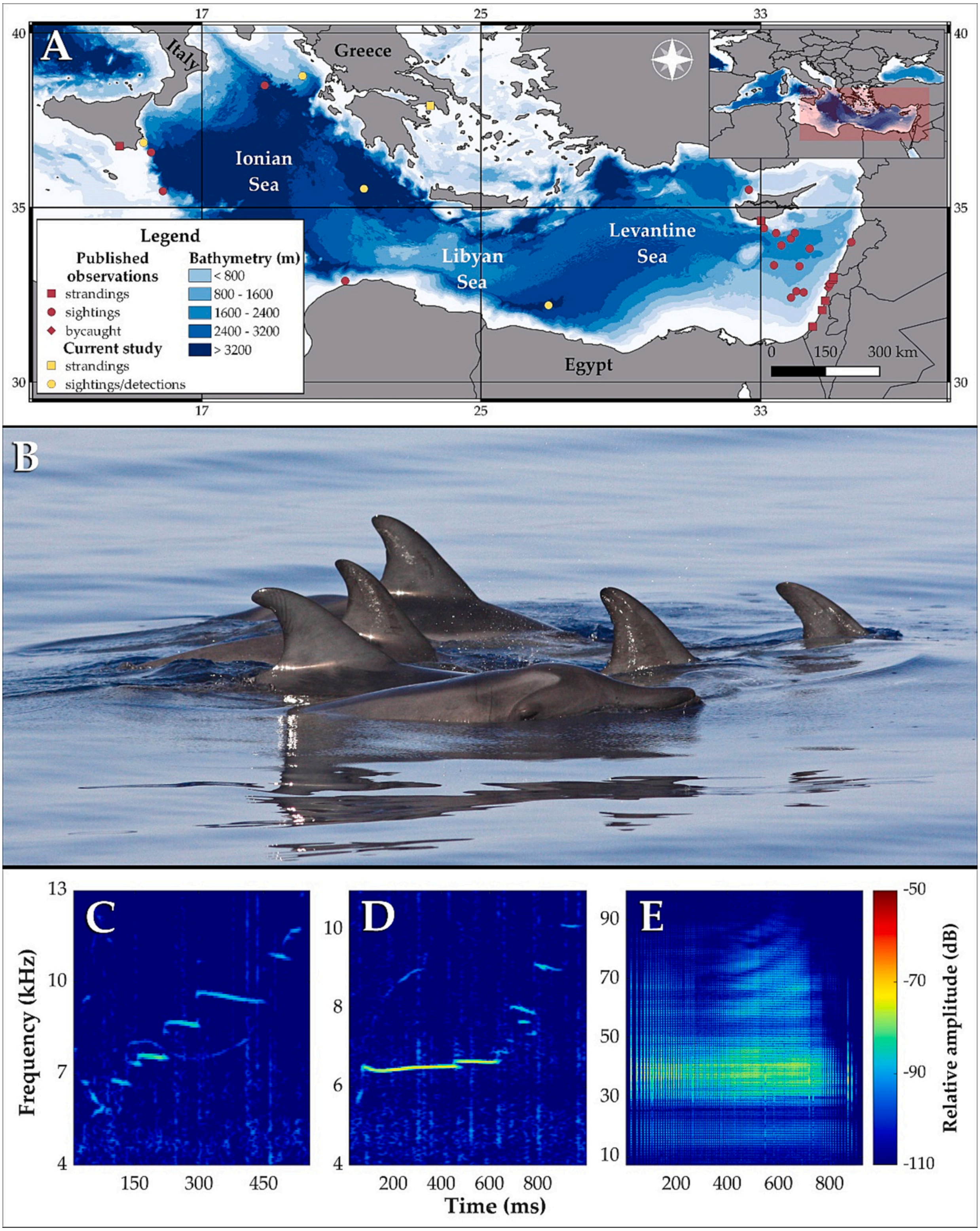

Fig. 1. A. Part of the eastern Mediterranean basin where all observations of rough-toothed dolphins have occurred since 1985. The observations reported in this note are depicted with yellow while the ones retrieved from the literature (Kerem, 2022; Kerem et al., 2016) with red. The map was made with the QGIS Geographic Information System (https://www.qgis.org) using available data for country borders (https://gadm.org) and bathymetry (https://www.emodnet-bathymetry.eu/). B. Six individuals from a group of eleven rough-toothed dolphins observed off southeast Sicily, Italy on 12 July 2016 (copyright for photograph: Silvia Frey). C, D & E. Two diagnostic whistles (C, D) and a fast click sequence (E, presumably a buzz) recorded from rough-toothed dolphins off southwest Greece on 24 August 2021. The recordings come from the channel with the highest signal-to-noise ratio [500 kHz sampling rate, Hamming window, 98 % overlap, discrete Fourier transform size, frequency and time resolution are respectively 8192 points, 0.06 kHz, 328 μs (C), 16,384 points, 0.03 kHz, 655 μs (D) and 4096 points, 0.12 kHz, 164 μs (E)]. The spectrograms were made with Matlab 2022a (The Mathworks Inc., Natick, MA, USA). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Table 1

Data on prey remains and debris items found in the stomach of the stranded rough-toothed dolphin. DML: dorsal mantle length; LHL: lower hood length; LRL: lower rostral length; %N: percentage number (N); SD: standard deviation; SE: standard error; %W: percentage weight (W). We took standard measurements from all lower beaks assigned to each species with the exception of *Onychoteuthis banksii* where we could measure 106 out of 108 lower beaks. Plastic debris was classified into sheet plastics (including plastic bags) and miscellaneous following Provencher et al. (2017).

Prey remains

Order	Family	Species	N	%N	W (g)	%W	LRL/LHL (mm)		DML (mm)	
							Mean	SD	Mean	Max
Oegopsida	Ommastrephidae	*Illex coindetii*	4	2.2	$1.2 \cdot 10^3$	32	6	0.7	225	253
	Onychoteuthidae	*Ancistroteuthis lichtensteinii*	2	1.1	95	2.6	4.1	0.1	130	133
		Onychoteuthis banksii	108	58.7	$1.3 \cdot 10^3$	35.8	2.4	0.3	82	100
	Broken beaks		14	7.6	–	–	–	–	–	–
Octopoda	Argonautidae	*Argonauta argo*	54	29.3	$1.2 \cdot 10^3$	29.1	3	1.1	42	102
	Ocythoidae	*Ocythoe tuberculata*	2	1.1	22	0.6	3.9	0.5	25	27

Debris items

Debris type	N	W (g)			Total W (g)	Total surface area (m^2)
		Mean (SD, SE)	Median	Range		
All plastics	7	14.9 (20.5, 7.7)	5	1–55	104	1.5
Sheets	7	14.9 (20.5, 7.7)	5	1–55	104	1.5
Bags	7	14.9 (20.5, 7.7)	5	1–55	104	1.5
Miscellaneous	9	45.1 (7.7, 2.6)	45	32–55	406	–

During a vessel-based survey on 12 July 2016, one of the authors (Silvia Frey) recorded a sighting of eleven rough-toothed dolphins 23 km off southeast Sicily, Italy (36.8575 N, 15.3273 E, depth range: 1750–2000 m, Fig. 1A, B) and photo-identified nine of them. Two years later, on 17 August 2018, we observed a group of six rough-toothed dolphins 52 km off southwest Antipaxos Island in northwest Greece (38.7708 N, 19.8867 E, depth: 485 m, Fig. 1A) and photo-identified five of them. This sighting took place during a vessel-based survey conducted by Marine Conservation Research (MCR) and Pelagos Cetacean Research Institute (PCRI) within the framework of the ACCOBAMS Survey Initiative (ASI) (ACCOBAMS, 2021). During ASI, MCR recorded on 30 October 2019 one more sighting of six rough-toothed dolphins 82 km north of the west Egyptian coasts (32.1993 N, 26.9155 E, depth: 3202 m, Fig. 1A) and photo-identified five of them; the dolphins were initially logged as bottlenose dolphins in the field, but only subsequent scrutiny of the photographs confirmed species identity, highlighting the difficulties in correctly identifying rough-toothed dolphins in the field. While comparing all 19 photo-identified individuals, we found no matches between the three different sightings. Lastly, on 24 August 2021, within the framework of a survey organized by Greenpeace in collaboration with PCRI and one of the authors (Kirsten F. Thompson), we used a towed, four-hydrophone array (for methodological details see Webber et al., 2022). While on effort and during the day, we detected for 4.3 min the diagnostic, stepped whistles emitted by rough-toothed dolphins (Fig. 1C, D, Caruso et al., 2019; de Lima et al., 2012; Kerem et al., 2016; Rankin et al., 2015). During this detection 123 km off southwest Greece (35.5383 N, 21.6454 E, depth: 3650 m, Fig. 1A), we simultaneously recorded echolocation clicks (Fig. 1E) that were presumably emitted by the same species as no other cetaceans were encountered in the region.

These four additional observations of free-ranging rough-toothed dolphins indicate that the range of the Mediterranean subpopulation may include the entire offshore waters of the eastern Mediterranean basin, suggesting in this way the presence of a corridor between the clusters of the Levantine and Ionian/Libyan Seas. There have yet to be any photo-identification matches between the two regions but this in part relates to a lack of offshore effort. Moreover, while clicks of rough-toothed dolphins are reported to have peak frequencies of approximately 22–26 kHz (Rankin et al., 2015; Ziegenhorn et al., 2022), the click peak frequencies from our recording (depicted with warmer colours in Fig. 1E) are higher than 30 kHz. This suggests that the diagnostic stepped whistles of this species are more useful for tuning detectors during passive acoustic monitoring.

On 13 July 2021, the port authorities of Piraeus-Keratsini in Greece reported a dolphin swimming next to the container port (37.5706 N, 23.3537 E). The available video material revealed this to be a rough-toothed dolphin. Two days later, the port police informed us that the same dolphin was swimming in shallow waters among swimmers in Limnionas bay, Salamis Island, Greece (37.5406 N, 23.3047 E), nine kilometers away from its initial sighting. The dolphin was 2.37 m long and was evidently emaciated. As a result, veterinarians and volunteers coordinated by the NGO Arion tried to rescue the dolphin for two consecutive days by force-feeding it. After this period, the condition of the dolphin was deemed satisfactory and thus, it was released in the same location. Six days later on 23 July 2021, the same dolphin was found stranded and dead in the same island (37.5545 N, 23.3220 E, Fig. 1A), 4 km away from its second sighting.

On 6 November 2021, we recovered the dolphin carcass with the assistance of Salamis Municipality that had transported and buried it after its stranding. Due to the extensive decomposition of the carcass, it was not possible to determine the sex of the dolphin. We removed the entire skeleton, teeth and stomach contents, and analysed the latter for prey remains and debris items. The only prey remains found were cephalopod beaks (184 lower and 86 upper) that we preserved in 70 % ethanol. Following Pedà et al. (2022), we used the lower beaks to identify the cephalopod prey to species level, measured the number of cephalopods from the number of lower beaks and took standard measurements of undamaged lower beaks with a digital Vernier caliper (±0.02 mm). We then estimated dorsal mantle length (DML) and weight (W) from standard regressions (Lu and Ickeringill, 2002; Pedà et al., 2022; Šifner et al., 2018) relating prey length and weight to lower rostral length (LRL) for squids or lower hood length (LHL) for octopods. For each cephalopod species, we also estimated the total weight represented by its beaks as (sum of weights represented by beaks measured)/(proportion of individuals measured) (Santos et al., 2001). We calculated dietary composition in terms of prey numbers and biomass by expressing the counts and summed weights for each prey species as a percentage of all-species totals.

The lower beaks we found belonged to five species: *Illex coindetii*, *Ancistroteuthis lichtensteinii*, *Onychoteuthis banksii*, *Argonauta argo* and *Ocythoe tuberculata*. These species are new records in the diet of rough-toothed dolphins and are all medium-sized cephalopods that can be

Fig. 2. A. The rough-toothed dolphin that stranded in Salamis Island, Greece on 23 July 2021. B. Seven plastic bags and nine squid-like plastic fishing lures were found in the stomach of this individual. C. Schematic of a squid-like lure attached to a fishing line with a hook (Copyright: Kinsey Brock). D. All lures were torn in this way indicating that the dolphin pulled them from the mantle and not the arms (copyright for photographs: Alexandros Frantzis/PCRI).

found in the upper water column (Finn, 2016a, 2016b; Roper et al., 2010; Roper and Jereb, 2010). The most important prey by number and weight were *O. banksii* and *A. argo* (Table 1) with the latter probably being females since males are dwarfed (Finn, 2016a). Although we only found a small number of lower beaks belonging to *I. coindetii*, this squid species had a high abundance by weight (Table 1). While these limited results come from an emaciated individual that is probably not representative of its subpopulation, they still shed some light on the virtually unknown feeding habits of Mediterranean rough-toothed dolphins (Kerem et al., 2012, 2016). These findings thus suggest that Mediterranean rough-toothed dolphins target, among other prey, epipelagic cephalopods. This is consistent with what is known about the diet of these dolphins from regions other than the Mediterranean Sea where they also target epipelagic fish (see Kerem, 2022; West et al., 2011 for reviews). Caution is needed in a full interpretation of prey preferences from this stomach though as the absence of fish bones is likely due to their high susceptibility to chemical degradation (Harvey, 1989).

However, the most prominent findings in this stomach content were seven whole or fragmented plastic bags and nine squid-like plastic fishing lures (Fig. 2B, Table 1) that had led to a complete gastric blockage. Although cephalopod beaks were found inside the plastic lures, we did not locate any fishing lines or hooks in the stomach. The color of the bags ranged from off/white-clear to black while that of the lures was orange-brown (Fig. 2B, color categories after Provencher et al., 2017), nearly identical to the color of real, live squids. All plastic debris were macroplastics (>20–100 mm) apart from a megaplastic bag (>100 mm, size categories after Barnes et al., 2009). The lures had five holes along their length (Fig. 2B, C, D) and their "mantle" and total length was respectively 13 and 28 cm. By searching for "squid skirt lure" in Google Search, we easily located the same lures and found that they were luminous and made from polyvinyl chloride (PVC). Moreover, one of the lures was significantly darker, harder and more worn than the rest (item no 9 in Fig. 2B) raising the possibility that the dolphin could have ingested it on a different and earlier occasion.

Seabirds, pinnipeds and dolphins have been reported to ingest fishing lures (Barcenas-De la Cruz et al., 2018; Byard et al., 2020; Donnelly-Greenan et al., 2019; Wells et al., 2008), which they can either remove from longlines or lines with single hooks. The high number of lures in this stomach suggests though that the dolphin encountered several of them within a small distance, making the longline scenario the most probable. Rough-toothed dolphins have been reported to interact both with gillnets and longlines/handlines (Kerem et al., 2016; Nitta and Henderson, 1993; Ortega-Ortiz et al., 2014; Weir and Nicolson, 2014; West et al., 2011). In the case of Weir and Nicolson (2014), rough-toothed dolphins off Angola removed plastic lures from fishing lines but subsequently abandoned them. Interestingly, the plastic lures we found were all torn in the same way with the tear originating from either the closest or the second closest hole to the arms of each lure (Fig. 2D). This indicates that the dolphin pulled the lures from the mantle and not the arms causing the hooks to tear the lures (Fig. 2C). This finding is consistent with the direction in which we found the lures in the stomach, namely the arms of the lures facing the mouth of the dolphin. Based on the available findings, we cannot tell if the dolphin was focused on the lures themselves or any prey that was caught on the lures.

Ingestion of macroplastics has been reported before in rough-toothed dolphins in the Atlantic (De Meirelles et al., 2007; Puig-Lozano et al., 2018) and Pacific Oceans (Walker and Coe, 1990). But like in our case, it is difficult to evaluate if the debilitation and eventual stranding of the affected individuals is the direct result of plastic ingestion, or another health problem led to starvation and the eventual ingestion of the macroplastics. Ingested macroplastics can damage or even block the digestive tract and cause starvation (Baulch and Perry, 2014). The PVC the lures were made from is a sink for toxic chemicals (Teuten et al., 2009) and thus their ingestion might have amplified the burden of endocrine disruptors in this rough-toothed dolphin with ripple effects on immunosuppression and poor health and reproductive status (De Guise et al., 1995; Routti et al., 2021).

The findings in this short note highlight that the Mediterranean subpopulation of rough-toothed dolphins may have a larger range than previously thought, which includes the entire deep waters of the eastern Mediterranean basin. Often these encounters occur in regions with very little dedicated research effort; for example, the ASI survey provided the first systematic survey for cetaceans in Egyptian waters, and rough-toothed dolphins were seen at least once during the survey. As the eastern basin is characterized by large data gaps, particularly during non-summer months (Mannocci et al., 2018), every attempt should be made to increase survey effort throughout the region. Our findings also suggest that apart from anthropogenic noise pollution and bycatch when found in shallow waters (Kerem et al., 2016), this subpopulation may be also threatened by ingestion of macroplastics as is the case for other subpopulations of toothed whales in the Mediterranean Sea (Alexiadou et al., 2019; Baulch and Perry, 2014; de Stephanis et al., 2013). Due to the spatial heterogeneity of plastic pollution in the Mediterranean Sea (ACCOBAMS, 2021), it still remains difficult to predict how a larger range will eventually affect the conservation risk for the small and isolated subpopulation of Mediterranean rough-toothed dolphins.

CRediT authorship contribution statement

Ilias Foskolos: Conceptualization, Methodology, Software, Formal analysis, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Paraskevi Alexiadou:** Conceptualization, Methodology, Investigation, Resources, Writing – review & editing. **Niki Koutouzi:** Investigation, Writing – review & editing. **Silvia Frey:** Investigation, Resources, Writing – review & editing. **Kirsten F. Thompson:** Investigation, Resources, Writing – review & editing. **Oliver Boisseau:** Investigation, Resources, Writing – review & editing. **Alexandros Frantzis:** Conceptualization, Methodology, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition.

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have influenced the work reported in this paper.

Data availability

Data will be made available on request.

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