Vol. 52: 163–176, 2023
https://doi.org/10.3354/esr01265

ENDANGERED SPECIES RESEARCH
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Published October 26

Summer and winter surveys of deep waters of the Hellenic Trench, Greece, provide insights into the spatial and temporal distribution of odontocetes

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ABSTRACT: The Mediterranean Sea provides habitat for globally threatened cetaceans. The Hellenic Trench is an Important Marine Mammal Area, providing core habitat for sperm whales *Physeter macrocephalus* and Cuvier's beaked whales *Ziphius cavirostris*. Surveys have characterized distributions of these species in near-shore areas (<2000 m deep). Sparse survey effort in deeper waters during winter has allowed speculation that it is not an important habitat in winter. We used passive acoustic monitoring from towed arrays to document cetaceans during summer and winter, covering 18 366 km of trackline off the Peloponnese and Crete. We confirmed the acoustic presence of 5 odontocetes: sperm whales (n = 49 encounters; mean depth ($\bar{x}$): 3360 m; range (R): 1250 to 4210 m), Cuvier's beaked whales (n = 4; $\bar{x}$: 3070 m; R: 1970 to 3770 m), Risso's dolphins *Grampus griseus* (n = 5; $\bar{x}$: 3340 m; R: 2250 to 4440 m), striped dolphins *Stenella coeruleoalba* (n = 2; $\bar{x}$: 2980 m; R: 2490 to 3470 m) and rough-toothed dolphins *Steno bredanensis* (n = 1; 3650 m). We also encountered 224 unidentified delphinids, including a potential blackfish (3020 m). We confirmed that these species are present in the Hellenic Trench throughout the year. Given the impact of multiple threats on sperm and Cuvier's beaked whales in the Hellenic Trench, we suggest that policymakers follow the precautionary approach in managing human activities in the area. Ongoing seismic surveys, hydrocarbon extraction and uncontrolled shipping could have potentially negative effects on these species at the population level and we advise caution in permitting such activities in future.

KEY WORDS: *Physeter macrocephalus* · *Ziphius cavirostris* · Passive acoustic monitoring · Mediterranean · Cetaceans · Oil and gas impacts

1. INTRODUCTION

The Mediterranean Sea is a 'miniature ocean' that contains extensive areas of deep abyssal plains and trenches bounded by slopes that provide important habitat for fisheries and deep-diving cetaceans, such as sperm whales *Physeter macrocephalus* and Cuvier's beaked whales *Ziphius cavirostris*. It is also one of the most highly impacted enclosed seas on Earth, with a suite of threats that include, most notably, anthropogenic noise and other pollution and poorly managed fisheries (overfishing, bycatch and entanglement) (Notarbartolo di Sciara 2016, Ramírez et al. 2018). All these threats interact synergistically to

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Publisher: Inter-Research · www.int-res.com

erode resilience to climatic changes and profoundly impact the Mediterranean marine ecosystems on which many coastal communities rely (Ramírez et al. 2018).

The Mediterranean sperm whale is a genetically distinct subpopulation and is listed as Endangered by the IUCN, according to C2a(ii) criterion — C2: <2500 mature individuals observed, estimated, projected, or inferred continuing decline, and a(ii): 95–100% of mature individuals in one subpopulation (IUCN 2012, Pirotta et al. 2021). The Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS) also classifies sperm whales within the region as endangered (Notarbartolo di Sciara & Birkun 2010). The IUCN listing notes that the total subpopulation size is between 500 and 5000 whales and, given the uncertainties, the mature sperm whale population is likely to be less than 2500 individuals. Trends in abundance are extremely difficult to determine due to a lack of data, but according to Rendell & Frantzis (2016), levels of mortality could potentially indicate a declining population. Aerial surveys conducted in the spring of 2021 are consistent and estimate ~2500 whales (Panigada et al. 2022). Other methods to better understand sperm whale population dynamics also include acoustic measurement of body size using stable inter-pulse intervals of individual clicks (Caruso et al. 2015). Such studies can inform us as to the body length of individuals within groups and populations. Caruso et al. (2015) reported that the sperm whales in the Ionian Sea were most represented by whales from 9 to 12 m (adult females or juvenile males), with older, larger males being absent, which may have implications for population dynamics.

The primary threats for sperm whales in the Mediterranean include mortality due to ship strikes, fishery bycatch (including entanglement in abandoned drift nets), ingestion of macro plastics, chemical pollutants, anthropogenic noise and disturbance from poorly managed whale-watching operations (Rendell & Frantzis 2016). Also relevant are the impacts of large-scale ecosystem change due to overfishing and climate change, but these factors are complex and difficult to quantify (Notarbartolo di Sciara 2014). Effective management of such threats is known to be lacking and, given the species' low growth rates, even low levels of mortality are potentially unsustainable at the population level (Pirotta et al. 2021). Genetic analyses have previously indicated that Mediterranean sperm whales form a single population (Pirotta et al. 2021), although further genetic analyses suggest that there may be some degree of weak west–east separation, with admixed individuals in the western basin and no admixed individuals in the eastern basin (Violi et al. 2023).

Significant research effort has been undertaken in several regions of the Mediterranean to better understand sperm whale abundance, population trends, social behaviour, connectivity and more localised threats (Rendell & Frantzis 2016). However, in many regions, sperm whale numbers, distribution and threats remain poorly understood.

Whilst the global population is classed as Least Concern, the Mediterranean subpopulation of Cuvier's beaked whales is listed by the IUCN as Vulnerable, based on criteria C2a(ii), with a population size estimate of 4807–7254 mature individuals and a decreasing trend in abundance (Cañadas & Notarbartolo di Sciara 2018). Cuvier's beaked whales, and indeed other beaked whale species, are known to be particularly vulnerable to anthropogenic sounds, with mass stranding events being linked to naval mid-frequency active sonar (Podestà et al. 2005, Bernaldo de Quirós et al. 2019, Hooker et al. 2019, Stanistreet et al. 2022).

The Hellenic Trench is a long and deep (5 km deep in some areas) bathymetric feature off the coast of Greece (see Fig. 1). It is an important habitat for both sperm and Cuvier's beaked whales, and it was designated as an Important Marine Mammal Area (IMMA) by the United Nations Protected Area Taskforce (IUCN-MMPATF 2017). The deep-water region of the Hellenic Trench is the target of current seismic survey operations (see www.greekhydrocarbons.gr/en/ExplorationDevelopmentProduction_en.html for examples of exploration blocks) and subject to intense vessel traffic (www.marinetraffic.com). Studies report direct evidence of ship strikes in the Hellenic Trench, with propeller cuts found on stranded sperm whales (Frantzis et al. 2019). Entanglement in illegal drift net fishing gear has also been reported for Mediterranean sperm whales (Blasi et al. 2021). Surveys by Frantzis et al. (2014) and Lewis et al. (2018) are consistent in estimating a population size of between 200 and 300 sperm whales for the Hellenic Trench area. Highest densities seemed to be located along the 1000 m bathymetric contour, though survey effort was biased towards waters closer to shore. More recent estimates indicate that the population size may have decreased alarmingly, potentially halving in size over the last 12–15 yr (Frantzis et al. 2022). The current abundance estimate for Cuvier's beaked whales along the Hellenic Trench is 478 (361–704) individuals (Frantzis et al.

2022), indicating a small current population contrasting with high sighting rates reported in the past (IUCN-MMPATF 2017). Following a long period of scarcity of Cuvier's beaked whale sightings in this area that was potentially related to multiple large mass strandings due to military sonar use (Frantzis 1998, 2015, Podestà et al. 2005, 2016), whales have been sighted locally within the Hellenic Trench IMMA (Pelagos Cetacean Research Institute unpubl. data). However, recent population estimates indicate a new decline during the last 3 yr (2019–2021) (Frantzis et al. 2022).

Visual–acoustic surveys for cetaceans by Lewis et al. (2018) were designed to cover the entire Mediterranean, thus, coverage of the deeper regions of the Hellenic Trench was sparse. More complete coverage of this region is needed, and surveys in multiple seasons could elucidate whether there is any seasonality to these distributions. The majority of surveys detailing the presence of sperm whales and Cuvier's beaked whales have been carried out during July and August, thus questions remain as to their distributions outside this season (Frantzis et al. 2014). Other species that have been recorded within the eastern Mediterranean basin and are known to have resident population units are fin whales *Balaenoptera physalus*, striped dolphins *Stenella coeruleoalba*, Risso's dolphins *Grampus griseus*, common dolphins *Delphinus delphis*, bottlenose dolphins *Tursiops truncatus*, false killer whales *Pseudorca crassidens* and rough-toothed dolphins *Steno bredanensis* (IUCN-MMPATF 2017).

The primary aim of this research was to investigate the presence of cetaceans within the region west and southwest of Crete in an area 61 500 km^2 within the deeper waters contiguous to the Hellenic Trench IMMA. Our goal was to improve spatial coverage in offshore waters and temporal coverage, especially in winter months. Data on the presence of all cetaceans was recorded during 2 time periods, approximately 3 wk in summer and 4 wk in winter. We recorded the acoustic presence of at least 5 species of odontocete across the 2 survey periods, including both sperm and Cuvier's beaked whales, confirming the presence of these species during the winter months.

2. MATERIALS AND METHODS

2.1. Survey design

The survey block of 61 500 km^2 area was chosen to cover the 2 blocks that are earmarked for seismic surveys and potential oil and gas exploration (west Crete and southwest Crete), with some overlap of the Hellenic Trench IMMA extending offshore to within 5 nautical miles of the boundary of the Greek Exclusive Economic Zone (Fig. 1).

Passive acoustic and opportunistic visual surveys were conducted across the survey area following predetermined track lines as generated using the software Distance (Buckland et al. 2001), following the standard principles for line-transect survey design to ensure coverage of the entire survey area (Fig. 1). Two vessels were used to conduct the surveys: the M/Y 'Arctic Sunrise' in summer (21 August to 11 September 2021, hereafter referred to as the summer survey) and the S/Y 'Rainbow Warrior' during winter–spring (9 February to 29 March 2022, hereafter referred to as the winter survey). The 'Arctic Sunrise' has been used as a survey vessel in previous passive acoustic surveys; therefore, these tracks were generated given the specific survey parameters of the system onboard (specifically, survey width of ~6 km; for more information see Webber et al. 2022). Webber et al. (2022) determined the combined hazard rate acoustic detection functions for sperm whales and delphinids across all transits of the 'Arctic Sunrise' and estimated an effective strip half-width of 3277 and 699 m, respectively. Two transects of approximately 3000 km in length were designed to provide coverage of the study area, with some overlap of the Hellenic Trench IMMA.

The 'Rainbow Warrior' had not previously been used as a survey vessel and no acoustic detection functions were known. However, as a sailing vessel and known to be much quieter than the 'Arctic Sunrise', we assumed that tracks would provide sufficient coverage. The 'Rainbow Warrior' is also limited in terms of being forced to sail according to the prevailing wind and sea conditions. Two transects of approximately 9000 km in total length were surveyed with some overlap of the Hellenic Trench IMMA. No estimate of acoustic detection functions for sperm whales or delphinids was carried out for the 'Rainbow Warrior', as more detections would be required and therefore the effective strip half-width could not be calculated.

2.2. Passive acoustic survey

Acoustic data were collected onboard the 'Arctic Sunrise' and 'Rainbow Warrior' using a towed hydrophone array (Vanishing Point) (Webber et al. 2022). The array's streamer section comprised 4 hydrophone

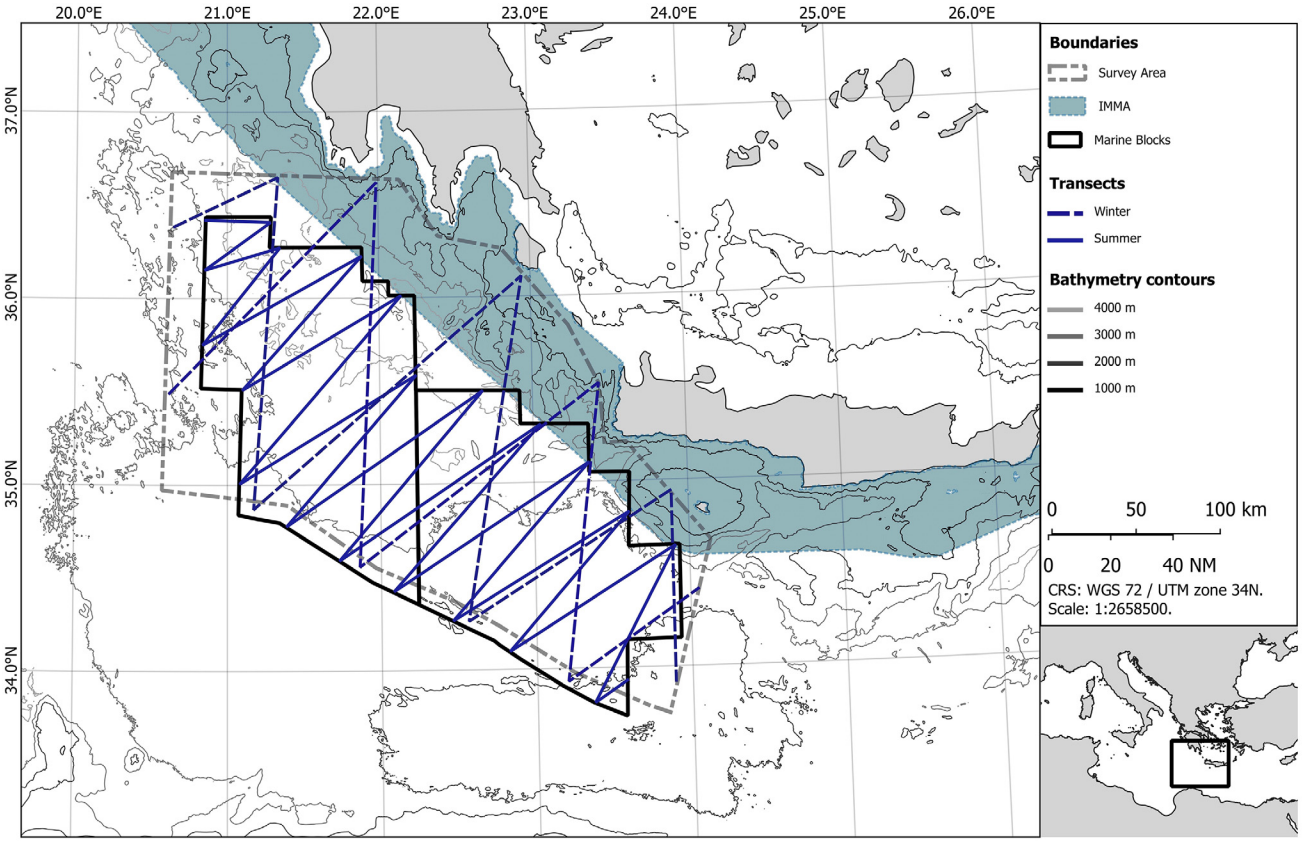

Fig. 1. Study area, including the Hellenic Trench Important Marine Mammal Area (IMMA; blue shading) and the 2 proposed blocks earmarked for seismic surveys. Bathymetric data from GEBCO (https://www.gebco.net/), coastline from Natural Earth (https://www.naturalearthdata.com/) and Hellenic Trench IMMA boundary from IUCN-MMPATF (2018)

elements mounted within an oil-filled (Isopar M) 5 m long, flexible, 35 mm diameter polyurethane tube. This was towed using a 350 m Kevlar-strengthened tow cable. Two hydrophones, the 'medium frequency' pair (Benthos AQ4 elements and Magrec HP02 pre-amplifiers, nominal frequency range 50 Hz to 40 kHz) were spaced 3 m apart while the 'wide frequency' pair (Magrec HP03 hydrophone and preamplifiers units, nominal frequency range 1 kHz to 200 kHz) were spaced 50 cm apart. Each array element was connected to one channel of a 4-channel SAIL data acquisition card (St Andrews Instrumentation), where analogue filtering and gain were applied before each channel was sampled at 500 kHz. A high-pass filter of 10 Hz and gain of 6 dB were applied to the 'medium frequency' channels 0 and 1, while a high-pass filter of 2 kHz and gain of 12 dB were applied to the 'high frequency' channels 2 and 3. Data from the SAIL acquisition card were written as 4 channel 16 bit lossless '.wav' files using PAMGuard (Gillespie et al. 2009; www.pamguard.org), which also carried out real-time acoustic processing, displayed results and logged the ships' locations from GPS.

Acoustic .wav files were processed in PAMGuard Viewer mode offline. A click detection module was implemented. For analysis of the Arctic Sunrise data a trigger threshold of 16 dB was used and a 20° angle veto was applied (all clicks from 0–20° were removed from further analysis). For the analyses of 'Rainbow Warrior' data, the trigger threshold was lower, at 12 db, and no bearing vetoes were applied. Various thresholds were tested in 3 dB steps, from 10 to 19 dB, to ensure maximum noise removal whilst keeping clicks from marine mammals. The click train detector module within PAMGuard was used to group clicks into trains (MacAulay 2020). Settings were determined through trial and error using a small subset of data to maximise the number of true click trains and minimise false trains following methods described in more detail in Webber et al. (2022). Three spectral template classifiers were applied to clicks within trains, the default spectrum templates for delphinids, sperm whales and beaked whales were used to classify clicks within trains. The whistle and moan detector PAMGuard was implemented to detect tonal signals in

the frequency band between 1 and 24 kHz (Gillespie et al. 2013). Whistles were then assigned a likelihood score for each of the species included in the PAMGuard whistle classifier (Gillespie et al. 2013). Species included in this classifier were bottlenose and common dolphins, false killer whales, killer whales *Orcinus orca*, pilot whales *Globicephala* spp., Risso's dolphins, rough-tooth dolphins *Steno bredanensis* and striped dolphins. Recordings of species used in classifier training were from Gillespie et al. (2013), recorded in the wider North Atlantic region. Not all species occurring within the Hellenic Trench could be included in the whistle classifier. Parameters used in whistle classifier training were taken from Gillespie et al. (2013), with fragment length and section length parameters of 30 bins (160 ms) and 60 fragments respectively. Confusion matrices outputted by the whistle classifier showed a combined correct classification score of 75.6% across all 6 dolphin species included in the classifier (Table 1). Any whistle with a likelihood score below the threshold of 0.8 (out of 1) was determined to be an unidentified delphinid.

Table 1. Confusion matrix for 6 species of odontocete used in whistle classification training within PAMGuard. Rows are the species while columns are the classification, with a correct classification score given as %

Species	Bottlenose	Common	Killer whale	Pilot whale	Risso's	Striped
Bottlenose	75.5	8.8	0.0	0.2	0.9	14.6
Common	4.2	74.5	0.0	0.4	11.6	9.3
Killer whale	0.0	0.0	95.3	4.8	0.0	0.0
Pilot whale	11.5	0.2	19.5	64.4	0.1	4.3
Risso's	0.5	7.4	0.0	2.4	82.2	7.5
Striped	6.3	28.2	0.0	0.0	7.3	58.2

Manual verification of recordings was conducted on sections identified by the detectors as containing potential odontocete presence. Click trains and whistles were manually marked in PAMGuard Viewer Mode, with the true location of acoustic encounters estimated using the 2-dimensional simplex method within the PAMGuard target motion analysis module. Delphinid encounters were defined as periods of whistles and/or echolocation clicks separated by at least 20 min of silence before and after, with each detection associated with a group rather than an individual dolphin since estimating the number of individual dolphins can be unreliable given the difficulty in distinguishing between overlapping click trains (Kimura et al. 2009). Sperm whale and beaked whale click trains could be combined into separate encounters since individual whales can be tracked using the time-bearing click display in PAMGuard. However, 2 whales that are so closely aggregated may potentially produce a train that cannot be separated using a time-bearing display, and in these cases, a single click train may contain clicks from 2 individuals. Sperm whale acoustic encounters were also grouped based on the temporal proximity of one click train to another, with silences over 2 h being treated as separate groups. Where silences were less than 2 h, click trains were assessed to determine if they could be from the same group based on the ship's position and speed, as well as the time between click trains and animals' estimated position based on target motion analysis.

2.3. Visual survey

A non-systematic visual survey was conducted during daylight hours (07:00–18:00 h local time). Where possible, data on species identity, location, numbers of animals and behaviour were collected.

Observers were located on the vessel deck and performed 1 h watches throughout the survey period, scanning using both binoculars and the naked eye throughout the watch. At the beginning and end of every watch, or if any change was noted, the following environment and effort variables were recorded: effort status (on- or off-effort, depending on whether there was an observer on station), observer identity, vessel position, speed of vessel over ground, Beaufort sea state, depth (according to the sounder on the bridge), water temperature (according to the previous reading taken by the bridge staff every 4 h using a thermometer), swell height and direction, visibility, glare and rain. Few observers had previous cetacean visual survey experience; therefore, the survey was considered to be opportunistic.

When cetaceans were observed, the following data were recorded: date, time (local), initial observer identity, effort status, ship's heading, position, depth, sighting method (naked eye or binoculars), initial sighting cue (blow, surface activity, body), bearing to the animal, closest distance (estimated), group size (minimum/maximum/best guess), presence of calves, species (highest taxonomic group possible) and confidence of species identity (definite/probable/possible). Species identity was confirmed using

Carwardine (2020). Where possible, photographs were taken of the groups for species identification.

3. RESULTS

3.1. Survey coverage

The acoustic surveys were conducted over a total of 71 d during the 2 seasons: approximately 22 d in summer (21 August to 11 September 2021; Fig. 2) and 49 d in winter (9 February to 29 March 2022; Fig. 3), covering a total track line distance of 18 366 km (9206 km in summer and 9160 km in winter).

3.2. Summer survey acoustic detections

A total of 119 encounters were recorded in the passive acoustic survey throughout the west and southwest Crete Blocks during summer, with the presence of 4 species being confirmed: sperm whales (35 encounters; 29.4%), Risso's dolphins (2 encounters; 1.6%) and a single encounter each of striped and rough-toothed dolphins (0.8% of total encounters). The majority of encounters (80 encounters; 67.2%) were of dolphins (Delphinidae) that could not be identified to species level using acoustic characteristics (Table 2).

Sperm whales were the most frequently encountered large cetacean with 35 encounters throughout the summer period in both west and southwest survey blocks, in water dephs between 1250 and 4210 m (Fig. 2). Acoustic detections of sperm whales were from regular clicks, with no coda vocalisations detected during the survey period. Dolphins classified using the whistle classifier with greater than a 0.80 likelihood score were Risso's (0.85 likelihood) and striped dolphins (0.99 likelihood). Recordings from an encounter, initially identified as false killer whales (0.77 likelihood), were sent to colleagues at the United States National Oceanic and Atmospheric Administration for expert identification. The calls in the recordings showed a characteristic 'stairstep' whistle

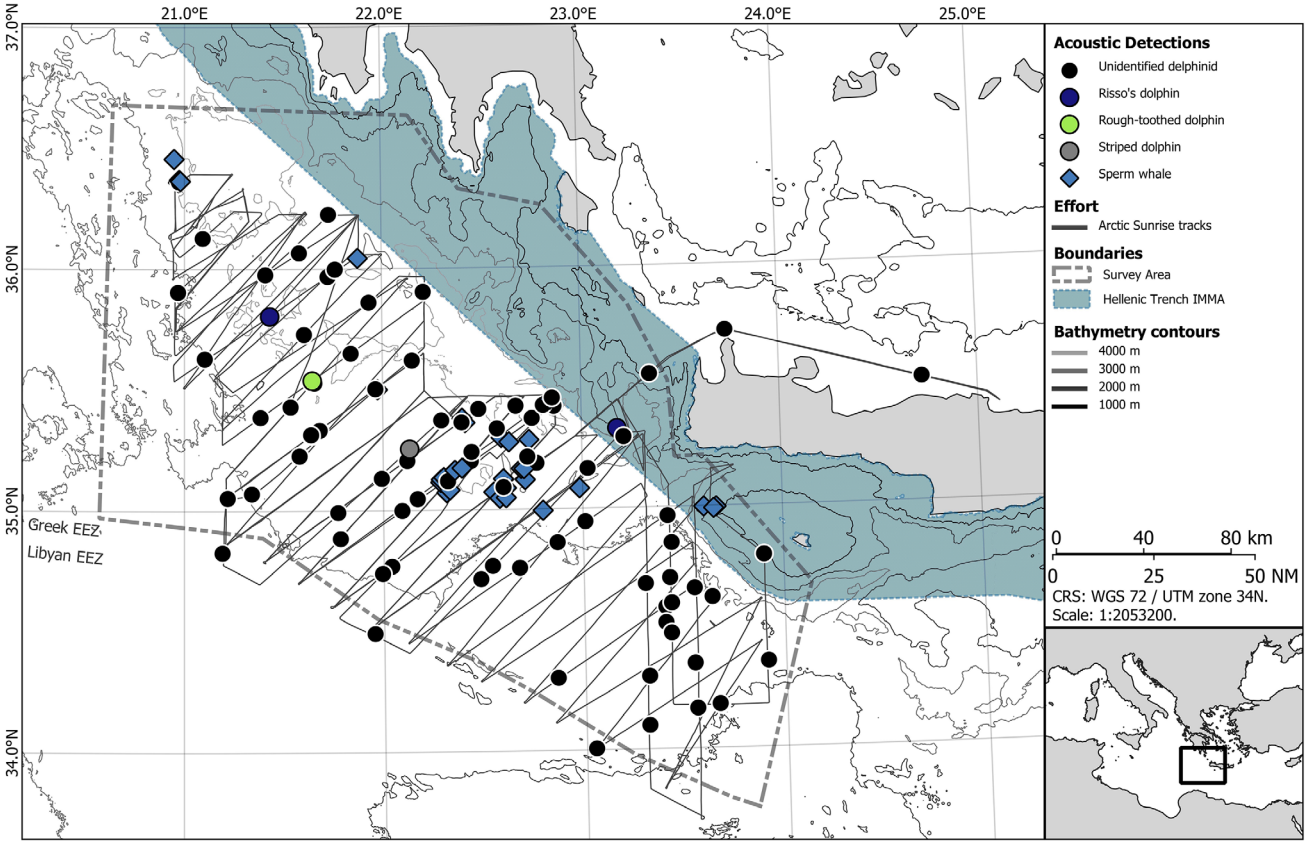

Fig. 2. Acoustic detections of cetaceans from the M/Y 'Arctic Sunrise' during the summer survey period (20 August to 11 September 2021). Bathymetric data from GEBCO (https://www.gebco.net/), coastline from Natural Earth (https://www.naturalearthdata.com/) and Hellenic Trench IMMA boundary from IUCN-MMPATF (2018)

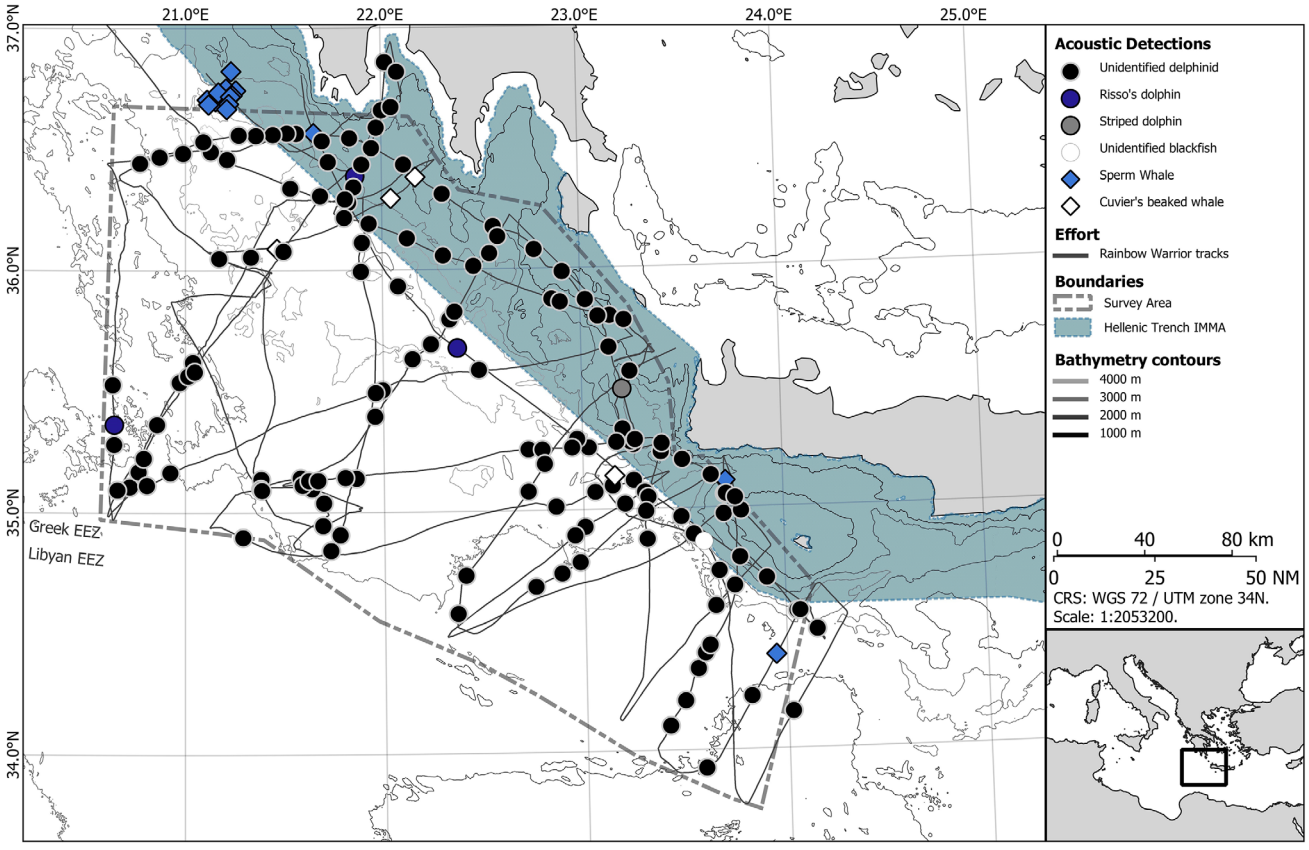

Fig. 3. Acoustic detections of cetaceans from the S/Y 'Rainbow Warrior' during the winter survey period (9 February 2022 to 29 March 2022). Bathymetric data from GEBCO (https://www.gebco.net/), coastline from Natural Earth (https://www.naturalearthdata.com/) and Hellenic Trench IMMA boundary from IUCN-MMPATF (2018)

that is consistent only with rough-toothed dolphins *Steno bredanensis* (J. McCullough & S. Baumann-Pickering pers. comm.).

3.3. Winter survey acoustic detections

The winter survey detected at least 5 species of cetaceans in 166 encounters: sperm whales (14 encounters; 8.4% of encounters), Cuvier's beaked whales (4 encounters from 2 groups), Risso's dolphins (3 encounters; 1.8%) and one detection of striped dolphins (confirmed with concurrent visual sighting) (0.6% of total encounters) (Fig. 3, Table 2). Again, the majority of detections were of delphinids that could not be assigned a species identity on acoustic characteristics alone and are reported as unidentified delphinids (144 encounters; 86.7% of encounters). A single encounter with a group of an unidentified delphinid thought to be a species of blackfish (i.e. likely a pilot whale *Globicephala melas* or false killer whale *Pseudorca crassidens*) (0.86 likelihood) was made, but no species identity could be assigned due to insufficient lengths of recordings. Delphinids detected using the whistle classifier with confidence (i.e. >0.80 likelihood score) were Risso's dolphins (0.91, 0.82 and 0.99 likelihood).

3.4. Sperm whale detections

The 35 individual sperm whale encounters during the summer survey were made up of 10 groups encountered in water depths between 1250 and 4210 m (Tables 2 & 3, Fig. 4). The shortest silent period between any 2 groups was over 4 h (approximately 40 km, given an average speed of 9.8 knots). During the encounters, there were 4 periods of silence of up to 20 min. During these periods, the vessel maintained a steady course and speed of 9.1–10.5 knots. Given that all click trains were first detected ahead of the vessel and ended behind the vessel, we can assume that all sperm whale detections within a group are from individual whales (Table S1 in the Supplement at www.int-res.com/articles/suppl/n052p163_supp.pdf).

Table 2. Acoustic detections of cetaceans using passive acoustic monitoring from the M/Y 'Arctic Sunrise' summer and S/Y 'Rainbow Warrior' winter surveys of the offshore area of the Hellenic Trench. Depth ranges are derived from GEBCO bathymetric data

Survey	Common name	Species name	No. of detections	Comments
Summer	Sperm whale	*Physeter macrocephalus*	35	Depth range: 1250–4210 m 10 group encounters
Summer	Risso's dolphin	*Grampus griseus*	2	Depth range: 2250–3830 m
Summer	Striped dolphin	*Stenella coeruleoalba*	1	Depth: 3470 m
Summer	Rough-toothed dolphin	*Steno bredanensis*	1	Depth: 3650 m
Summer	Unidentified delphinid	Delphinidae	80	Depth range: 440–4390 m
Winter	Sperm whale	*Physeter macrocephalus*	14	Depth range: 1940–4070 m 4 group encounters
Winter	Cuvier's beaked whale	*Ziphius cavirostris*	4	Depth range: 1970–3770 m 2 group encounters Peak click frequency: Group 1 (3 animals): 35.6, 30.5 and 31.0 kHz Group 2 (1 animal): 30.1 kHz
Winter	Risso's dolphin	*Grampus griseus*	3	Depth range: 2930–4810 m Whistle classifier confidence for each group encounter: 0.91, 0.82 and 0.99 respectively
Winter	Striped dolphin	*Stenella coeruleoalba*	1	Depth: 2830 m Whistle classifier confidence: 1 (concurrent sighting)
Winter	Unidentified blackfish	Delphinidae	1	Depth: 2760 m Whistle classifier confidence: 0.86
Winter	Unidentified delphinid	Delphinidae	143	Depth range: 270–4720 m
Total summer survey			**119**	M/Y 'Arctic Sunrise'; no. of days: 22
Total winter survey			**166**	S/Y 'Rainbow Warrior'; no. of days: 49
Total			**285**	

The 14 individual sperm whale encounters during the winter survey were made up of 4 group encounters of overlapping regular clicks (Table 3, Fig. 4). Depths ranged between 1940 and 4070 m. The shortest silent period between any 2 groups was over 24 h. There was one instance within a group encounter where there was a silent period of 8 min. The vessel maintained a steady course at a speed of 7.5 knots, and all click trains were first detected ahead of the vessel and ended behind the vessel, suggesting that it is highly likely that all sperm whale detections within a group are from individual whales (Table S1).

3.5. Cuvier's beaked whale detections

Beaked whale acoustic encounters (Fig. 5) were assigned as Cuvier's beaked whales based on the peak frequency and inter-click intervals (ICI) of vocalisations. The peak frequency range for all 4 encounters was between 30.1 and 35.6 kHz (Fig. 5), which falls within the vocal range (20.3–49.2kHz) of this species recorded by Baumann-Pickering et al. (2013) in the North Pacific, and recorded by Zimmer et al. (2005) in the Ligurian Sea. The mean (±SD) ICIs across all 4 encounters was 0.45 ± 0.06 s, similar to ICIs reported in both the Ligurian Sea (Zimmer et al. 2005) and in the Pacific (Baumann-Pickering et al. 2013). Given this consistent evidence, we are confident that these detections are from Cuvier's beaked whales in deep waters between 1970 and 3770 m.

3.6. Visual survey observations

Visual observations of cetaceans were opportunistically collected to help verify species identity and ascertain group sizes, the presence of calves and behaviour. Visual survey effort totalled 653 h; 441 h during the summer survey and 212 h during the winter survey (Table 4). A total of 25 sightings confirmed Risso's and striped dolphins. A further 10 sightings were noted as unidentified dolphins. The presence

of striped dolphin calves was noted during an encounter that was verified by images on 22 February 2022. No sperm whales were seen during the survey, even though there were acoustic encounters during daylight hours.

4. DISCUSSION

The Hellenic Trench was among the first marine areas to be listed as an IMMA at the global scale because it provides critical habitat for both sperm whales and Cuvier's beaked whales (IUCN-MMPATF 2017, Frantzis et al. 2019). Our study completed 71 d of acoustic surveys over 2 seasons — 22 d in summer and 49 d in winter — covering a total distance of 18 366 km (9206 km in summer and 9160 km in winter). We report the presence of at least 5 species: sperm whale, Cuvier's beaked whale, Risso's dolphin, striped dolphin and rough-toothed dolphin. In addition, both surveys detected a total of 224 delphinids that could not be classified to species level, with one blackfish (n = 1; 3020 m). Sightings confirmed some species identities and also confirmed the presence of calves within a striped dolphin encounter on 22 February 2022. No fin whales, or indeed any other baleen whales, were encountered during the survey.

Sperm whales were detected in the deep waters of the Hellenic Trench during both the summer and winter surveys (range: 1250 to 4210 m, summer mean depth: 3390 m based on 35 encounters, winter mean: 3290 m from 14 encounters). A total of 10 groups

Table 3. Group encounters of sperm whales during both summer and winter surveys with the start and end time of each encounter

Survey	Group	No. of click trains	Start (UTC)	End (UTC)
Summer	1	9	20-Aug-21 10:13	20-Aug-21 11:17
Summer	2	1	21-Aug-21 17:28	21-Aug-21 17:33
Summer	3	5	23-Aug-21 07:28	23-Aug-21 07:36
Summer	4	1	24-Aug-21 05:05	25-Aug-21 05:58
Summer	5	5	25-Aug-21 23:49	26-Aug-21 00:41
Summer	6	7	30-Aug-21 18:22	30-Aug-21 19:19
Summer	7	2	30-Aug-21 23:27	30-Aug-21 23:36
Summer	8	1	01-Sept-21 19:08	01-Sept-21 20:09
Summer	9	1	10-Sept-21 04:59	10-Sept-21 05:32
Summer	10	3	11-Sept-21 17:03	11-Sept-21 17:18
Winter	1	1	19-Feb-22 04:26	19-Feb-22 05:24
Winter	2	1	21-Feb-22 16:07	21-Feb-22 17:07
Winter	3	11	24-Feb-22 09:15	24-Feb-22 11:17
Winter	4	1	27-Mar-22 16:24	27-Mar-22 18:12

Table 4. Visual observations of cetaceans from the M/Y 'Arctic Sunrise' summer and S/Y 'Rainbow Warrior' winter surveys of the offshore area of the Hellenic Trench. Observations are to supplement acoustic surveys and document group size and the presence of calves where possible

Survey	Common name	Species name	No. of encounters	Comments
Summer	Risso's dolphin	*Grampus griseus*	2	One encounter designated as 'possible' based on description. Not confirmed by acoustic data Second encounter confirmed with images and acoustics Group size: 40 dolphins, no calves present
Summer	Unidentified delphinid	*Delphinidae*	7	Too distant to verify, no images Group size: 2–12 dolphins
Summer	Loggerhead turtle	*Caretta caretta*	5	–
Winter	Striped dolphin	*Stenella coeruleoalba*	5	Three encounters confirmed by images Acoustic detection on 4 March 2022, but whistle classifier did not ascertain species identity Groups size: 3–10 dolphins, calves present on 22 February 2022
Winter	Unidentified delphinid	Delphinidae	3	Descriptions suggest striped dolphins. Acoustic detection on 26 March 2022 but whistle classifier did not ascertain species identity Group size: 1–5 dolphins, no calves present
Winter	Unidentified turtle	Chelonioidea	3	
Total Summer survey			**14**	
Total Winter survey			**11**	
Total			**25**	

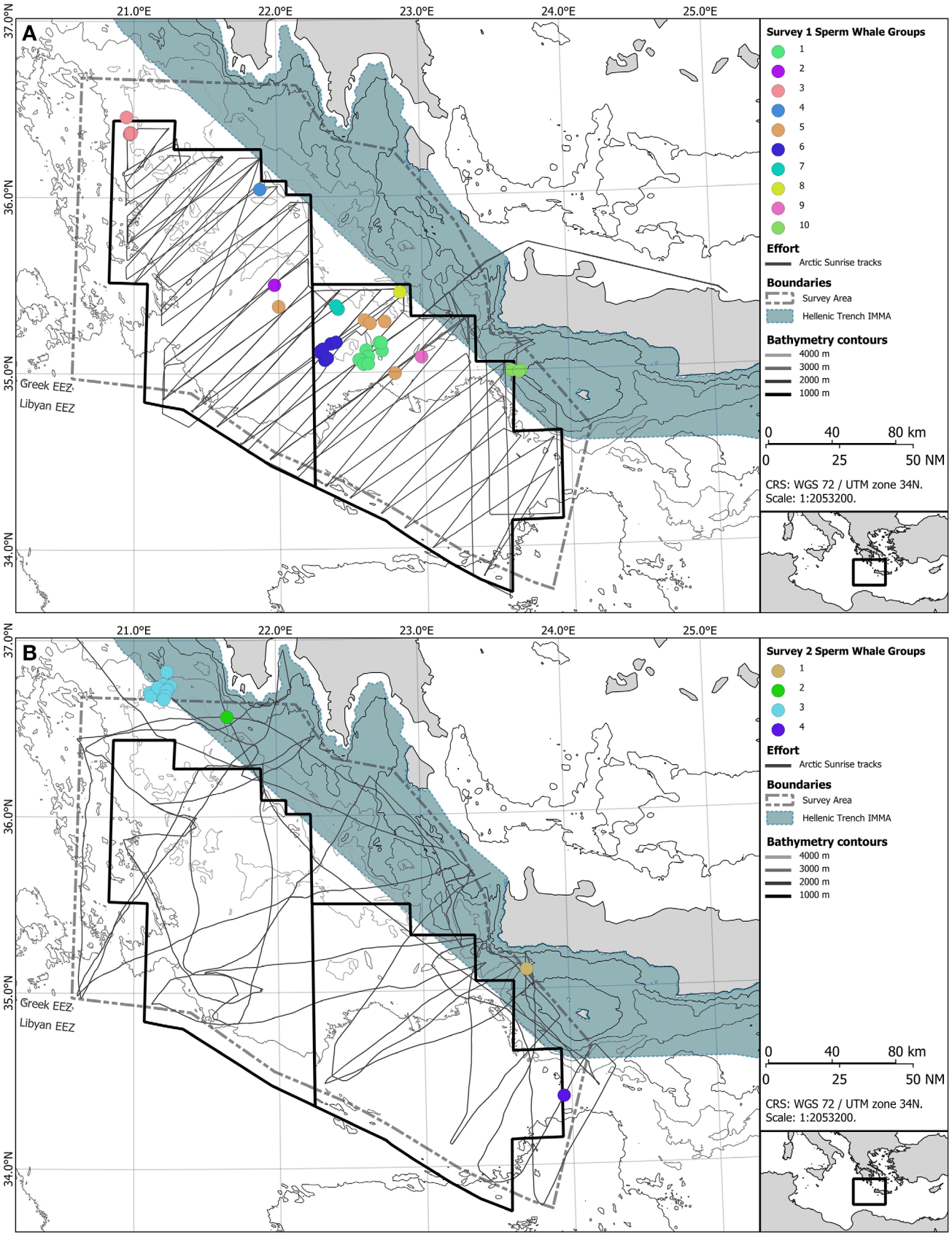

Fig. 4. Sperm whale groups acoustically detected during the summer and winter surveys. (A) Summer survey conducted by the M/Y 'Arctic Sunrise' between 20 August and 11 September 2021; (B) winter survey conducted by the S/Y 'Rainbow Warrior' between 9 February 2022 and 29 March 2022. Bathymetric data from GEBCO (https://www.gebco.net/), coastline from Natural Earth (https://www.naturalearthdata.com/) and Hellenic Trench IMMA boundary from IUCN-MMPATF (2018)

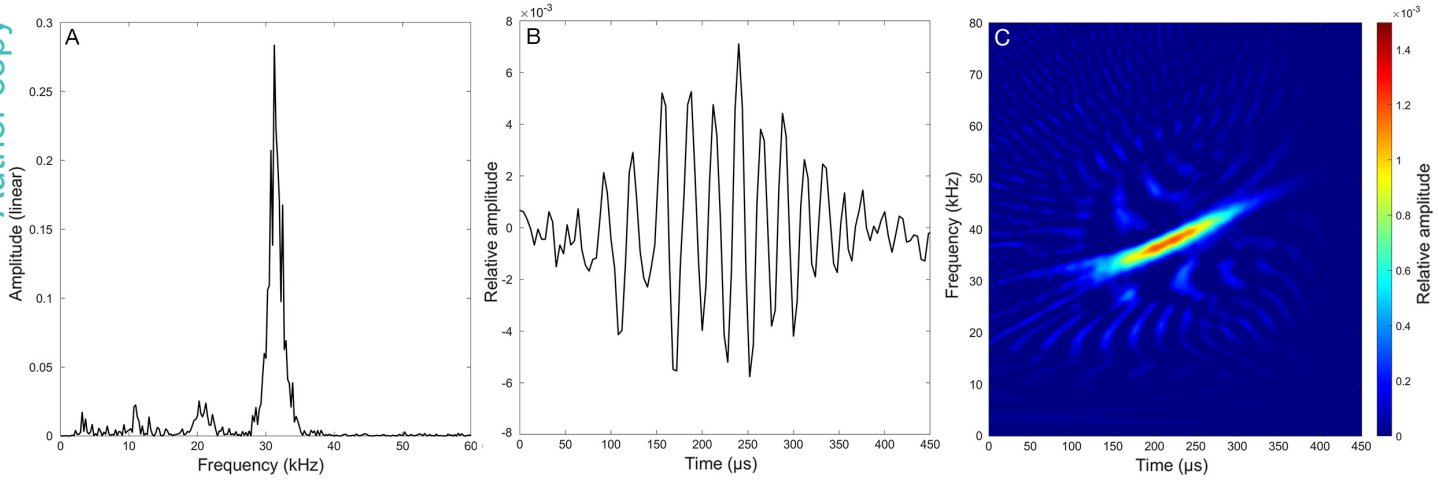

Fig. 5. Acoustic characteristics of a Cuvier's beaked whale detected during the winter survey conducted by the S/Y 'Rainbow Warrior'. (A) Example spectrum, (B) waveform and (C) Wigner plot. All are consistent with this species' identity and distribution (Baumann-Pickering et al. 2013, Podestà et al. 2016)

were detected during the summer survey and 4 during the winter survey. Detection rates for sperm whales were lower in the winter survey but we show that this species is present in the deep-water habitats of the Hellenic Trench during the cooler periods of the year. Improving seasonal coverage is important for improving understanding of seasonal changes in densities, distributions and habitat use. This will also provide new understanding of exposure to different threats through the year. Also useful would be further acoustic measurement of body length as implemented by Caruso et al. (2015) in the Ionian Sea. Such an analysis could provide more detailed information on the number of individual whales present in an area, and the age- and sex-structure of groups encountered.

We confirmed the presence of Cuvier's beaked whales in the Hellenic Trench during winter, which is consistent with stranding reports that occur year-round along the Hellenic Trench (Pelagos Cetacean Research Institute stranding database unpubl. data). Other species of beaked whales potentially extant in the Mediterranean either vocalise at higher peak click frequencies (e.g. Sowerby's and Gervais' beaked whales; see Baumann-Pickering et al. 2013, Clarke et al. 2019). Some of the peak click frequencies detected here do fall within the range reported for Blainville's beaked whales (Baumann-Pickering et al. 2013), but Blainville's are thought to be absent in this area. During 19 visual surveys along the Hellenic Trench from 1998 to 2022 and in all stranding records from the Greek coasts, no beaked whale species except Cuvier's beaked whales have ever been detected (Pelagos Cetacean Research Institute unpubl. data). Given this consistent evidence, we are confident that the beaked whales we encountered were Cuvier's beaked whales. Acoustic surveys during the winter months are sparse and, given the knowledge of this species' sensitivity to anthropogenic noise, we suggest extreme caution in furthering potentially impactful human activities in this area throughout the year (Frantzis 1998, Cox et al. 2006).

Beaked whales, and particularly the Mediterranean subpopulation of Cuvier's, are facing an increasing number of threats (Podestà et al. 2016, Cañadas & Notarbartolo di Sciara 2018, Hooker et al. 2019). Vulnerability to noise disturbances caused by military sonar, naval traffic and geological and seismic surveying is known to be a serious issue for beaked whales (Cox et al. 2006, Hooker et al. 2019, Li & Rosso 2021). Impacts related to the extensive use of airguns for seismic surveys and military activity could have a cumulative impact on the whales that rely on the Hellenic Trench habitat.

This marine area is a known ecological hotspot for Cuvier's beaked whales in the Mediterranean (Podestà et al. 2016), and therefore these threats, acting in combination with other stresses, could have serious population-level consequences for small and isolated local population units that are already reported to be in decline (Frantzis et al. 2022). The impacts of other anthropogenic activities are already evident in this Cuvier's beaked whale population. For example, Alexiadou et al. (2019) reported the results of necropsies performed on stranded Cuvier's beaked whales since 1993, with the cause of death in one case noted as gastric blockage by macro-plastics. Mortality caused by exposure to military sonar has

been reported repeatedly in the area (Frantzis 1998, 2015) and Cuvier's beaked whales appear to be particularly sensitive to some types of acoustic disturbance in the Hellenic Trench as in other areas of the world. For example, Falcone et al. (2017) recorded changes in foraging behaviour of Cuvier's beaked whales in response to mid-frequency active sonar, noting that responses were evident up to 100 km away from the source. DeRuiter et al. (2013) reported that this species elicited a strong behavioural response to playback experiments involving mid-frequency sonar, where individuals ceased foraging during the playback. Such responses, if repeated, could result in significant fitness costs to individuals and potentially have population-level implications. The impact of seismic survey operations is less clear. However, a review by Forney et al. (2017) indicates that individuals in small and resident populations of Cuvier's beaked whales that are repeatedly exposed to loud and persistent seismic survey blasts, described as behavioural harassment events, could experience injury. Further, effective mitigation is particularly difficult to achieve for beaked whales, given their long dives, cryptic surfacing behaviour and periods of silence at the surface, which mean that that observers are unlikely to detect their presence. The Hellenic Trench Cuvier's beaked whale population could be repeatedly exposed to seismic surveying and the noise of subsequent gas extraction for many years to come, and any population-level impacts may only be evident years after they occur, and then only if they are severe. Therefore, it is important for policymakers to follow the precautionary principle by preventing further impacts from anthropogenic activities in the Hellenic Trench, particularly those activities that relate to noise and other types of pollution.

Our study confirms the presence of several offshore delphinid species, with Risso's dolphin presence confirmed in offshore areas of the Hellenic Trench during summer and winter survey periods (2250 to 3830 m deep in summer; 2930 to 4808 m deep in winter). Risso's dolphins feed exclusively on squid and are thought to prefer the outer-slope habitats (Cañadas et al. 2002, Azzellino et al. 2008). The distribution of detections here appears consistent with other surveys, although in our study the groups were encountered in much deeper waters. For example, in the Ligurian Sea, Azzellino et al. (2008) reported Risso's at a mean depth of 821 m (range: 374 to 1100 m). However, more extensive surveys would be required to confirm whether there are any significant differences in Risso's dolphin habitat use within the Hellenic Trench and other areas or seasonal shifts in distributions. Striped dolphins were detected both acoustically and visually in both surveys.

Rough-toothed dolphins are a rarely observed species in the Mediterranean and were detected acoustically during the summer survey at a depth of 3650 m. Boisseau et al. (2010) conducted surveys of cetaceans throughout the Mediterranean over several field seasons and encountered rough-toothed dolphins 3 times at depths 320 to 2882 m (mean depth: 1448 m). The authors noted that according to their data and that of others, this species appears to regularly occur in the region, certainly during the summer months when most surveys were conducted. Foskolos et al. (2023) reviewed the distribution of rough-toothed dolphin sightings, strandings and acoustic encounters that indicate that this species is likely distributed across the entire offshore waters of the eastern basin. A lack of winter survey data hinders any conclusions on the seasonality of their distributions. Kerem et al. (2016) suggested that the Mediterranean population of rough-toothed dolphins regularly occur in the eastern region of the sea beyond the Sicilian Channel, noting that there may be sparse evidence for seasonal shifts in distributions from deep to shallower waters. Here, we show this species in the deep waters of the Hellenic Trench during September 2021 and highlight the need for more deep-water acoustic surveys to learn more about this species' distribution in the Hellenic Trench.

5. CONCLUSIONS

Our study has confirmed the presence of sperm and Cuvier's beaked whales outside of the warmer summer months in the deeper waters of the Hellenic Trench beyond the 2000 m bathymetric contour, beyond the boundary of the IMMA. We also confirmed the presence of Risso's, rough-toothed and striped dolphins during this period.

The broader Hellenic Trench region is subject to seismic survey operations, oil and gas extraction and intense shipping. Such activities, in combination with the impact of fisheries and widespread ecosystem alterations due to climate change, could potentially lead to population-level impacts on cetaceans that rely on the Hellenic Trench as a key habitat. Given the diversity and threat status of cetaceans present in the region throughout the year, we urge caution in issuing new permits for activities such as seismic sur-

veys and hydrocarbon extraction throughout the wider Hellenic Trench area.

Acknowledgements. Many thanks to the crew of the 'Rainbow Warrior' and 'Arctic Sunrise', in particular radio operators Tararak Ruchirabha and Neil Brewster, Greenpeace Research Laboratory staff, Kostis Grimanis (Greenpeace Greece), Olly Boisseau and Doug Gillespie. We also thank Jennifer McCullough, Simone Baumann-Pickering and Robin Baird for their invaluable help in the correct identification of the rough-toothed dolphin, and Frants Jensen for the attempt to identify the blackfish from the short recording. This research is based on a Greenpeace project that is described in 2 preliminary project reports that can be found online at the Greenpeace Research Laboratories website (https://www.greenpeace.to/greenpeace/wp-content/uploads/Greenpeace_HellenicTrenchSummary_GRLAnalyticalRep2022-03.pdf and https://www.greenpeace.to/greenpeace/wp-content/uploads/2021/11/Visual-Acoustic-Survey-Hellenic-Trench-Cetacean-Survey-2021.pdf). The manuscript benefited greatly from the thoughtful comments provided 3 anonymous reviewers. All research was conducted under the permit of the Marine Research Licensing Committee (MRLC). MRLC is a special inter-ministerial committee, the operation of which is based on provisions of the Greek Ministry of Foreign Affairs' Service Organisation.

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Editorial responsibility: Ana Cañadas, Durham, North Carolina, USA
Reviewed by: 3 anonymous referees

Submitted: December 19, 2022
Accepted: July 4, 2023
Proofs received from author(s): September 29, 2023