Regional Studies in Marine Science 66 (2023) 103164

Contents lists available at ScienceDirect

Regional Studies in Marine Science

journal homepage: www.elsevier.com/locate/rsma

Cetaceans of the Saya de Malha bank region, Indian Ocean: A candidate Important Marine Mammal Area

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ARTICLE INFO

Article history:
Received 21 March 2023
Received in revised form 9 August 2023
Accepted 16 August 2023
Available online 19 August 2023

Keywords:
Bioacoustic
Biodiversity
Cetacean
Mascarene plateau
Platform of opportunity
Saya de Malha
Sperm whale

ABSTRACT

The banks of Saya de Malha and the surrounding Mascarene Plateau in the Indian Ocean are among the least studied shallow sea water regions in the world. The steep sloping bathymetry of this region is thought to drive high levels of primary productivity and support a diverse range of marine species. Until now, no surveys for cetaceans have been conducted in the waters surrounding Saya de Malha, and so the diversity of cetaceans is unknown. Opportunistic visual and acoustic surveys for cetaceans were conducted onboard a platform of opportunity, the *MY Arctic Sunrise*, which was involved in a wider project to document the marine life in the region. Survey effort was conducted over 7,700 km, with twelve species of cetacean encountered, including Bryde's, sperm, beaked and killer whales, along with spinner, striped, pantropical spotted and bottlenose dolphins. A match of a sperm whale coda vocalisation to another, well-studied population off the coast of Mauritius suggests possible connectivity between these regions although further data would be required to confirm this. The banks of Saya de Malha appear to support a diverse range of cetacean species and further systematic surveys are required to increase our understanding of how different species utilise the banks. We provide whistle contours from visually confirmed acoustic detections to contribute towards building a region-specific whistle classifier. Given the diversity of species detected in the region, we suggest that the Saya de Malha bank area be designated, either as an Important Marine Mammal Area or as a marine protected area.

1. Introduction

The Indian Ocean is home to at least 30 species of marine mammal, some of which are resident while others undergo long distance migrations through the region, such as blue whales (*Balaenoptera musculus*) and humpback whales (*Megaptera novaeangliae*). During the 20th century the Indian Ocean was a focus for large-scale industrial whaling and was the main whaling ground for large baleen whales that feed in the Southern Ocean (Rocha et al., 2015). Since then, few dedicated surveys have investigated the offshore distributions of cetaceans across the Indian Ocean, although surveys off the coasts of the Seychelles, Madagascar, Mauritius and La Réunion indicate a high diversity of species around the islands (Ridoux et al., 2010; Kiszka et al., 2007, 2009; Webster et al., 2020).

Located in the Western Indian Ocean, Saya de Malha is one of the world's most remote and least studied shallow sea water ecosystems. The bank is situated along the central region of the Mascarene Plateau that runs between Mauritius and the Seychelles. Over 300 km away from the nearest coastline, the northern Ritchie and more southerly Saya de Malha banks combine to cover an area of approximately 40,800 km^2, much of which lies within international waters. Depths on the two banks range between 8 and 150 m, and they are separated by an ~1,000 m deep channel, with the banks eventually sloping on all sides to deep open ocean (New et al., 2005). The South Equatorial Current interacts with the topography of the banks and the channels between them to form regions of upwelling and mixing, a major driver of primary productivity in the region (e.g., Bhagooli et al., 2021; Soondur et al., 2021). This primary

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https://doi.org/10.1016/j.rsma.2023.103164

productivity is thought to support a diverse range of marine taxa, occurring in both shallow waters and into the open ocean beyond (Nesis, 1993; Neumann and Piridonov, 1999; Ramah et al., 2021b; Sirenko, 1993). For example, although the bank is poorly studied, it is known to support mixed coral and seagrass communities with what is reputed to be the world's largest contiguous seagrass meadow (*Thalassodendron ciliatum*) (Hilbertz and Goreau, 2002) and rhodolith beds (Ramah et al., 2021a).

To this point, there have been no surveys which have reported on the diversity of cetacean species occurring in the Saya de Malha region. Previously, visual ship-based (Ballance and Pitman, 1998) and aerial (Van Canneyt, 2022) surveys were conducted around the wider Indian Ocean documented 21 and 27 cetacean species, respectively. These surveys were focused primarily on the north and south-western areas. As top predators, odontocete cetaceans can influence the structuring of marine ecosystems and are often considered sentinel species (Estes et al., 2011). Understanding the diversity of cetacean species, where species occur, what factors drive their distribution and how these change over time, is key to aiding management decisions (Redfern et al., 2006). Moreover, initial surveys to document the diversity of a region are important in informing further survey efforts, allowing for the collection of more detailed data to quantify species abundance, occurrence trends and other indices (Buckland et al., 2005).

Conservation of marine ecosystems in the remote areas of the high seas, or areas beyond national jurisdiction, is a challenge. The true oceanic areas are remote and expensive to survey, and the designation of marine protected areas is often complicated due to fragmented governance. However, it is well established that such protection helps in biodiversity conservation and resilience to climate change (O'Leary et al., 2016; Roberts et al., 2017). Governments have committed to protecting at least 30% of land and of sea by 2030 in a system of protected areas as part of the Kunming-Montreal Global Biodiversity Framework under the UN Convention on Biological Diversity (CBD, 2022). While the Seychelles and Mauritius exercise joint sovereignty of the continental shelf of Saya de Malha (United Nations, 2012), the water column, including the organisms living within it, is outside of national jurisdiction (United Nations, 1984). On 19 June 2023, the Intergovernmental Conference on Marine Biodiversity of Areas Beyond National Jurisdiction adopted, by consensus, the Agreement under the United Nations Convention on the Law of the Sea on the conservation and sustainable use of marine biological diversity of areas beyond national jurisdiction (United Nations, 2023). The Agreement aims to provide a mechanism for designating marine protected areas in highly biodiverse regions. Current initiatives highlighting areas of the ocean that are biologically significant for certain taxonomic groups include, Important Bird and Biodiversity Areas (IBAs) as championed by Birdlife International, and similarly Important Marine Mammal Areas (IMMAs) as identified by the International Union for Conservation of Nature's (IUCN) Marine Mammal Protected Areas Task Force (MMPATF). The MMPATF have identified 37 IMMAs in the Western Indian Ocean, including those around bathymetric features such as islands and seamounts (www.marinemammalhabitat.org/imma-eatlas). The MMPATF use four criteria for designation: Criterion A — Species or Population Vulnerability; Criterion B — Distribution and Abundance; Criterion C — Key Life Cycle Activities; Criterion D — Special Attributes, that include areas which sustain populations with important genetic, behavioural or ecologically distinctive characteristics, or those that support an important diversity of marine mammal species. As the waters surrounding the Saya de Malha bank have not been surveyed for cetaceans, important questions on the diversity, distribution and abundance of species in these waters remain unanswered.

Two regions of the Mascarene Plateau fulfil the specific criteria and are designated as IMMAs by the MMPATF. The northern Seychelles Plateau and Adjacent Waters IMMA fulfils criteria related to criterion A — Species or Population Vulnerability; Criterion B — Distribution and Abundance and; Criterion D — Special Attributes, with key species noted as spinner dolphin (*Stenella longirostris*), sperm whale (*Physeter macrocephalus*) and bottlenose dolphins (both *Tursiops truncatus* and *Tursiops aduncus*) (IUCN-MMPATF, 2021). At the southern region of the Mascarene Plateau is the Mascarene Islands and Associated Oceanic Features IMMA that encompasses the waters surrounding Réunion, Mauritius and the La Perouse seamount and Saint-Brandon bank. This IMMA was designated as such based on Criterion A — Species or Population Vulnerability; Criterion B — Distribution and Abundance; Criterion C — Key Life Cycle Activities and Criterion D — Special Attributes, with sperm and humpback whales, bottlenose and spinner dolphins as key species (IUCN-MMPATF, 2020). Whilst the IMMA process is useful in areas of high survey effort, critics have noted how a lack of survey data in many regions of the ocean hinders identification and designation of appropriate important areas. As the Saya de Malha region is geographically contiguous to these two IMMAs, there is a potential for this area to support a range of cetacean species and could similarly fulfil the IMMA criteria given sufficient survey effort. Our study aimed to contribute to filling this knowledge gap by providing the first report of cetacean diversity surrounding the banks of Saya de Malha using a visual-acoustic survey in March 2021.

2. Materials and methods

Visual-acoustic surveys for cetaceans were conducted from the *MY Arctic Sunrise* in March of 2021 as part of a wider expedition to document the marine life in the region, focusing on an area extending from the inner islands of the Seychelles to Saya de Malha. A non-systematic visual survey was conducted during daylight hours (07:00 to 18:00 local time) to provide evidence of cetacean presence in the survey area and, where possible, data on species identity, location, numbers of animals and behaviour. During the survey there was always at least one observer scanning the area in front of the ship, from approximately −90° through to 90° (relative to the ship's heading) out to the horizon at a platform height of 1296 mm. For the majority of survey time, however, two observers were on watch scanning approximately +/−90° from the bow to the beam of either the port or starboard side. Observers were located on the vessel's bridge-wings and performed one-hour watches throughout the survey period, scanning using both binoculars and unaided eye throughout the watch. At the beginning and end of every watch, or if any change was noted, environmental and effort variables were recorded as follows: effort status, observer identity, position, speed of vessel over ground, Beaufort sea state, depth, water temperature, swell height and direction, visibility, glare and rain.

If cetaceans were observed, the following data set was recorded: date, time (local), initial observer identity, effort status, ship's heading, position, water depth, sighting method (unaided eye or binoculars), initial sighting cue (blow, surface activity, body or submerged), initial bearing and distance to the animal, closest distance (estimated), group size (minimum/ maximum/ best estimate), presence of calves, species (highest taxonomic group possible), and confidence of species identity (definite/ probable/ possible). Distances were estimated using reticule binoculars and bearings to animals were measured using angle boards attached to the bridge wings. Species identity was confirmed using the guides of Carwardine (2020) and Shirihai et al. (2006). Where possible photographs were taken of animals for species identification. When animals were seen to be remaining in the area, an unmanned aerial vehicle (UAV — Phantom 4 Pro V 2.0) was launched to record visual observations from above to document their behaviour with minimal disturbance (Torres et al., 2018). UAV flights were opportunistic and based on the presence of animals and of suitable weather conditions for flight. The UAV was launched from either the deck of *MY Arctic Sunrise* or from a rigid-hulled inflatable boat (RHIB) during other data collection. Photographs of sperm whale flukes were also collected where possible to allow individuals to be matched to previous identification efforts. All fluke images of sperm whales were uploaded to Flukebook (https://www.flukebook.org) which uses two algorithms (CurvRank and OC/WDTW) to match new fluke photographs to previously uploaded fluke photographs. Photographs of sperm whale flukes were also compared to catalogues of sperm whale flukes collected from around Reunion and Mauritius islands (Huijser et al., 2020; Globice, unpublished data).

Acoustic data were collected using a four-channel hydrophone array (Vanishing Point Ltd, United Kingdom) deployed and towed from the stern of the *MY Arctic Sunrise*. The array comprised a 'medium frequency' and a 'high frequency' pair of hydrophones (Medium: Benthos AQ4 elements and Magrec HP02 preamplifiers, nominal frequency range 50 Hz to 40 kHz; High: Magrec HP03 hydrophone and preamplifiers units, nominal frequency range 1–200 kHz). Each hydrophone was connected to a SAIL data acquisition card (St Andrews Instrumentation Ltd), where all four channels were sampled at 500,000 samples per second (500 kHz). Filtering and gain were applied (Medium: high pass filters of 10 Hz, gain of 6 dB; High: high pass filter of 2 kHz, gain of 12 dB), and sound was written as four-channel .wav files using PAMGuard (Gillespie et al., 2008) (available at www.pamguard.org), which also logged the ship's location from GPS.

Offline processing of recorded towed array .wav files followed the methods outlined in Webber et al. (2022). In summary, odontocete clicks were detected using a PAMGuard click detector module with a threshold of 16 dB and angle veto of 20° to reduce the noise detected from the towing vessel. Clicks were processed as follows: First, three narrowband click classifiers with frequency sweeps were run on all click detections, two to detect beaked whales and third, to detect narrowband high frequency (NBHF) odontocetes. Clicks were then run through a Multi-Hypothesis Tracking Click Train Detector module in PAMGuard (Macaulay and Gillespie, 2022). The group size of sperm whales was estimated by counting distinct click trains which were on consistent bearings within PAMGuard. Click trains were then localised using PAMGuard's Target Motion Analysis module using the two-dimensional simplex method. Delphinid whistles were detected using a PAMGuard whistle and moan detector module and run through a whistle classifier (Gillespie et al., 2013) to determine species identity. As the classifier used was trained on species not recorded from the region, it is possible that whistle classification is incorrect. Therefore, any classifications with likelihood scores of <0.8 were discarded. Once the automated processing in PAMGuard was complete, manual verification of click classifiers, click trains and whistle classification was conducted to remove any false positive detections and verify species classifications. For example, the classification was corrected according to the visual sighting record, the Wigner transformation was plotted for a given click to look for upsweeping of beaked whale clicks (Papandreou-Suppappola and Antonelli, 2001; Yack et al., 2013) and the presence of spectral banding in the echolocation clicks was checked as these are indicative of Risso's dolphins (Soldevilla et al., 2008)

A two-channel hydrophone was also deployed opportunistically from a RHIB when in visual range of sperm whale groups at the surface to record coda vocalisations, stereotyped repetitive series of clicks with patterns described by the number of clicks and the inter-click intervals. When sperm whale codas were detected from either recording system, efforts were made to describe coda types following Weilgart and Whitehead (1997) to allow for comparison to coda types described in other regions of the Indian Ocean.

3. Results

Approximately 7,700 km of survey effort was conducted onboard the *MY Arctic Sunrise* between the 11th and 30th of March 2021 across Saya de Malha and the Seychelles, with an average cruising speed of 5.7 kn. Visual surveys recorded 44 sightings of cetacean groups, including dolphins, baleen whales, sperm whales and beaked whales (Figs. 1 and 2). Drone flights captured video footage of sperm whales, a Bryde's whale (*Balaenoptera brydei)* and spinner dolphins. Approximately 487 h of acoustic data were recorded with 181 acoustic detections of odontocete groups verified manually. Of these, 65 groups were classified to species level, either manually using vocalisation characteristics (29 groups), using concurrent visual sightings (seven groups) or by using a whistle classification likelihood $\geq$ 0.8 ($n = 29$). The remaining 116 acoustic encounters were dolphins which could not be classified to species level and a further seven sightings were attributed to unidentified baleen whales (Fig. 3). Baleen whale vocalisations are unlikely to be detected acoustically as they occur within the frequency range most masked by noise from the towing vessel. A total of twelve cetacean species were identified across the survey (Table 1) with cue, behavioural data and number of animals recorded where visually sighted (Table 2).

3.1. Bryde's whales

Bryde's whales were the only baleen whale species identified during the survey (Fig. 4a). A total of seven sightings were recorded with one sighting of two individuals and six sightings of single animals. Most whales were sighted in water depths between 1,250 m and 2,560 m and were seen to be either travelling or resting at the surface between dives. UAV footage captured one individual resting at the surface, making a series of shallow dives before diving to deeper depths and being lost from sight of the drone.

3.2. Sperm whales

Sperm whales were the most abundant cetacean species encountered with a total of 33 group encounters acoustically detected or visually sighted comprising an estimated 163 animals. Based on click trains alone, we cannot determine whether or not some of these groups may have been counted twice. The mean group size across both visual and acoustic detections was five animals. Most sperm whales were encountered in waters of depths between 320 and 2,870 m, where they were either sighted resting at the surface, or acoustically detected during their foraging dives. During one encounter, approximately six animals were acoustically detected in waters shallower than 600 m (depth at the location of the click train estimated by the target motion analysis module within PAMGuard), and six animals were visually sighted when they surfaced, seen to be resting and socialising between the foraging dives. UAV footage recorded groups of sperm whales resting at the surface prior to diving (Fig. 4b), tail slapping and on one occasion animals were observed rubbing up against each other. Fluke photographs were taken of 11 individuals, and comparisons were made with 122 individuals previously documented in Reunion and Mauritius, resulting in no photographic recapture. No calves were visually sighted. One recording of sperm whales contained coda vocalisations. The codas recorded at the Saya de Malha were of the 6-click 2fast+3+1 type ($n = 11$))(Fig. 5).

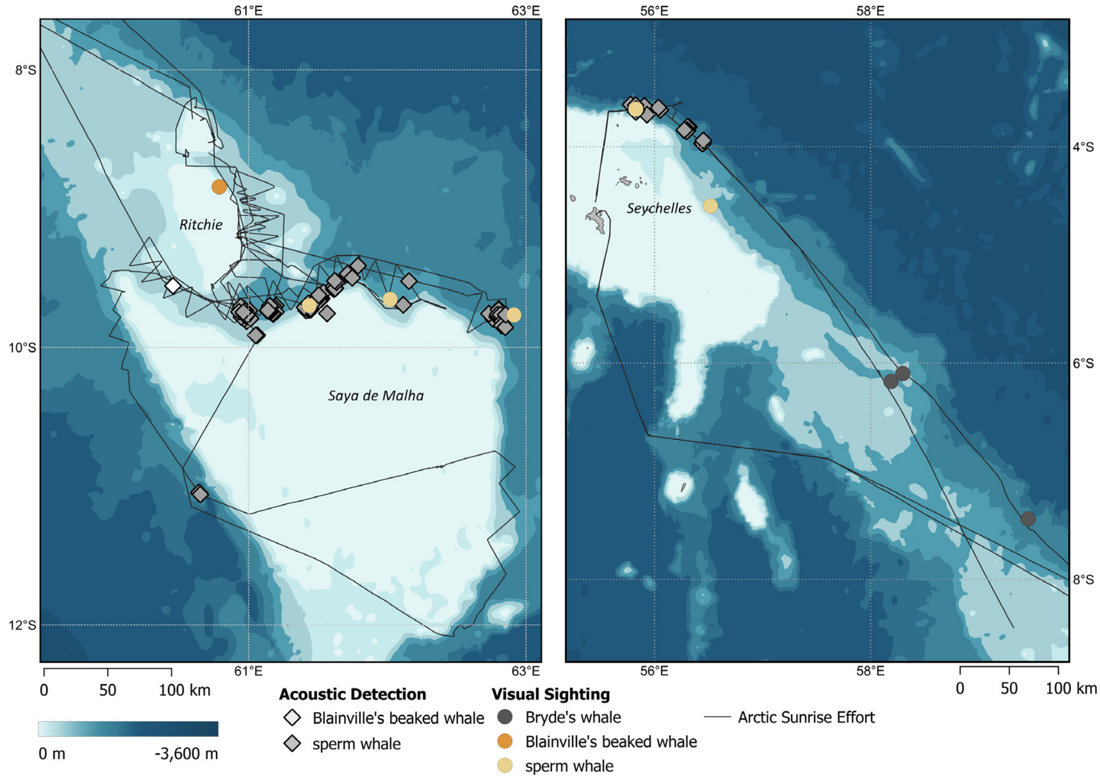

Fig. 1. Sightings and acoustic detections of large whales during the *MY Arctic Sunrise* survey in March of 2021.

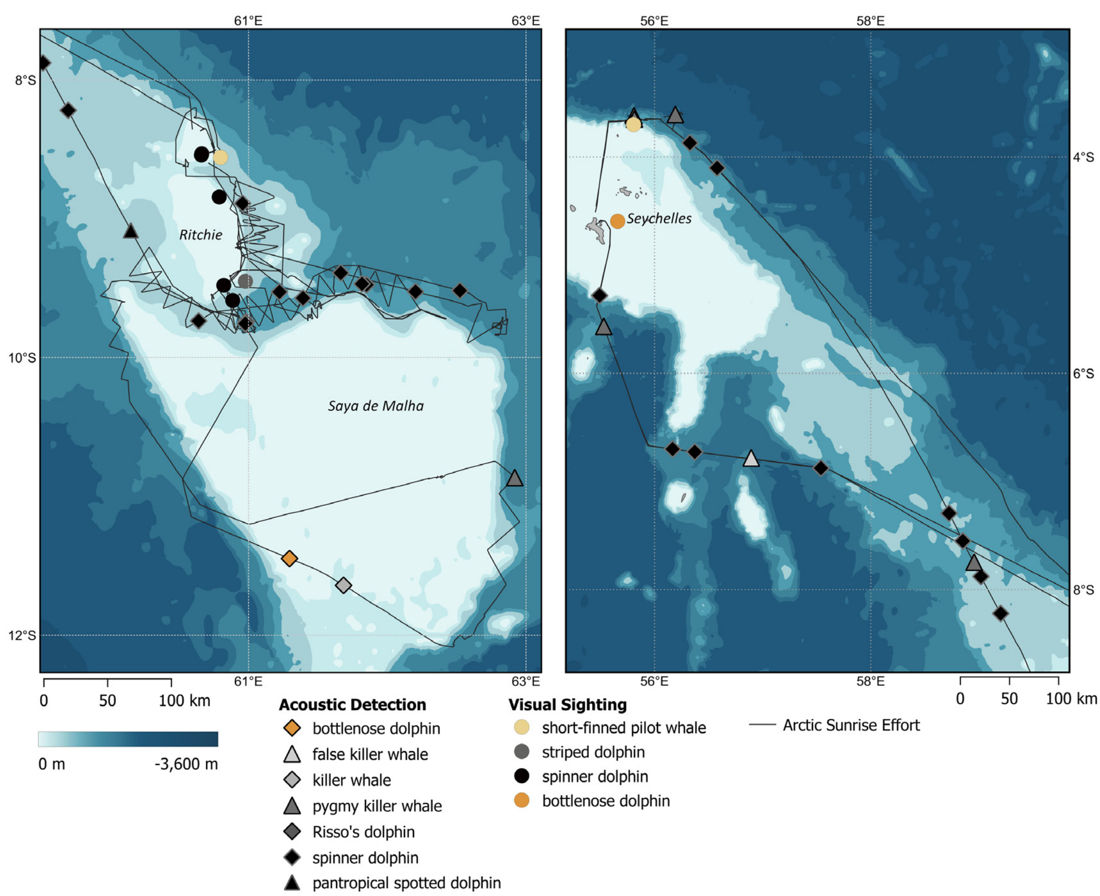

Fig. 2. Sightings and acoustic detections of delphinids during the *MY Arctic Sunrise* survey in March of 2021.

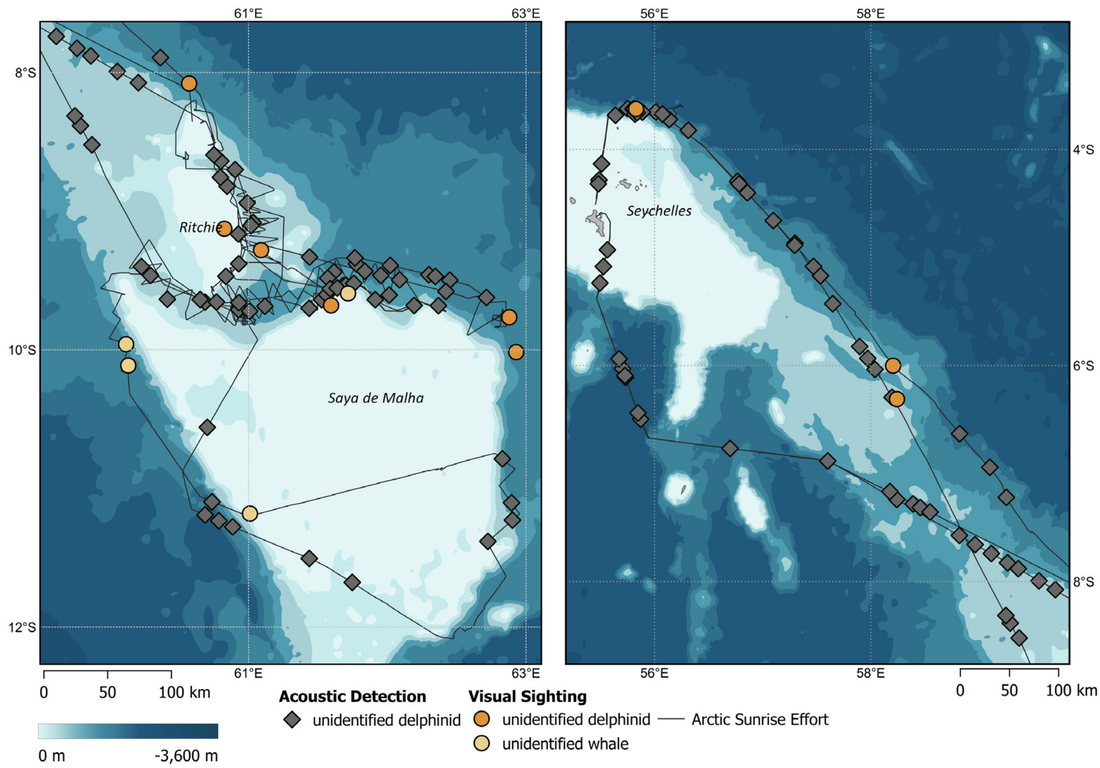

Fig. 3. Sightings and acoustic detections of unidentified marine mammals during the *MY Arctic Sunrise* survey in March of 2021.

Table 1
Cetacean species identified during visual and acoustic surveys of the Saya de Malha banks onboard the *MY Arctic Sunrise*. Number (N) of encounters refers to the combined number of visual sightings and acoustic detections of animal groups, with concurrent detections referring to animal groups which were detected both acoustically and visually.

Species	Common name	Number of encounters	Number of sightings	Number of acoustic detections	Number of concurrent visual and acoustic detections
Baleanoptera edeni	Bryde's whale	7	7	0	0
Physeter macrocephalus	sperm whale	33	5	31	3
Mesoplodon densirostris	Blainville's beaked whale	2	1	1	0
Tursiops spp.	bottlenose dolphin	2	1	1	0
Pseudorca crassidens	false killer whale	1	0	1	0
Orcinus orca	killer whale	1	1	1	1
Stenella attenuata	pantropical spotted dolphin	1	1	0	0
Stenella coeruleoalba	striped dolphin	1	1	1	1
Feresa attenuata	pygmy killer whale	6	1	6	1
Grampus griseus	Risso's dolphin	1	0	1	0
Globicephala macrorhynchus	short-finned pilot whale	2	2	0	0
Stenella longirostris	spinner dolphin	27	6	22	1
Balaenoptera spp.	unidentified baleen whale	7	7	0	0
Delphinidae	unidentified delphinid	126	11	116	1

3.3. Beaked whales

Two encounters with Blainville's beaked whales (*Mesoplodon densirostris*) were recorded during the survey around the banks of Saya de Malha. One was a visually confirmed sighting of two individuals in waters of ~800 m depth, approximately 400 m from the survey vessel during a spinner dolphin sighting (Fig. 4c). The second group was detected acoustically through click properties similar to those described by Baumann-Pickering et al. (2013) with a mean peak frequency of 35.1 kHz (34.3–36.1) and mean click length of 280 µs (228–331) (Fig. 6). This acoustic detection was recorded in waters of ~600 m depth, in an area over the steep sloping shelf.

3.4. Delphinids

There was a single sighting of a bottlenose dolphin (*Tursiops* spp.) which spent a short time bow riding in front of the survey vessel at 37 m deep whilst coming into Victoria, Mahe Island, Seychelles. There were insufficient photographs to be able to identify confidently to species level, given the range overlap of *Tursiops aduncus* and *Tursiops truncatus* in the Indian Ocean (Dulau-Drouot et al., 2008). A single acoustic encounter of dolphins was attributed to bottlenose dolphin by the whistle classifier (likelihood score 0.97). This acoustic only encounter was in waters of 167 m deep. There was a single sighting of pantropical spotted dolphins (*Stenella attenuata*) with a concurrent acoustic detection comprising approximately 15 animals. There was also a single sighting

Table 2
Initial cue, behaviour and number of animals of visually sighted cetacean species during visual and acoustic surveys of the Saya de Malha banks onboard the *MY Arctic Sunrise*.

Encounter	Species	Initial cue	Behaviour	Best estimate of number of animals (min, max)
1	short-finned pilot whale	dorsal fin	normal swim	6 (3,5)
2	unidentified dolphin	dorsal fin	normal swim	20 (10,15)
3	spinner dolphin	dorsal fin	normal swim	110 (50,80)
4	Blainville's beaked whale	back and dorsal fin	approaching boat	2 (2,2)
5	unidentified baleen whale	blow	normal swim	1 (1,1)
6	striped dolphin	dorsal fin	normal swim	60 (20,40)
7	unidentified whale	breach	breaching	1 (1,1)
8	unidentified whale	blow	breaching	1 (1,1)
9	unidentified whale	tail & blow	diving	2 (2,2)
10	killer whale	back and dorsal fin	normal swim	1 (1,1)
11	Bryde's whale	dorsal fin	normal swim	2 (1,2)
12	unidentified baleen whale	blow	normal swim	1 (1,1)
13	unidentified baleen whale	blow	normal swim	1 (1,1)
14	pantropical spotted dolphin	surfacing	normal swim	11 (8,15)
15	unidentified baleen whale	dorsal fin	diving	1 (1,1)
16	Bryde's whale	dorsal fin	diving	1 (1,1)
17	unidentified baleen whale	blow	diving	2 (2,2)
18	unidentified dolphin	back and dorsal fin	normal swim	30 (15,20)
19	unidentified baleen whale	back and dorsal fin	normal swim	1 (1,1)
20	sperm whale	blow, back and dorsal fin	diving	10 (5,8)
21	pygmy killer whale	dorsal fin	normal swim	10 (4,6)
22	bottlenose dolphin	dorsal fin	bow riding	1 (1,2)
23	unidentified dolphin	splashing and surface activity	unknown	100 (20,40)
24	spinner dolphin	dorsal fin	spinning	20 (10,16)
25	spinner dolphin	dorsal fin	spinning	10 (4,8)
26	unidentified dolphin	back and dorsal fin	normal swim	15 (5,10)
27	spinner dolphin	splashing and breaching	spinning	30 (10,40)
28	spinner dolphin	splashing and breaching	spinning	10 (6,8)
29	sperm whale	blow	normal swim	6 (6,6)
30	unidentified dolphin	dorsal fin	normal swim	1 (1,1)
31	unidentified dolphin	dorsal fin	normal swim	50 (20,42)
32	Bryde's whale	back and dorsal fin	normal swim	1 (1,1)
33	Bryde's whale	blow, back and dorsal fin	normal swim	1 (1,1)
34	Bryde's whale	dorsal fin	normal swim	1 (1,1)
35	spinner dolphin	spinning	normal swim	15 (1,10)
36	sperm whale	blow	normal swim	1 (1,1)
37	unidentified dolphin	dorsal fin	normal swim	50 (30,40)
38	sperm whale	dorsal fin	normal swim	1 (1,1)
39	unidentified dolphin	dorsal fin	normal swim	10 (4,8)
40	unidentified whale	blow	normal swim	2 (1,2)
41	unidentified dolphin	dorsal fin	normal swim	3 (3,3)
42	Bryde's whale	blow	normal swim	1 (1,1)
43	Bryde's whale	dorsal fin	normal swim	1 (1,1)
44	unidentified dolphin	dorsal fin	normal swim	10 (5,7)
45	unidentified baleen whale	blow	unknown	1 (1,1)
46	sperm whale	blow	diving	6 (4,8)
47	unidentified dolphin	breaching	breaching	5 (2,3)

of striped dolphins (*Stenella coeruleoalba*) which comprised approximately 40 animals. A total of 22 acoustic detections were attributed to spinner dolphins (*Stenella longirostris*) by the whistle classifier, one of which was visually confirmed, and a further five sightings of spinner dolphins were also recorded. Group sizes ranged from approximately eight to 80 animals, comprising a mix of age classes including calves. During four of the sightings, animals were seen to be spinning, as is characteristic of the species, while the other two groups were observed to be travelling. Spinner dolphins were recorded in water depths between 26 and 2,773 m. The single concurrent visual and acoustic detection was estimated to be ~3,700 m from the vessel by visual observers and so only a small number of faint whistles were detected by the whistle and moan detector. During the UAV flights, footage was captured of animals socialising (Fig. 4d).

There were six acoustic encounters with pygmy killer whales (*Feresa attenuata*) as identified by the whistle classifier, one of which was also visually confirmed with an estimated group size of six individuals. There was a single concurrent visual and acoustic detection of a single killer whale (*Orcinus orca)* seen travelling within 100 m of the survey vessel at Saya de Malha. In addition, there were two sightings of short-finned pilot whales (*Globicephala macrorhynchus*) in Seychelles waters, the first with an approximate group size of five animals which were travelling within 1 km of the survey vessel and the second with a group size of 17, including two calves. A single detection of a Risso's dolphin was identified by the whistle classifier. During the Risso's dolphin detection, there were no echolocation clicks which were detected above the 16 dB threshold which could be used to look for the characteristic peak and notch structure described for Risso's in other regions of the world (Soldevilla et al., 2008). A single acoustic detection was attributed to false killer whales (*Pseudorca crassidens*) by the whistle classifier, which occurred in waters of 2,652 m depth.

4. Discussion

The survey data reported here for cetaceans were collected from the vessel *SY Arctic Sunrise* as a survey platform of opportunity. As such, it constitutes a preliminary investigation of the Saya de Malha region and provides the first reports of cetacean presence and diversity around this remote oceanic area. The high

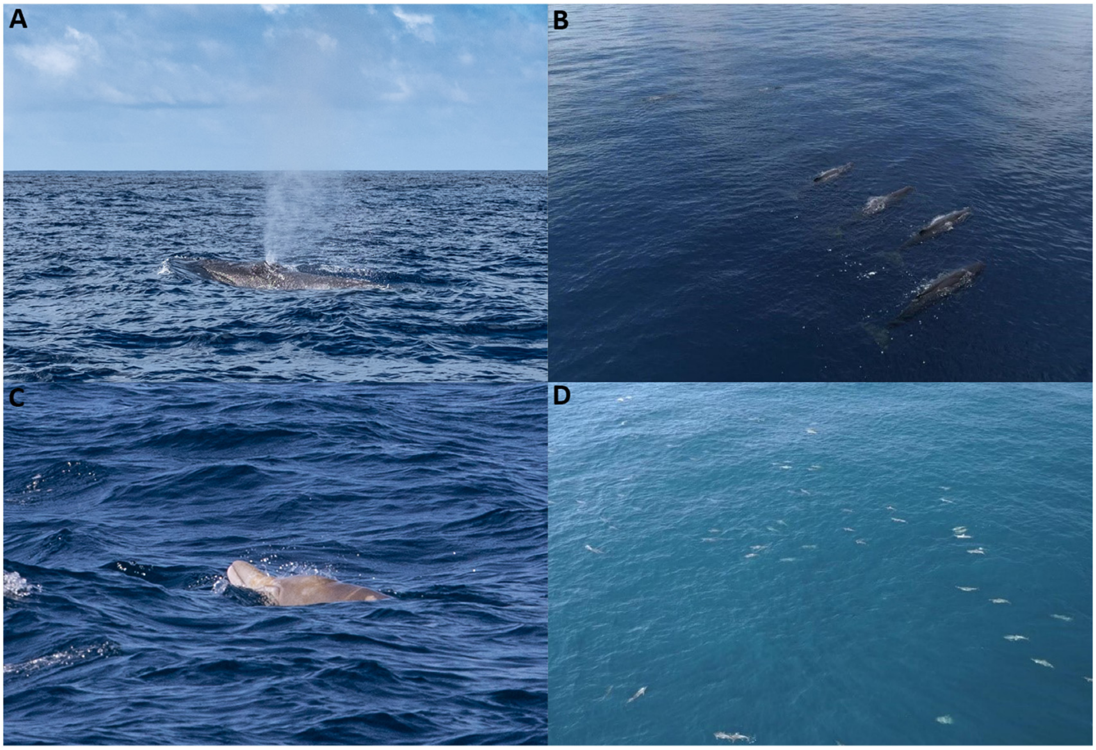

Fig. 4. Visual sightings of species from Saya de Malha region. Top left: Bryde's whale surfacing. Credit Greenpeace, Tommy Trenchard. Top right: Group of six sperm whales. Credit Greenpeace, Maarten van Rouveroy. Bottom left: Blainville's beaked whale surfacing. Credit Greenpeace, Tommy Trenchard. Aerial photograph of a spinner dolphin pod. Credit Greenpeace, Maarten van Rouveroy.

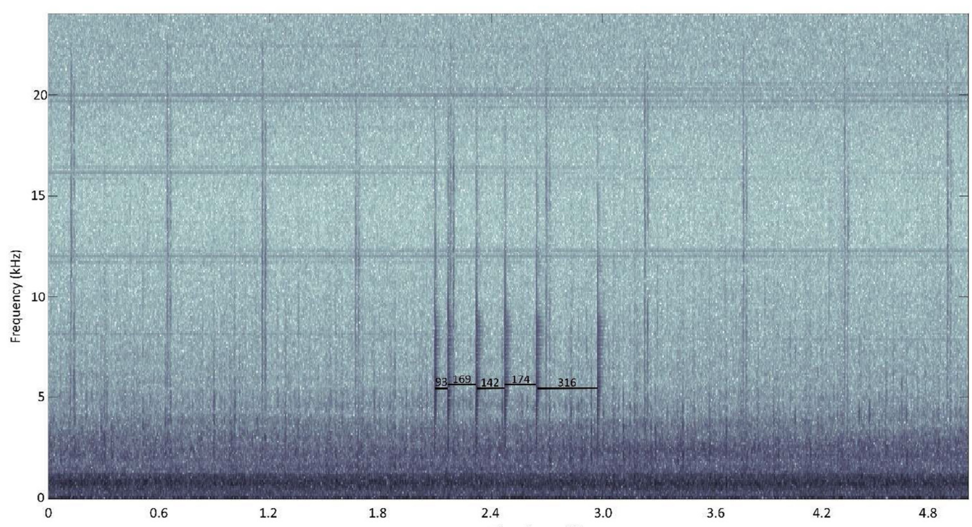

Fig. 5. Spectrogram of the 2fast3+1 sperm whale coda vocalisation with Inter-click Interval reported in milliseconds. The fainter regular clicks of a foraging sperm whale can also be seen, as well as the electrical noise picked up by the recording system: horizontal lines at approximately 8, 12, 16 and 20 kHz.

diversity of cetaceans reported here is likely supported by the productive waters surrounding the bank, where the waters of the South Equatorial Current interact with the shallow banks of Saya de Malha potentially causing upwelling currents (Ardron et al., 2009; Spencer et al., 2005).

In total, twelve species of cetacean were reported around the banks, with sperm whales being the most frequently detected. Their apparent relatively high abundance, in comparison to other species, is likely due to the detectability of their echolocation clicks, which can be detected from several kilometres away (Fais et al., 2015; Gordon et al., 2020; Lewis et al., 2018). Previous efforts have estimated an effective strip half-width (ESHW) of 3.3 km for the *MY Arctic Sunrise* using the same recording equipment (Webber et al., 2022). Sperm whales were most frequently sighted in groups, as is common in tropical waters where females and juveniles remain in the warmer waters of the low latitudes (Gero et al., 2009, 2013; Pitman et al., 2001; Whitehead, 1999).

Connectivity between sperm whale groups across the Indian Ocean basin is poorly understood. Previous work within the Indian Ocean has focused on small study regions around the waters of the Seychelles (Whitehead and Kahn, 1992), Sri Lanka (Gordon, 1987) and Mauritius (Huijser et al., 2020; Chambault et al.,

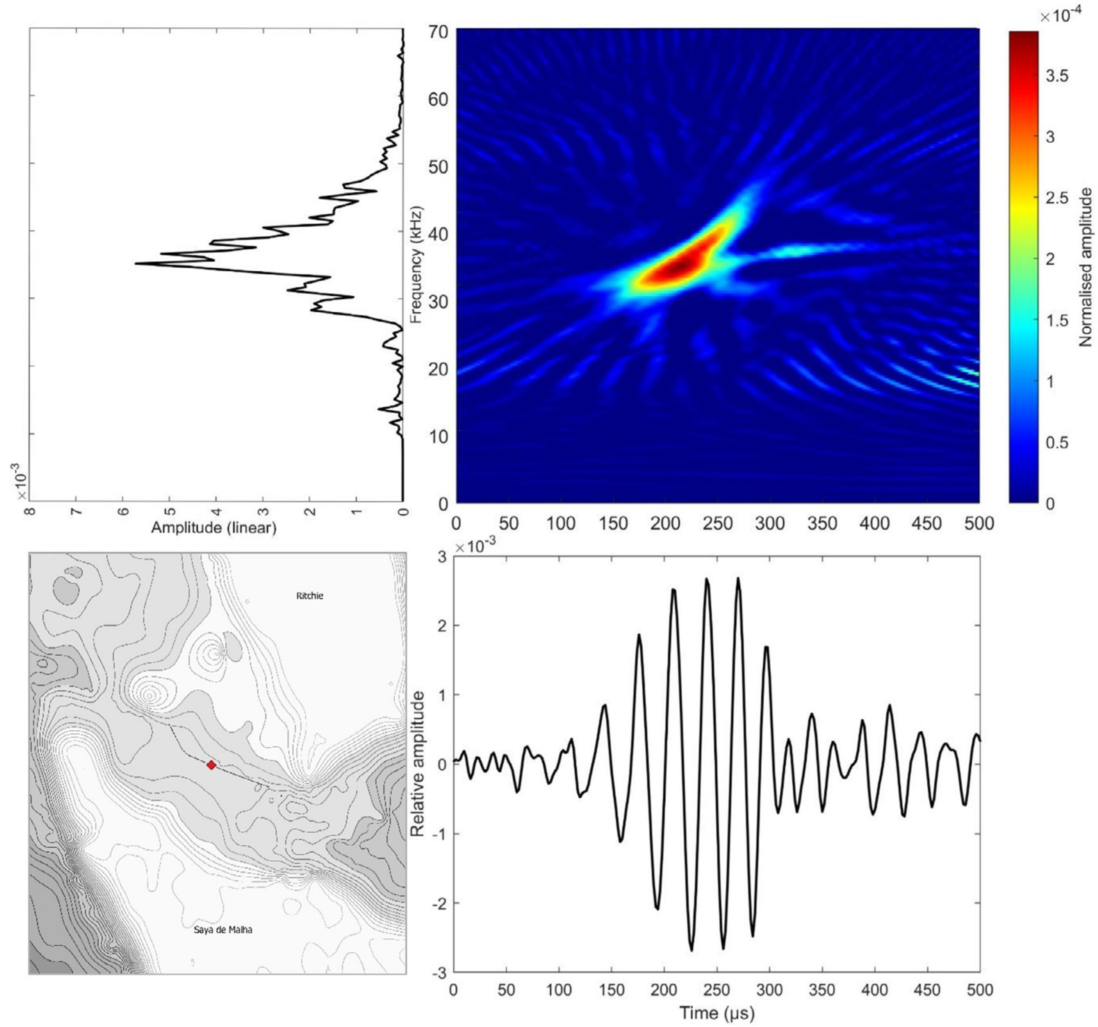

Fig. 6. Example of echolocation click properties (top left: click spectrum, top right: Wigner distribution, bottom right: waveform) from Blainville's beaked whales detected near the banks of Saya de Malha and Ritchie (bottom left) with the red marker locating the acoustic detection and track lines of Arctic Sunrise in the hour preceding and following detection.

2020; Sarano et al., 2021) with few data obtained on movement between these regions. Satellite tracking data indicate individual movement at the scale of the Mascarene archipelago (Reunion, Mauritius, Rodrigues Islands), but connectivity between these regions and the wider Indian Ocean is currently unknown (Chambault et al., 2020). From earlier analysis of the mitochondrial DNA (mtDNA) of Indian Ocean sperm whales, it has been inferred that haplotype repartitioning reflected a more pronounced regional population structure of Indian Ocean sperm whales compared to those in the Pacific, likely due to strong female philopatry in the Indian Ocean (Alexander et al., 2016). Coda vocalisations have been used to associate sperm whales into vocal clans (Rendell and Whitehead, 2003), which can then be used to infer social organisation across a given geographical range (e.g., Antunes, 2009). The 2fast3+1 coda type identified in Saya de Malha has also been identified in the coda repertoire (of a total of 24 coda types) used by sperm whales in Mauritius (Huijser et al., 2020). This coda was shared by the two sympatric vocal clans described in Mauritius (Huijser et al., 2020). However, the number of codas recorded during the present study was too low to assess if sperm whales from the Seychelles are part of the same vocal clans. Further study is required to assess if vocal clans within the Indian Ocean follow a similar pattern of vocal sympatry documented in the Pacific (Rendell and Whitehead, 2003), or of geographic variation documented in the Atlantic (Antunes, 2009). More extensive acoustic survey efforts to record sperm whale codas in the region could provide a more robust insight into connectivity between sperm whale populations across the wider Indian Ocean basin. No images of flukes were matched to individuals previously identified in waters around Réunion and Mauritius. Fluke images from 11 individuals were collected on this survey and uploaded to Flukebook, and we hope that images of sperm whale flukes from future surveys will be uploaded to enable comparisons across the Indian Ocean catalogue with these Saya de Malha whales.

The only baleen whale species sighted during the survey period were Bryde's whales. Bryde's whales are thought to have contrasting movement patterns depending on the population studied and their taxonomic status is not well resolved (Constantine et al., 2018). Some populations move across their resident ocean basins rather than making large seasonal migrations (Lockyer and Brown, 1981; Weir, 2010; Kato and Perrin, 2018). Given that the Bryde's whale sightings at the Saya de Malha region were made far offshore, it is reasonable to assume that these may be the larger, oceanic, form which constitutes the subspecies, *B. edeni brydei* (Constantine et al., 2018). Since none of the whales were seen feeding, we were unable to collect any data on the foraging behaviour of this species at the Saya de Malha. However, the frequency of sightings indicates that there are future opportunities to study Bryde's whales in the Saya de Malha region. In particular, visual surveys (including detailed behavioural observations) could help us to understand the habitat use, densities and foraging mode of this species around the banks. A static, bottom-mounted hydrophone could be a valuable way to examine the seasonal presence of Bryde's whales in the region and genetic studies would inform us as to the sub-species and of any connectivity between these whales and those in other areas of the Indian Ocean.

Nine species of delphinid were documented with spinner dolphins by far the most numerous, in terms of the number of groups recorded as well as the number of individuals, with group sizes estimated to be up to 80 animals. Previous survey efforts by Ballance and Pitman (1998), reported spinner dolphins as the most abundant delphinid observed in the northern Indian Ocean, in terms of the number of groups and the number of animals within groups. All but two species were both acoustically and visually detected across our survey. In the case of the Risso's dolphin and false killer whales, both were identified by the whistle classifier, but no visual sighting of either species was made throughout the survey. Given that the whistle classifier used in this study was not trained from recordings made in the study area, it is plausible that some classifications may be incorrect. However, on the occasions where a whistle classification overlapped a visual sighting, the classification made by the classifier matched the species recorded by the visual observer. Further efforts to collect acoustic recordings along with concurrent visual sightings would help to build a region-specific whistle classifier. Such a classifier would greatly enhance the power of long-term acoustic monitoring and enable dolphin groups to be identified to species level, providing insights into temporal patterns in behaviour and habitat use. As such, we have made available recordings of all concurrent visual and acoustic detections of dolphin whistles in order to assist researchers working in the region (DOI: 10.5281/zenodo.8285619).

An additional environmental DNA survey conducted during the same time period has provided preliminary results that corroborate both the visual and acoustic detections made here, as well as indicating the presence of other cetacean species which are more difficult to detect, such as *Kogia* spp. (K.F. Thompson, unpublished data). Where survey time is short, or a survey area is logistically and financially challenging to get to, a holistic approach to survey cetacean diversity which includes eDNA sampling may become commonplace in the future, potentially highlighting species not detected by the main survey. While eDNA currently cannot indicate species density in a region, it is nonetheless a useful complementary tool to further explore species diversity.

Our results highlight the high diversity of cetaceans in this region and the need for more data to provide insight into the density or temporal occurrence of cetaceans around Saya de Malha. We hope these data can help inform future systematic surveys. We also suggest that additional visually verified acoustic recordings of all odontocetes would greatly aid researchers in compiling a database of vocalisations and, therefore, a more complete whistle classifier for the region. Long-term monitoring from fixed recorders moored around the banks could allow investigations into the temporal trends, as well as enabling the study of species such as baleen whales which produce lower frequency vocalisations which are difficult to detect with towed arrays. Recording over longer time periods also increases the likelihood of detecting rarer species, such as beaked whales or *Kogia* spp.

Laran et al. (2017) identified high cetacean diversity in both the northern and southern regions of the Mascarene Plateau through the use of aerial survey data. Here we provide data through a preliminary visual-acoustic survey for the region surrounding the Saya de Malha banks within the central area of the Mascarene Plateau. Our data indicates that the Plateau is an ecologically important area for cetaceans and other pelagic species. With IMMAs already designated to the north and south of Saya de Malha, we recommend, on the basis of the criteria set out below, that the banks of Saya de Malha be similarly designated, hence filling the gap to provide IMMA status across the whole Mascarene Plateau. Firstly, we suggest that the IMMA be based on Criterion A — Species or Population Vulnerability (described as areas containing habitat important for the survival and recovery of threatened and declining species), whereby the high detection rates of sperm whales suggests the area is an important feeding habitat for sperm whales, globally designated as Vulnerable on the IUCN Red List of Threatened Species. Also relevant is Criterion C — Key Life Cycle Activities, under Subcriterion C2 — Feeding Areas (areas and conditions that provide an important nutritional base on which a species or population depends). Matching of one coda type to Mauritius could suggest that the banks of Saya de Malha may be important for connectivity in Indian Ocean sperm whales. More codas are needed to compare fully the repertoires and to understand better whether sperm whales from the Mascarene Plateau (Seychelles, Saya de Malha and the Mascarene Islands) are part of the same vocal clan. The diversity of marine mammal species encountered from a relatively low amount of opportunistic survey effort during this study also suggests that the Saya de Malha region also fulfils Criterion D — Special Attributes, specifically Sub-criterion D2 — Diversity (defined as areas containing habitat that supports an important diversity of marine mammal species).

5. Conclusions

Our study indicates that the productive waters surrounding the banks of Saya de Malha may support a high diversity of cetacean species, adding to our understanding of this ecologically important region and the Mascarene Plateau as a whole. Our study provides initial data to aid in the design of more systematic surveys for cetaceans in the region. We also provide visually verified recordings of delphinids, and images of sperm whale flukes that are now widely accessible to other researchers. Further, we suggest that the Saya de Malha region be included in current IMMA designations, either by joining the adjacent IMMAs to the north and south to form a large continuous, and highly diverse, IMMA across the whole of the Mascarene Plateau, or as a separate candidate IMMA. Based on the diversity of cetaceans, combined with previous reports of unique seagrass and coral shallow water ecosystems, we concur with previous assessments suggesting that biodiversity in the area needs long-term conservation. Progress with the United Nations Biodiversity Beyond National Jurisdiction (BBNJ) Treaty can perhaps provide the pathway to protecting such important ecosystems in the global oceans.

CRediT authorship contribution statement

Thomas Webber: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. **Tim Lewis:** Investigation, Methodology, Data curation. **Sheena Talma:** Data curation, Writing – review & editing. **Shaama Sandooyea:** Data curation, Writing – review & editing. **Laura Meller:** Funding acquisition, Project administration, Writing – review & editing. **Violaine Dulau-Drouot:** Writing – review & editing. **Kirsten F. Thompson:** Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request

Acknowledgements

We thank the crew of the *MY Arctic Sunrise* and the Greenpeace International campaign team for help with this survey — many long hours were spent scanning the sea and retrieving the hydrophone!

Also thanks to Greenpeace Research Laboratories for logistical support and specifically Paul Johnston and David Santillo for insightful comments on the manuscript. We thank the Joint Commission of the Joint Management Area, Governments of Seychelles and Mauritius for welcoming the research as well as advice during the Greenpeace 2021 research expedition to the Saya de Malha Bank. This work was funded by Greenpeace International to provide independent scientific advice to that organisation.

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