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Assessing marine mammal diversity in remote Indian Ocean regions, using an acoustic glider

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Abstract :

Many observations collected from whaling logbooks or more recent satellite tags and acoustic surveys report that the Indian Ocean is a very important place for large baleen whales. They undergo long seasonal migrations from Southern feeding grounds to tropical and subtropical mating and breeding grounds. However, whether and where they stop to rest or feed during their long travels are poorly known. The Indian Ocean is also home to many odontocete species such as sperm whales, killer whales and multiple delphinid species. In this paper, we analyze passive acoustic data collected by an electric glider around two steep bathymetric features located in the Western sub-tropical Indian Ocean (Walters Shoal) and in the mid sub-tropical Indian Ocean (St. Paul and Amsterdam islands), both included in Important Marine Mammal Areas (IMMAs). The acoustic data were manually reviewed and annotated by two analysts. The aim of this experiment was to improve the knowledge on marine mammal presence in these little studied IMMAs. We found that bioacoustic activity was quite high in both monitored areas with 40% of the records containing marine mammal sounds in Walters Shoal and 70% in St. Paul and Amsterdam islands. Calls from Antarctic blue whales, Southwestern and Southeastern Indian Ocean pygmy blue whales, fin whales and an unidentified baleen whale were detected at one or both sites. Odontocete clicks and whistles were also recorded at both sites. The discussion puts these marine mammal acoustic detections back into the context of their seasonal and geographical presence already described by other studies in the Indian Ocean and makes hypotheses about the role of the two studied areas for marine mammals.

2 Introduction

The Indian Ocean (IO) is home to more than 30 species of marine mammals[1]. Some of these species are regionally dependent [Robineau et al., 2007, Minton et al., 2020] and others undergo very long migrations from summer feeding grounds to winter breeding grounds [Leroy et al., 2016, Double et al., 2014, Bestley et al., 2019]. The IO also has the particularity of hosting more blue whale (*Balaenoptera musculus*) sub-species and acoustic populations than

[1] http://www.marinemammals.in/mmi/identification-guide/, consulted on August 23

any other ocean [McDonald et al., 2006, Branch et al., 2007]. During the 20th century, the IO was a main whaling ground especially for large baleen whales who gather in Antarctica in the austral summer to feed [Rocha et al., 1982]. More than 2 million whales from 8 species were severely hunted and brought to the brink of extinction [Clapham et al., 2009]. Despite the end of whaling in the 70's, the populations of blue and humpback whales (*Megaptera novaeangliae*) still remain below pre-exploitation levels [Branch et al., 2007, Clapham et al., 2009].

In order to protect this large diversity of vulnerable marine mammals, the International Union for Conservation of Nature (IUCN) and the Marine Mammal Protected Areas Task Force (MMPATF) identified 37 Important Marine Mammals Areas (IMMA) in the Western IO, mainly around bathymetric features such as islands and seamounts [2]. They both attract a large marine biodiversity, often more important and diverse than the surrounding open ocean waters. Plankton populations exist above average in these areas, inducing aggregations of fish [Morato et al., 2010, Genin, 2004, Roberts et al., 2020], which in turn are preyed upon by top predators, such as marine mammals [Kaschner, 2007].

This paper investigates marine mammal presence around two IMMAs in the Southernn Indian Ocean, using passive acoustic monitoring (PAM). The first study site is located around the French St. Paul and Amsterdam islands. Both volcanic islands separated by about 85 km, St. Paul and Amsterdam islands are the only emerged part of a narrow oceanic plateau surrounded by depths of more than 3000 meters. Amsterdam island is occupied yearly by about 20 to 40 scientists while St. Paul is a totally protected wildlife sanctuary. Regulated fishing activity occurs in the French Exclusive Economic Zone (EEZ), targeting rock lobsters (*Jasus paulensis*) and Antarctic rouffe (*Hyperoglyphe antarctica*). Previous studies assessed the seasonal presence of killer whales, fur seals, elephant seals, fin whales, Southern right whales, humpback whales and sperm whales mainly from January to March [Prévost and Mougin, 1970, Roux, 1986, Richards, 2009].The marine area surrounding the islands is known to be located within the migration route of multiple blue whale populations [Samaran et al., 2013, Leroy et al., 2016, Leroy et al., 2018a, Torterotot et al., 2020], fin whales (*Balaenoptera physalus*) [Leroy et al., 2018a], Southern right whales (*Eubalaena aus-*

[2]https://arabianseawhalenetwork.org/2020/01/15/37-important-marine-mammal-areas-identified-in-the-western-indian-ocean-and-arabian-seas/ and https://www.marinemammalhabitat.org/imma-eatlas/, consulted on August 23

tralis) [Richards, 2009] and potentially humpback whales from the Western Indian Ocean population [Bestley et al., 2019]. However, there are only few visual reports of the presence of these large baleen whales close to the islands. On the contrary, visual observations of killer whales (*Orcinus orca*), sperm whales (*Physeter macrocephalus*) and other odontocetes are often reported in this region [Tixier et al., 2018].

The second area studied in this paper spans around Walters Shoal, a group of seamounts that reach to within 18 m of the surface, located about 850 km south of Madagascar in the Indian Ocean. It is part of the candidate IMMA that covers the southern Madagascan plateau. The little knowledge regarding marine mammal presence in the area comes from visual observations and Argos satellite tag localization data and mainly focuses on humpback whales [Best et al., 1998, Trudelle et al., 2016].

PAM proved to be a very efficient method to monitor marine mammals in the wild [Mellinger et al., 2007 The vocal repertoires of marine mammals are species-specific (especially for mysticetes) [Au and Hastings, 2 and in some cases even sub-species and populations-specific [McDonald et al., 2006], allowing fine scale identification without requiring any visual observations. The type of vocalization can indicate the animal's behavior, such as with odontocete echolocation clicks indicating feeding and whistles indicating communication between individuals [Au and Hastings, 2008]. PAM allows a non-invasive and continuous observation regardless of weather and light conditions. Moreover, this observation method can be implemented over long periods of time (several months to several years) and in remote locations. Although PAM is dependent on cetaceans vocal activity, [Clark et al., 2010] showed that for the North Atlantic right whale, a sometimes vocally cryptic species, PAM was more reliable to detect their occurrence than aerial surveys. Overall, combined visual and acoustic surveys are the most effective, however in remote areas PAM is the easiest to implement and most cost-effective continuous monitoring tool.

An underwater glider is a category of autonomous underwater vehicle (AUV) that uses both variable-buoyancy propulsion to move vertically between the surface and a predetermined depth, and wings to glide horizontally [Webb, 1986, Simonetti, 1992]. This study used battery powered gliders, which we will refer to as just "gliders" here on out. The remotely controlled trajectories allow the glider to monitor large areas of interest (hundreds to thousands of kilometers) during periods that last up to several month [Davis et al., 2002]. Gliders have been deployed in all the oceans since 2000 to carry out high resolution measurements of physical (e.g. temperature, salinity) and biogeochemical parameters (e.g. dissolved oxygen, chlorophyll, water turbidity), then used for multiple oceanographic applications [Testor et al., 2010, Meyer, 2016, Rudnick, 2016]. Underwater gliders have also been equipped with passive acoustic recorders with the aim of monitoring biological and geological activity [Matsumoto et al., 2011, Wall et al., 2013, Wall et al., 2017, Guihen et al., 2014], with some studies focusing on marine mammals [Moore et al., 2007, Baumgartner et al., 2008, Klinck et al., 2012, Baumgartner et al., 2013, Baumgartner et al., 2014, Cauchy et al., 2020]. The latter involve short- and long-term population monitoring, real-time acoustic reporting, association between acoustic behavior, oceanographic conditions and prey distribution. PAM using gliders allows to collect data along a controlled trajectory for periods up to a few months, which is complementary to underwater acoustic observations collected during short term ship surveys or by fixed moorings or drifting floats [Verfuss et al., 2019]. The absence of propulsion noise and the low platform noise of the glider is an additional advantage, first because it restricts the masking of animal sounds in the recordings and second because the animal reaction to small and low noise platforms is likely to be low.

The aim of these two PAM deployments in St. Paul and Amsterdam and in Walters Shoal was to improve our knowledge on marine mammal presence in these little studied IMMAs.

3 Methodology

3.1 Data collection

Acoustic data were collected by a HTI92 WB hydrophine mounted on a SeaExplorer battery powered glider developed by ALSEAMAR ALCEN (Rousset, France). This 2-meter long autonomous device was designed to collect data as it moves through the water column (from surface up to 700m deep) by changing buoyancy changes. It was equipped with a GPS and with a passive acoustic recorder. Two sites were monitored (Figure 1): The Walters Shoal in the western Indian Ocean and the St. Paul and Amsterdam islands in the southern Indian

Ocean.

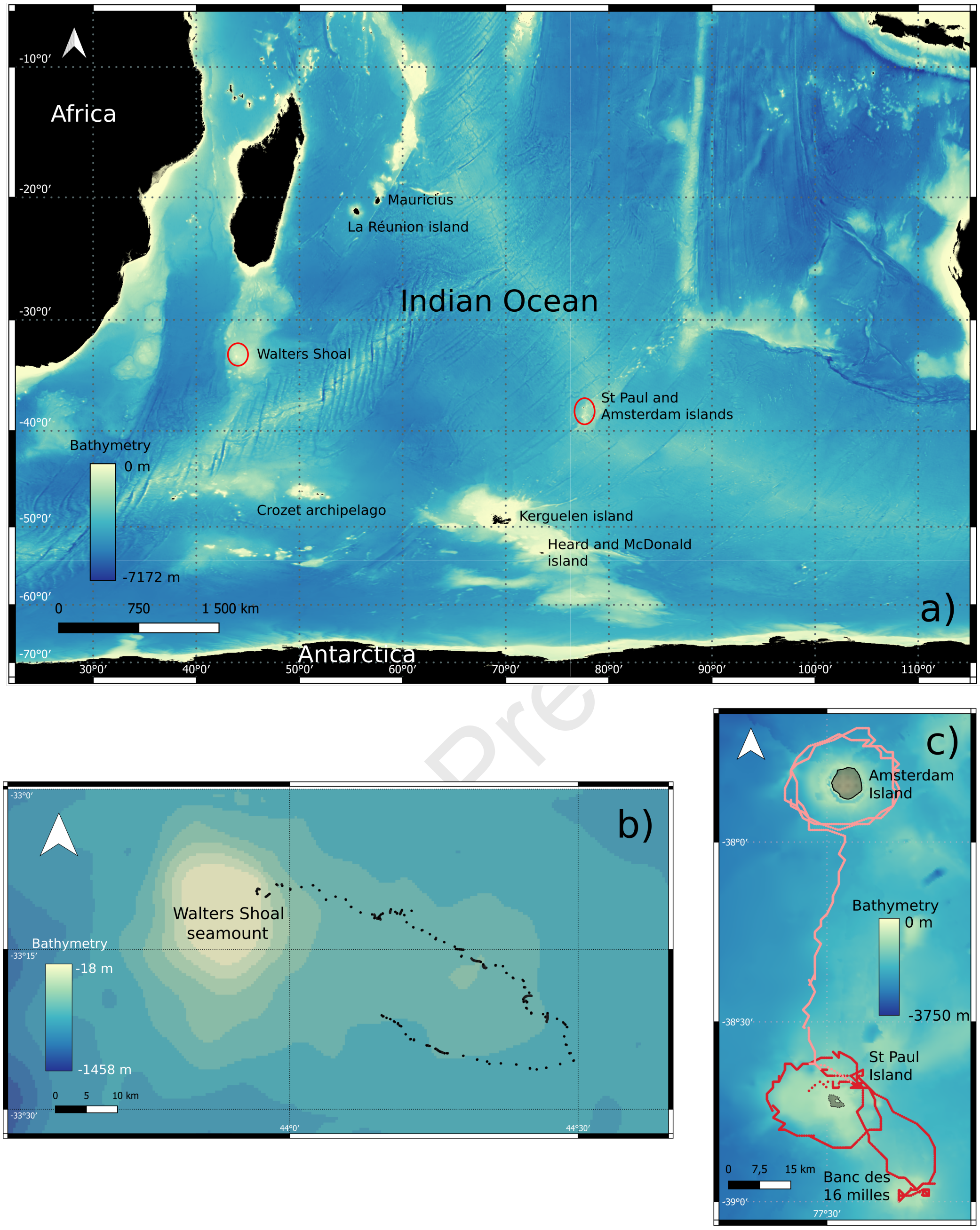

Figure 1: a) Map of the southern Indian Ocean. The two studied areas are circled in red and zoomed in. b) Map of Walters Shoal seamount area. Black dots represent the glider track. c) Map of St Paul and Amsterdam islands area. Red dots represent the glider track during the first mission. Pink dots represent the glider track during the second mission.

3.1.1 St. Paul and Amsterdam

Acoustic data were collected during two consecutive deployments, near the St. Paul and Amsterdam French sub-Antarctic islands, in the Indian Ocean (38°16 10 S, 77°32E) around March 2019 (Figure 1 c)). The first glider deployment lasted from February 28th until March 15th.

The second deployment started on March 19th and ended on April 5th. The glider was equipped with a high-frequency hydrophone (sampling rate : 48 kHz) that recorded continuously.

3.1.2 Walters Shoal

Data were collected during the Walters Shoal oceanographic expedition near the Walters Shoal seamounts (32°30S 44E) in the mid-Indian Ocean in May 2017 [Bouchet et al., 2017]. The glider was launched east of the seamount on May 1st and was recovered on May 11th, after 10 days at sea (Figure 1 b)). The glider was equipped with a high-frequency hydrophone (sampling frequency : 32 kHz) that recorded continuously.

3.2 Data analysis

3.2.1 Call detection

Specific call types described in literature were targeted and logged by two annotators to mark species presence (Table 1), using acoustic analysis software Raven Pro (Cornell Lab of Ornithology) and the web-based annotation platform APLOSE (ENSTA Bretagne) [Nguyen Hong Duc et al., 2020]. Studies show that inter-annotator variability can lead to differences in the final number of detections [Leroy et al., 2018b, Nguyen Hong Duc et al., 2020]. In this study, each annotator focused on a dataset, with no overlap between the annotated datasets. We did not compare the annotations of both annotators on a third sub-set to evaluate a possible operator dependence to detection and classification, but both annotators were trained, and instructed to annotate only when they were sure of the presence of bioacoustic sound.

To be able to detect mysticete low frequency calls as well as odontocete high frequency calls, the annotation was split into three frequency bands: the low frequency (0-240Hz), the medium frequency (0-2kHz) and the high frequency bands (0-16kHz for Walters Shoal and 0-24kHz for St Paul and Amsterdam).

The low frequency annotation was performed on the dataset resampled at 480 Hz. Spectrograms were viewed using Raven Pro (512 samples Hanning window with 50% overlap, nfft

= 512 samples), and the annotator logged each vocalization found. The begin and end time as well as upper and lower frequency of each detection were then saved f or analysis. Targeted species were great baleen whales, and especially blue and fin whales (Table 1). Both species produce stereotyped long, loud and low frequency calls that are repeated regularly to form songs [Cummings and Thompson, 1971]. Blue whale calls are specific to sub-species and acoustic populations [McDonald et al., 2006]. The Antarctic blue whale calls have a Z-shape time-frequency signature between 15 and 30 Hz. They last about 25 seconds and are repeated every 40 to 70 seconds [Ljungblad et al., 1998]. The SEIO pygmy blue whale calls are composed of three units comprised between 15 and 120 Hz. They can last more than 2 minutes and are repeated every 3 minutes [McCauley et al., 2001]. The SWIO pygmy blue whale calls are composed of two units comprised between 15 and 50 Hz. They can last about 1 minutes and are repeated every 2 minutes [Ljungblad et al., 1998]. Fin whale produce broadband stereotyped pulsed calls ($<$ 1 second long) ranging from 15 to 30 Hz with a powerful upper note around 90-110 Hz, repeated every 12 to 35 seconds [Watkins, 1981, Širović et al., 2004]. P-calls are acoustic signals from unidentified marine mammals. These vocalizations display similarities with blue whale songs (low frequency and repetitive calls which show an inter-annual frequency decline), but to date there is no simultaneous acoustic recording and visual observation, or genetic testing to confirm this hypothesis. They are composed of only one unit repeated every 3 minutes that range from 25 to 30 Hz and last about 10 seconds. The function of these songs is not unanimously agreed upon, but observation of only male whales singing have led to the hypothesis that they are a breeding display [McDonald et al., 2001, Croll et al., 2002]. Blue and fin whale also produce non-stereotyped calls respectively named D-calls and 40-Hz calls. D-calls are described as short frequency modulated calls that last from 1 to 8 seconds and range from 30 to 90 Hz [Thompson, 1996, Ljungblad et al., 1997, Miller et al., 2019b]. Unlike songs, this call type is shared by all blue whale populations [Ljungblad et al., 1997, McDonald et al., 2001, Mellinger and Clark, 2003, Rankin et al., 2005, McDonald et al., 2006, Samaran et al., 2010a, Schall et al., 2019, Barlow et al., 2020, Buchan et al., 2021] and produced by males and females [Oleson et al., 2007a, Lewis et al., 2018]. 40-Hz calls are short (about 1 second long) pulsed sounds ranging from 30 to 100 Hz [Watkins, 1981, Širović et al., 2013]. Unlike song, these call types are produced by males and females and they are not thought to be specific to populations [Oleson et al., 2007a, McDonald et al., 2006]. Studies suggest that these call types could be associated with feeding [Širović et al., 2013, Oleson et al., 2007a] and/or social behaviours [Oleson et al., 2007b, Lewis and Širović, 2017, Szesciorka et al., 2020, Schall et al., 2019].

The medium frequency annotation was performed on the dataset resampled at 4 kHz. Odontocete vocalizations are generally numerous which cause them to overlap a lot, making call-by-call annotation more time consuming and complex. Therefore, detection was performed as presence-absence of vocalizations within each 10-minute audio file. The detection process was switched to a new web-based annotation platform called APLOSE for a more optimized view with the targeted analysis settings. The 10-minute spectrograms (1024-point Hanning window with 50% overlap, nfft = 2048) could be screened up to a x8 zoom on the y-frequency-scale. Targeted species were minke, humpback or Southern right whales, killer whales and sperm whales (Table 1). Minke whales have a large acoustic repertoire made of repetitive low-frequency (100-500 Hz) pulse trains, "boing" sounds (brief pulse around 1300 Hz followed by a call at 1.4 kHz) and bio-duck sounds (downsweep pulses ranging from 50 to 300 Hz [Risch et al., 2013, Rankin and Barlow, 2005]. Humpback whales produce song that are composed of a structured repetition of a large variety of vocalizations lasting from 0.1 to 5 second long and ranging up to at least 24 kHz (peak frequency 30Hz to 5 kHz) [Hafner et al., 1979, Au et al., 2001]. They also produce social vocalizations that range from 30Hz to 2.5 kHz. Unlike song, these sounds are not produced in structured repetitive patterns [Dunlop et al., 2007, Rekdahl et al., 2013]. Southern right whales vocalizations were classified into 10 call types among which the most frequently observed types were pulsive, upcall and low tonal vocalizations. Their frequency band ranges from 80 Hz to about 4 kHz [Clark, 1982, Webster et al., 2016]. Blackfish (pilot and killer whales) produce clicks and calls. Their clicks are short (20 to 40 µs) broadband pulses used for echolocation and range from 9 kHz to 112 kHz [Eskesen et al., 2011]. Their calls are frequency modulated tonal sounds with several harmonics, lasting up to a few seconds and ranging from 2 kHz to 20 kHz [Thomsen et al., 2001, Mellinger et al., 2007]. Sperm whales produce broadband clicks (400 Hz - 25 kHz), which they use to find their bearings, to hunt and to communicate [Goold and Jones, 1995].

The high frequency annotation was performed on the whole frequency band (up to 24 kHz). The annotation process was similar than for the medium frequency dataset, with the 10-minute spectrograms (1024-point Hanning window with 50% overlap, nfft = 2048) displayed in APLOSE. The previous labels given by the annotator during the medium frequency dataset annotation stage were already selected for the corresponding files to avoid the task of re-annotating the same label. Targeted species were all odontocetes. The purpose of the high frequency annotation was to catch any additional odontocete sounds missed during the medium frequency annotation.

In this study, the clicks and calls attributed to killer and pilot whales were grouped into the same categories respectively called 'blackfish clicks' and 'blackfish calls', as no one could clearly distinguish between the two (Figure 8). As clicks and whistles are very similar between delphinid species, they could not be associated to a particular species. The vocalizations that could not be attributed to a particular species were grouped into the 'undetermined biological sounds' label.

For the Walters Shoal dataset, the medium (0-2kHz) and high (0-16kHz) frequency datasets were annotated together by representing both spectrograms on top of each other, whereas for St Paul and Amsterdam dataset, the two frequency bands were analysed separately, because this feature was not yet available.

3.2.2 Data processing

Depending on the type of annotation (*ie*: call by call annotation for the low frequency dataset or presence/absence annotation for the mid and high frequency dataset), the results are presented as single detection or as 10-minute positive time frames. The glider position was originally sampled every time it surfaced, approximately every 4 hours. To locate the annotations on the glider path, their timestamps were interpolated between two consecutive surfacing positions.

Bioacoustic activity is defined as the % of 10-minute time bins in which there are some bioacoustic detections.

Bioacoustic diversity is defined as the number of species (or populations) acoustically detected. Since D-calls could be produced by all blue whale populations, they were discarded from

Table 1: List of labels used for the manual annotation of the low, mid and high frequencies of both datasets, with their description

Analysis process	Label	Species	Description	Frequency range (Hz)	Reference
Low frequencies	Antarctic blue whale call	Antarctic blue whale	Stereotyped vocalizations emitted by Antarctic blue whale males to form songs	15-30	[Ljungblad et al., 1998]
	Southwestern Indian Ocean (SWIO) pygmy blue whale call	SWIO pgmy blue whale	Stereotyped vocalizations emitted by SWIO pygmy blue whale males to form songs	15-50	[Ljungblad et al., 1998]
	Southeastern Indian Ocean (SEIO) pygmy blue whale call	SEIO pygmy blue whale	Stereotyped vocalizations emitted by SEIO pygmy blue whale males to form songs	15-120	[McCauley et al., 2001]
	D-call	Blue whale	Non-stereotyped vocalizations emitted by all blue whales individuals and populations	30-90	[McDonald et al., 2001]
	P-call	Undetermined baleen whale	Stereotyped vocalizations emitted by an unknown baleen whale species	25-30	[Leroy et al., 2017]
	Fin-whale 20 Hz call	Fin whale	Stereotyped vocalizations emitted by fin whale males to form songs	15-110	[Watkins, 1981, Širović et al., 2009]
	Fin whale 40 Hz call	Fin whale	Non-stereotyped vocalizations emitted by all fin whales individuals	30-100	[Watkins, 1981, Širović et al., 2013]
	Undetermined sound	Undetermined species	Undetermined biological sound most likely emitted by a mysticete	<240	
Mid and high frequencies	Sperm whale clicks	Sperm whale	Sperm whale echolocation clicks	400 - 25000	[Goold and Jones, 1995, Madsen et al., 2002]
	Blackfish clicks	Killer whale or pilot whale	Killer or pilot whale clicks	9000-112000	[Eskesen et al., 2011]
	Blackfish calls	Killer whale or pilot whale	Killer or pilot whale whistles	2000-20000	[Thomsen et al., 2001]
	Delphinid clicks	Delphinid species	Undetermined delphinid clicks	20000-200000	[Mellinger et al., 2007]
	Delphinid whistles	Delphinid species	Undetermined delphinid whistles	1000-20000	[Mellinger et al., 2007]
	Undetermined sounds	Undetermined species	Undetermined biological sound most likely emitted by an odontocete	<24000 Hz	

the bioacoustic diversity index. Moreover, fin whale 20 Hz and 40 Hz calls labels were grouped, as were blackfish clicks and calls, and delphinid clics and whistles. Note that multiple species could actually be captured in the blackfish and delphinid categories, so bioacoustic diversity is capturing a minimum value for species diversity. Finally, all detections from undetermined species were also discarded. We used 10-minute bins because it is the smallest time bin used for manual annotations of the medium and high-frequency data. We computed this metric separately for the low frequency labels and for the high frequency labels.

3.2.3 Detection range

The hydrophone's detection range relies on many variables such as the ambient noise, the bathymetry, the water column properties (temperature, salinity) and the vocalization properties (amplitude, frequency) [Širović et al., 2007, Helble et al., 2013]. As the glider is constantly changing depth and location, the water column properties surrounding the hydrophone, and therefore the detection range, are also constantly changing. Computing the detection range for a mobile vehicle is beyond the scope of this manuscript, but the water column properties also measured by the glider could help investigate this question. We refer to the previous studies that show the detection ranges based on species and area (Table 2). The propagation range of mysticete vocalizations is higher than odontocete's, especially the one of low frequency blue and fin whales songs which can propagate over tens of kilometers. However, the St. Paul and Amsterdam and the Walters Shoal shallow plateau prevent the low-frequency sounds to propagate as far as in open ocean, probably reducing the propagation range of baleen whale calls to tens of kilometers [Širović et al., 2007].

Table 2: References of detection range estimations for the species detected in this study.

Species/call type	Area	Estimated detection range	Reference
Blue whale song and D-call	Western Antarctic Penisula and Crozet Archipelago Southern Indian Ocean	< 200 km	[Širović et al., 2007, Samaran et al., 2010b, Gavrilov et al., 2011]
Fin whale call	Western Antarctic Peninsula	< 60 km	[Širović et al., 2007]
Sperm whale clicks	Pelagos Sanctuary Mediterranean sea	< 30km	[Sanguineti et al., 2021, Poupard et al., 2022]
Killer whale clicks	Vestfjord, Norway	around 1 km	[Simon et al., 2007]
Killer whale vocalizations	Salish sea Canada and Crozet Archipelago Southern Indian Ocean	< 16 km	[Miller, 2006, Austin et al., 2021, Richard et al., 2022]
Delphinid clicks	New River, North Carolina and eastern Indian Ocean	< 1km	[Roberts and Read, 2015, Caruso et al., 2020]
	Sarasota Bay Florida, seagrass shallow water	<500m	
Delphinid whistles	Sarasota Bay Florida, mud bottom shallow water	< 2km	[Quintana-Rizzo et al., 2006]
	Sarasota Bay Florida, channels	> 20km	

4 Results

4.1 Saint Paul and Amsterdam

The acoustic data recorded by the glider around the St. Paul and Amsterdam islands confirmed that this region is rich in marine mammals. At least 5 different species were recorded and the bioacoustic activity reached 74%.

The baleen whale species detected in the low-frequency dataset were the blue whale and an undetermined species. Among the blue whale vocalizations, songs of two sub-species were recorded : the Antarctic and the pygmy blue whale, among which two acoustic populations were identified : the Southwestern Indian Ocean (SWIO) and the Southeastern Indian Ocean (SEIO) pygmy blue whale. Blue whale D-calls were also detected. The vocalizations emitted by an undetermined species were named P-calls, by analogy with previous observations in the Indian Ocean [Leroy et al., 2017, Ward et al., 2017].

SEIO pygmy blue whale songs were the most detected (55% of the 10 minute files positive to detection) followed by SWIO pygmy blue whale songs (9% of the files), P-calls (7% of the files) and finally Antarctic blue whale songs and D-calls (1.5% of the files) (Figure 2). The songs of SEIO pygmy blue whales were detected all along the glider's path (Figure 3 (d)). The songs of the SWIO pygmy blue whales were recorded around the two islands and on the 16 mile bank but no detection was made on the route between the 2 islands (Figure 3 (c)). P-calls were mainly detected around St. Paul, on the banc des 16 milles and midway between the islands (Figure 3 (b)). Antarctic blue whale songs were detected repeatedly for short periods both around St. Paul, between the islands and west of Amsterdam (Figure 3 (a)). D-calls were mainly recorded around St. Paul and on the banc des 16 milles (95% of call-by-call detections)

(Figure 3 (e)).

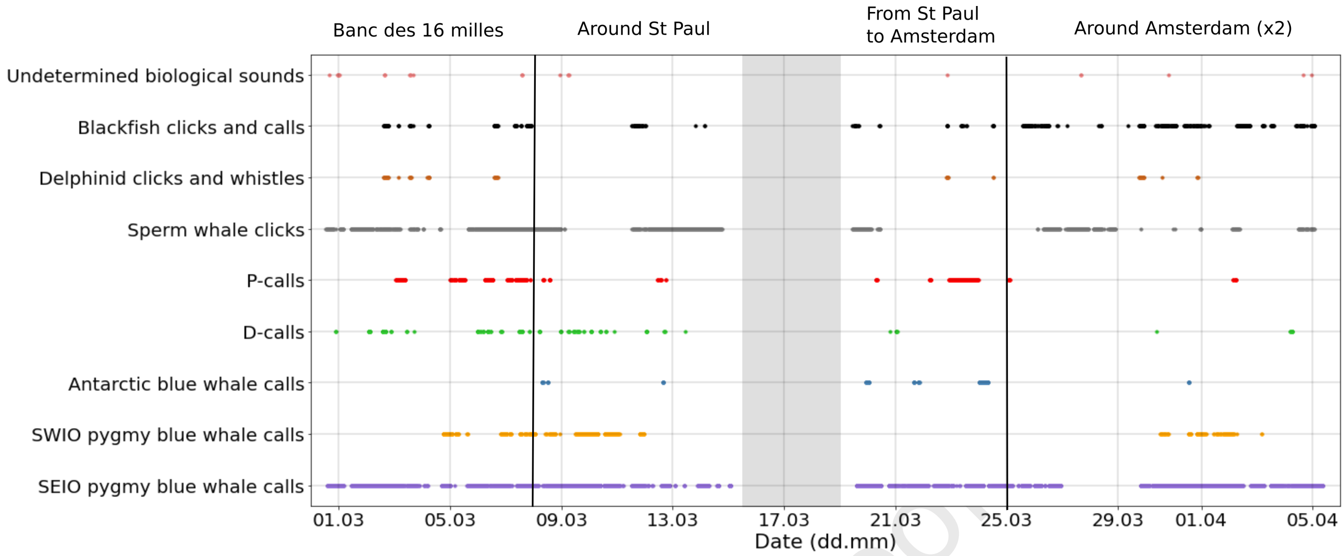

Figure 2: Timeline showing all detections per label during the glider deployments around the St. Paul and Amsterdam islands. Each dot represents a positive detection of SEIO pygmy blue whale call (purple), SWIO pygmy blue whale call (orange), Antarctic blue whale call (white), D-call (green), P-call (red), sperm whale click (grey), delphinids click and whistle (brown), blackfish click and call (black), and undetermined biological sound (pink)

Sperm whales, killer whales or pilot whales (*Globicephala*), undetermined delphinids and undetermined biological sounds were detected in the medium and high frequency data.

Sperm whale clicks were the most detected (30% of the 10-minute files positive to detection), followed by blackfish calls (10% of the files with detection). The presence of other types of vocalizations was very low (<1%) (Figure 2). Sperm whale clicks were mostly detected during the first deployment, around St. Paul island and the banc des 16 milles (more than 70% of the detections, Figure 3 (h)) whereas blackfish clicks and calls were mostly detected around Amsterdam island (more than 73% of the detections, Figure 3 (f)). Undetermined delphinid clicks and whistles were mostly detected around the banc des 16 milles and Amsterdam island. Note that no sperm whale clicks and only a few blackfish and delphinid vocalizations were recorded during the glider's journey from St. Paul to Amsterdam island.

For the low frequency dataset, the bioacoustic diversity ranged from 0 to 3 (Figure 4). The areas with the highest low frequency bioacoustic diversity were east and west of St. Paul and northwest of Amsterdam. Areas with low bioacoustic diversity were found on the banc des 16 milles and northeast of Amsterdam during the first route around the island. For the high frequency dataset, the bioacoustic diversity ranged from 0 to 3 (Figure 4). The areas

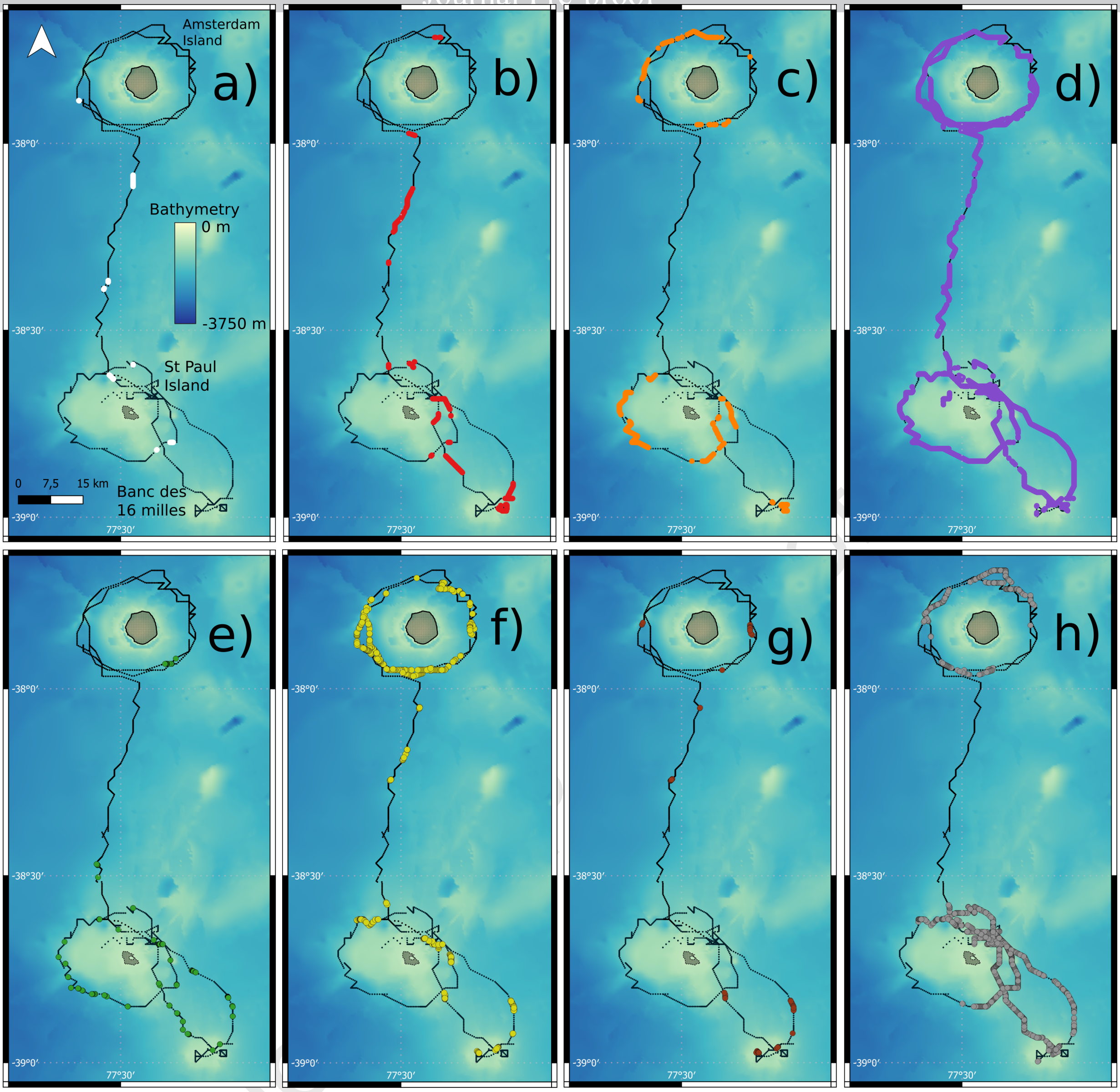

Figure 3: Map showing the glider path in black and the location of the detections of (a) Antarctic blue whale calls (white), (b) P-calls (red), (c) SWIO pygmy blue whale calls (orange), (d) SEIO pygmy blue whale calls (purple), (e) D-calls (green), (f) blackfish clicks and calls (yellow), (g) delphinids clicks and whistles (brown), (h) sperm whale clicks (grey)

with the highest high frequency bioacoustic diversity were located east of St. Paul and around Amsterdam whereas the areas with low bioacoustic diversity were found on the west of St Paul and between the two islands.

4.2 Walters Shoal

About 40% of the 10-minute audio files contained bioacoustic activity associated with the presence of at least 4 cetacean species.

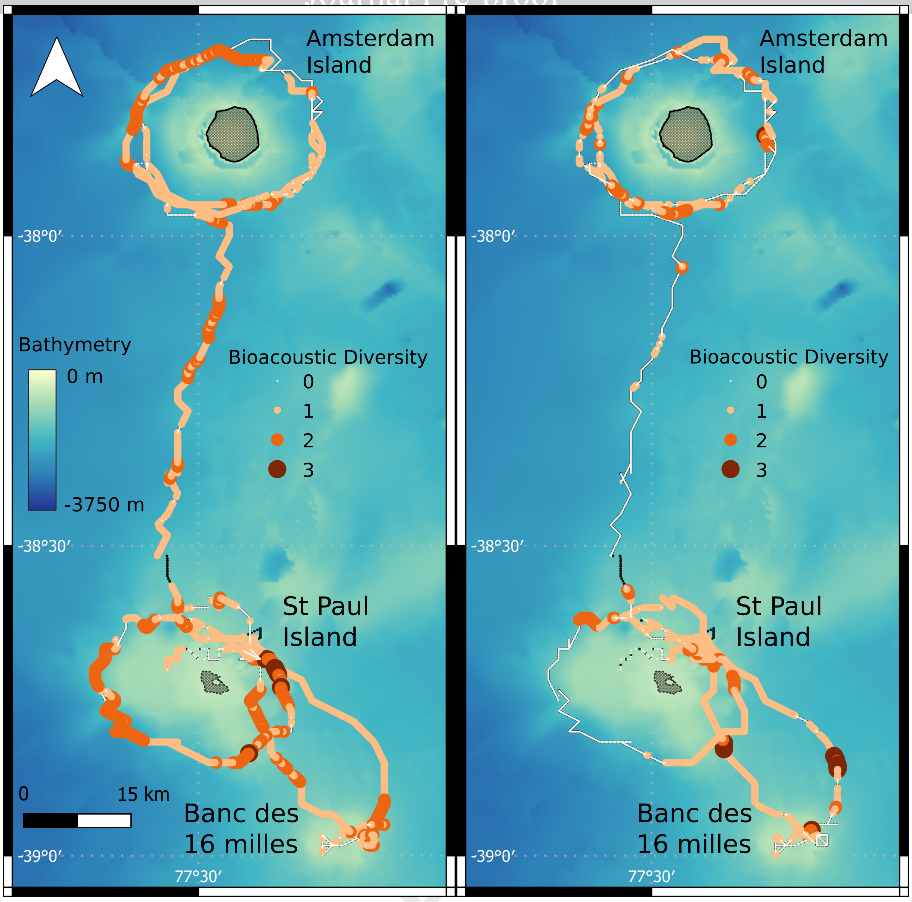

Figure 4: Maps of the St. Paul and Amsterdam region. Each colored dots represent the bioacoustic diversity of the low frequency dataset (left) and of the high frequency dataset (right) computed over a 10-minute time bin. Low bioacoustic diversity is represented with a small size light colored dot whereas high bioacoustic diversity is represented with a larger and darker dot.

Blue and fin whales were recorded around the Walters Shoal seamount during the 10-day deployment (Figure 5). Two blue whale subspecies were identified: the Antarctic blue whale and the SWIO pygmy blue whale. Blue whale D-calls were also detected. Two types of vocalizations emitted by fin whales were identified: 20 Hz calls and 40 Hz calls.

Blue whale songs were present in a little more than 5% of the recordings with 3% of the recordings positive for SWIO pygmy blue whale songs, 1% for Antarctic blue whale songs and less than 0.1% for D-calls. Finally, fin whale vocalizations were present in less than 0.1% of recordings. Antarctic blue whale songs were detected all along the glider path (Figure 6 (a)), whereas SWIO pygmy blue whale songs and fin whale 20 Hz calls were only recorded in the East of the sampled area (Figure6 (b) and (d)). Blue whale D-calls and fin whale 40 Hz calls were recorded only once, the first near the Walters Shoal seamount (Figure 6 (c)) and the second above the eastern seamount (Figure 6 (e)).

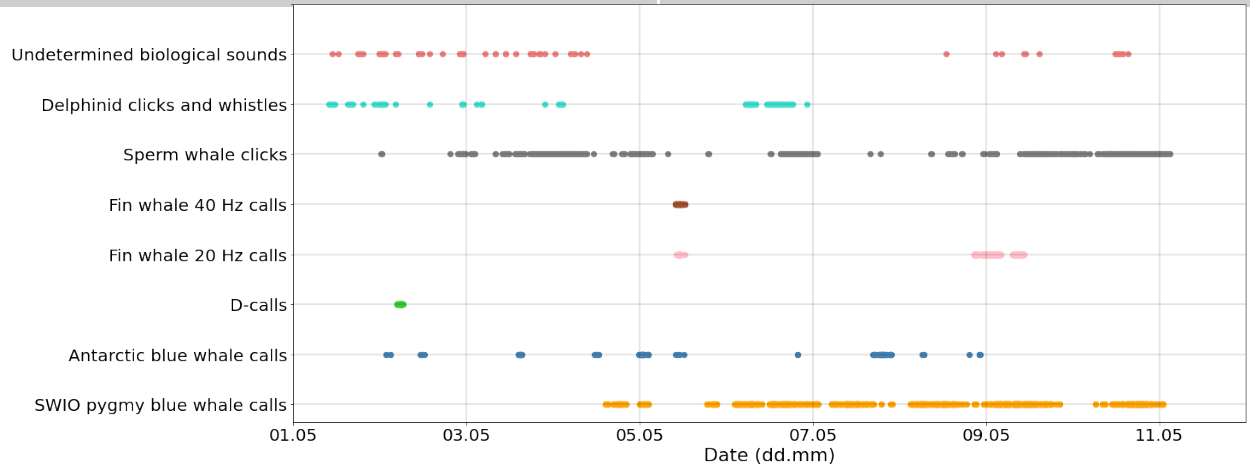

Figure 5: Timeline showing all detections per label during the glider mission around the Walters Shoal. Each dot represents a positive detection of SWIO pygmy blue whale call (orange), Antarctic blue whale calls (dark blue), D-calls (green), fin whale 20 Hz calls (pink), fin whale 40 Hz calls (dark brown), sperm whale clicks (grey), delphinid click and whistle (light blue) and undertermined biological sounds (dark pink)

Sperm whale clicks and undetermined delphinids clicks and whistles were detected in the medium and high frequencies dataset. Other species were also recorded by the glider but could not be formally identified and were grouped under the undetermined biological sounds label.

During the 10 days of recordings, sperm whales were the most detected species in the area. 30% of the recordings contained sperm whale clicks, followed by delphinid with 7% of recordings containing whistles and 4% containing clicks. 97% of the files with delphinid clicks also contained delphinid whistles while only 57% of files with whistles also contained clicks. Sperm whale clicks were not recorded close to the Walters Shoal seamount, but they were detected almost continuously along the eastern part of the glider path (Figure 6 (g)). Delphinid clicks and whistles were detected around the two seamounts (Figure 6 (f)) and undetermined biological sounds were mostly detected close to the Walters Shoal seamount (Figure 6 (h)).

For the low frequency dataset, the bioacoustic diversity ranged from 0 to 3 (Figure 4). The area with the highest low frequency bioacoustic diversity was east of Walters Shoal. Areas with low acoustic biodiversity were found close to the seamount. For the high and medium frequency datasets, the acoustic biodiversity ranged from 0 to 2 (Figure 7). There was one main areas with high bioacoustic diversity: close to a second seamount, west of Walters Shoal. Areas with low bioacoustic diversity were found on the easternmost part of the glider's path.

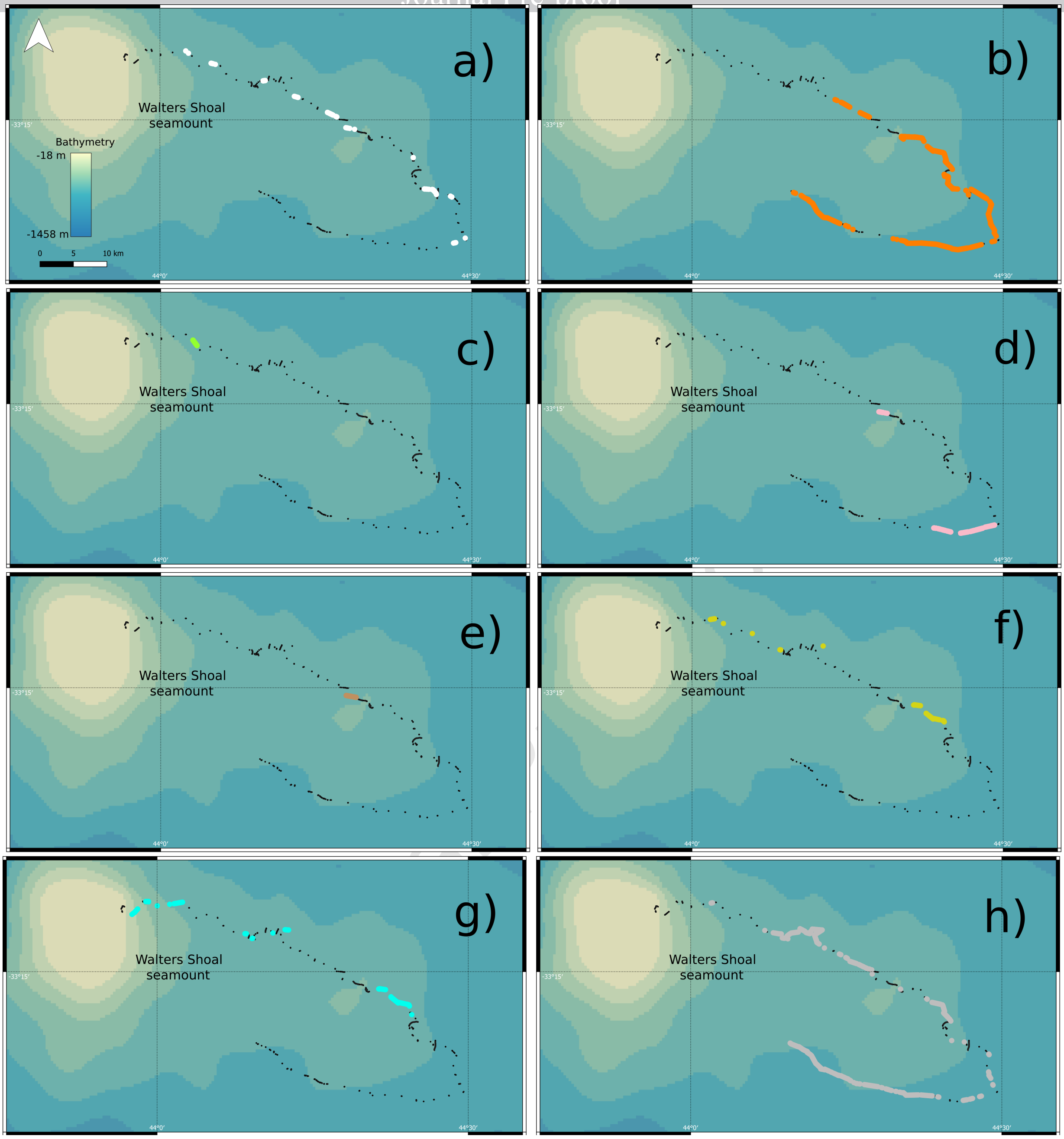

Figure 6: Map showing the glider path in black and the location of the annotation for (a) Antarctic blue whale calls (white), (b) SWIO pygmy blue whale calls (orange), (c) D-calls (fluo green), (d) fin whale 20 Hz calls (pink), (e) fin whale 40 Hz calls (light brown), (f) delphinid clicks (anise green) (g) delphinid whistles (blue), (h) sperm whale clicks (grey).

5 Discussion

The high marine mammal presence both in Walters Shoal and around St. Paul and Amsterdam islands corroborate the previous evidences of the attractiveness of abrupt topographic features for these animals [Moore et al., 2002, Seabra et al., 2005].

The bioacoustic activity measured around the Walters Shoal seamount is lower than the

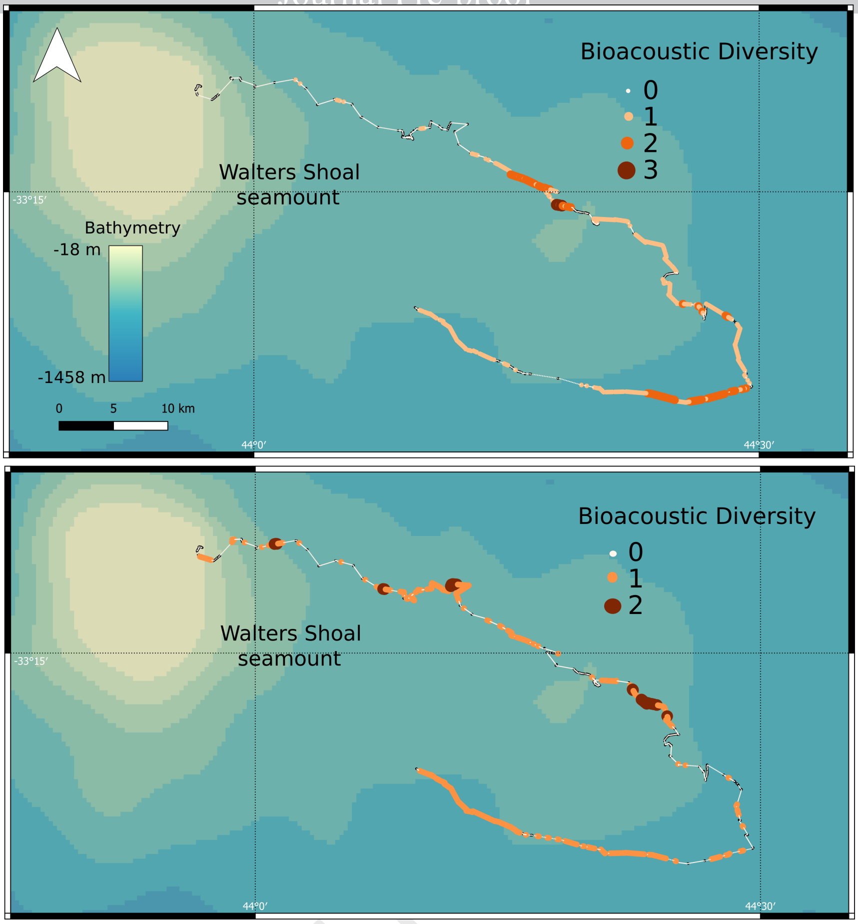

Figure 7: Maps of the Walters Shoal region. Each colored dots represent the bioacoustic diversity of the low frequency dataset (left) and of the high frequency dataset (right) computed over a 10-minute time bin. Low bioacoustic diversity is represented with a small size light colored dot whereas high bioacoustic diversity is represented with a larger and darker dot.

one measured in St Paul and Amsterdam, with only 40% of recordings containing bioacoustic activity compared to over 70% in St. Paul and Amsterdam. However, among the large baleen whales, only blue whales were recorded in St. Paul and Amsterdam whereas both fin and blue whales were detected in Walters Shoal. Regarding odontocetes, sperm whales and smaller delphinids were recorded at both sites. The bioacoustic diversity reached 6 in St. Paul and Amsterdam and 4 in Walters Shoal, further demonstrating the attractiveness of both areas.

5.1 Learnings and limitations from passive acoustic monitoring

Opportunistic visual surveys, which occurred over the same time period and area as the glider survey, noted the presence of killer whales and large baleen whales from unidentified species around St Paul and Amsterdam. The acoustic data recorded during the glider deployment in March and April 2019 corroborates the presence of killer whales in the area, and also highlights the presence of sperm whales and blue whales. Long-term offshore acoustic recordings already showed that blue whales dwell in this region of the Indian Ocean [Leroy et al., 2016, Torterotot et al., 2020], but it is the first time that their acoustic presence is recorded so close to the islands. As blue whale sub-species and populations have distinctive songs, our acoustic data even allowed to specify that Antarctic blue whales as well as SWIO and SEIO pygmy blue whales were present in the area during March and April 2019, where visual observation could not have been this precise as all populations look extremely similar. Our recordings also revealed the presence of an unknown whale species, who produces the P-calls. This call type is thought to be emitted by a great baleen whale and has already been recorded in a few places in the Indian Ocean, but never with combined visual observation [Leroy et al., 2017].

In Walters Shoal, joint visual observation efforts were conducted throughout the oceanographic campaign [Gadenne and Saloma, 2017] during which the glider was deployed. Of the 15 or so cetacean sightings, only two species were identified: bottlenose dolphins (*Tursiops aduncus*) and sperm whales (five sightings each). Again here, PAM allowed to supplement the visual observations and showed that 2 baleen whale species (fin and blue whales) were present, from which none were sighted. The acoustic data also show that the Antarctic and the SWIO pygmy blue whale sub-species were dwelling simultaneously in the area and corroborate the sightings of sperm whales and small delphinids.

More than solely identifying the species, PAM also allowed to detected multiple call types produced by the same species. For blue and fin whales it is not yet clear what is the function of each call type, but they could either be related to reproduction or social communication [McDonald et al., 2006]. The detection of these call type might therefore give some indications about the ecological function of such areas. In the same way, the detection of delphinid clicks implies that both areas could be used for feeding purposes.

From the spatial covering of the glider, the bioacoustic diversity index pointed areas of high bioacoustic diversity within the studied areas, such as the south of Amsterdam island, the southeast of St. Paul island and the vicinity of the two main seamounts in Walters Shoal. These results are representative of the spatial presence of marine mammals during a short period of time (ie in March 2019 in St Paul and Amsterdam and during 10 days in May 2017 in Walters

Shoal). Most cetacean species are highly mobile, so this bioacoustic diversity map should not be taken as a picture of the preferred habitats of the animals, but as evidence of their attendance of this region at a given time. Furthermore, a low bioacoustic diversity does not mean that the area is less frequented by marine mammals, but that they may vocalize less there at this time, that they change their acoustic behavior or that the is more prone to acoustic masking, due to the water column properties and/or the bathymetry.

Using acoustic data to monitor such remote places still raises other limitations. For example in Walters Shoal, the study of the clicks and whistles present in the spectrogram doesn't allow to identify the source species. In St. Paul and Amsterdam, the distinction between killer and pilot whales clicks, calls and whistles is highly subjective and relies frequently on the annotator's perception (Figure 8). Still, these sounds were most likely produced by killer whales, observed around the islands during the deployment by the sailor of the Austral trawler.

Ultimately, another drawback of acoustic data is that a few unidentified sounds were detected and could not have been attributed to any specific species. The time frequency shape of the sounds indicates that they are likely produced by a biological source, but some might also be anthropogenic or geophysical sounds. Some examples of unattributed sound spectrograms are displayed in Figure 9.

5.2 Indian Ocean occupation by marine mammals

5.2.1 Baleen whales

Recent acoustic or visual observations combined with data from whaling catches in the Indian Ocean have made it possible to draw up a partial inventory of the migrations of the different blue whale populations. This information is essential for the conservation of this species, classified as endangered by the International Union for Conservation of Nature (IUCN). The Antarctic subspecies has been selectively targeted during the whaling period and is even classified as critically endangered [Cooke, 2019]. [Branch et al., 2004] estimate that the population size of Antarctic blue whales decreased by more than 99%, from more than 200,000 individuals to only about 300 in 1970. Information on the pygmy subspecies, described only in the 1960s

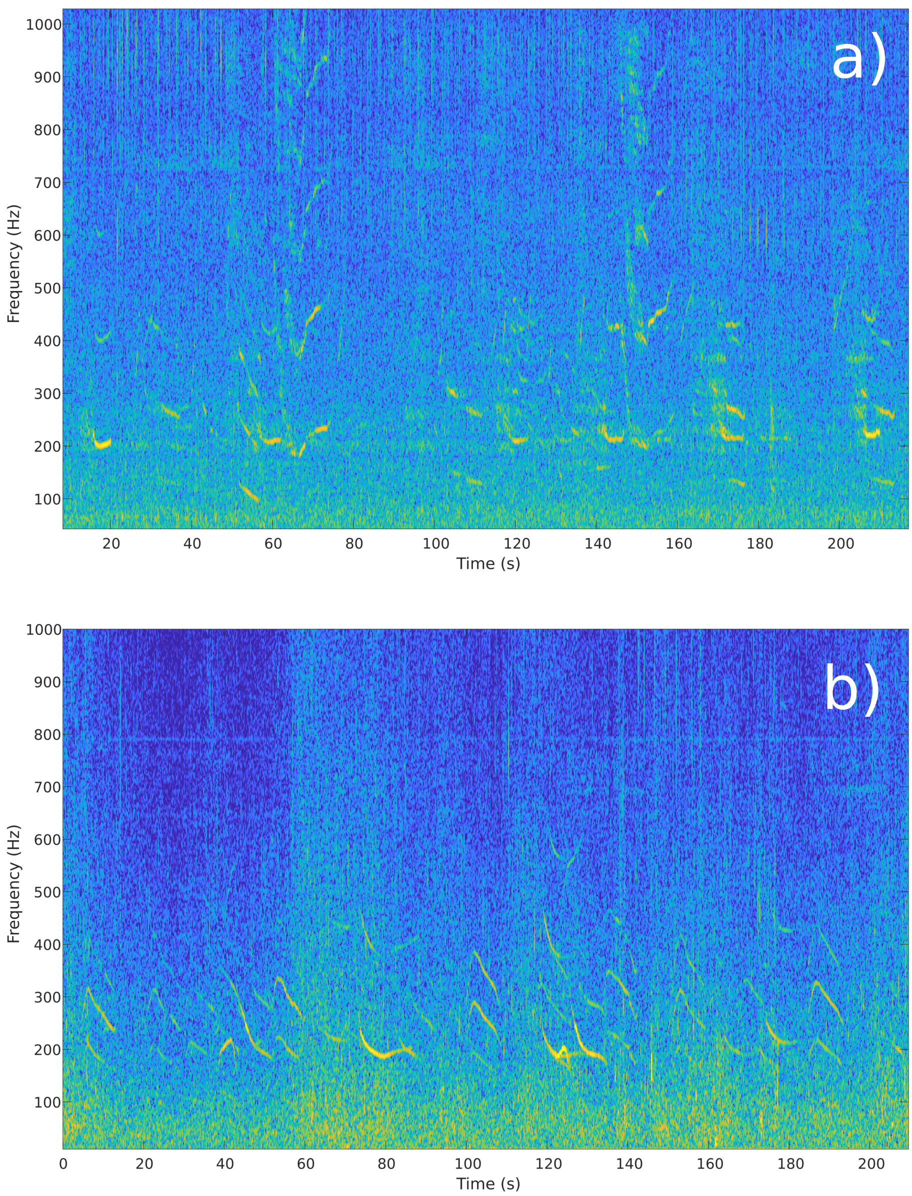

Figure 8: Spectrograms of blackfish whistles that could not clearly be attributed either to killer whales or to pilot whales, recorded around St. Paul and Amsterdam, hence, this study grouped and analyzed all of these vocalizations as blackfish. Spectrogram parameters: fast Fourier transform Hanning window, frequency resolution = 0.3 Hz and time resolution = 25 ms

[Ichihara, 1966], is still too sparse to classify this species in the IUCN Red List. Whaling no longer represents a threat for this species and numbers seem to be increasing, but still remain far from pre-hunting estimates [Branch et al., 2004]. In addition, many new dangers such as chemical, plastic or acoustic pollution, entanglement and collision, persist and threaten the survival of the species.

The Antarctic blue whale mainly feeds in Antarctic waters during the austral summer, before migrating to more tropical latitudes where they spend the austral winter and autumn to

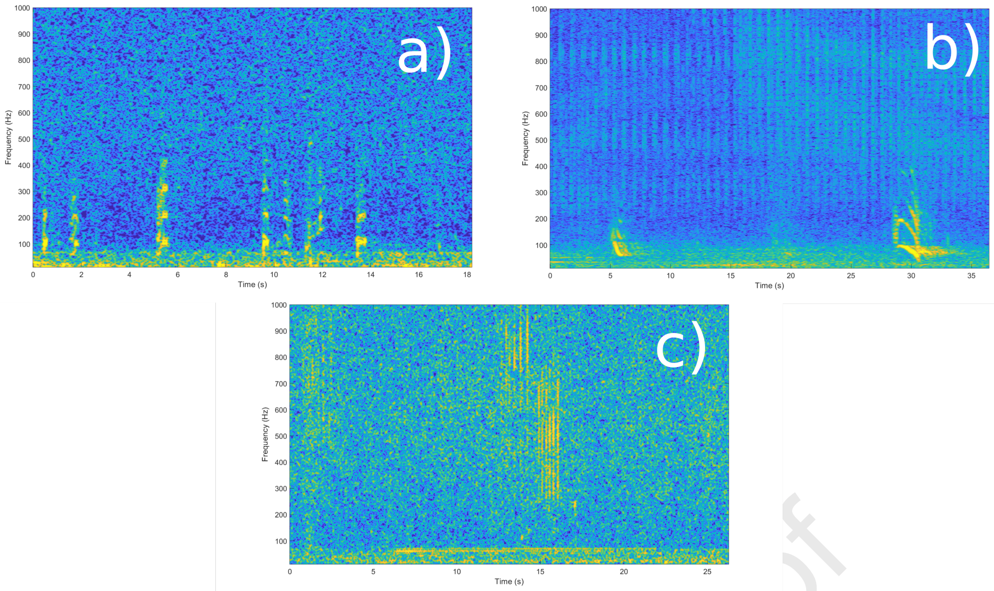

Figure 9: Spectrograms of undetermined biological sounds recorded around St. Paul and Amsterdam islands. Spectrogram parameters: a) fast Fourier transform Hanning window, frequency resolution = 0.3 Hz and time resolution = 25 ms, b) and c) fast Fourier transform Hanning window, frequency resolution = 0.3 Hz and time resolution = 20 ms

mate and give birth [Leroy et al., 2016]. While the feeding grounds are properly identified from whaling logbooks data [Branch et al., 2007] and from more recent acoustic and visual surveys [Miller et al., 2019a, Thomisch et al., 2016], the exact locations of the breeding wintering areas remains unknown. Some studies suggest that only some individuals undergo this migration while the others remain in subtropical latitudes throughout the year [Thomisch et al., 2019]. Furthermore, even if the main feeding grounds of this population are in Antarctica, it is likely they feed on their migration to and from wintering grounds, as observed from other blue whale populations [Buchan et al., 2018, Gill, 2002], although this has never been demonstrated. The St. Paul and Amsterdam islands are located on the migratory route of this blue whale subspecies, halfway between its known feeding and theoretical wintering grounds. The recording of only a few Antarctic blue whale vocalizations in our study corroborates the beginning of their arrival at these latitudes in March. The Walters Shoal sea mounts are also located on the Antarctic blue whales migratory route. The hydrophones of the OHASISBIO network [Royer, 2009] located South East of the seamounts start recording Antarctic blue whale calls around April/May [Torterotot et al., 2020]. The few calls recorded in our study on Walters Shoal data either indicate that in 2017 blue whales arrived later at these latitudes, that their vocalization production rhythm is lower at these latitudes, or that their migration route is more likely to be located east of Walters Shoal.

The satellite tracking of a few SEIO pygmy blue whales has described their migration along the Australian coast from austral autumn to austral winter when they arrive in tropical Indonesian waters [Double et al., 2014]. Songs of this population were also seasonally detected at the NEAMS and SWAMS sites of the OHASISBIO network, suggesting that at least part of the population would rather migrate to the northeastern Indian Ocean, away from the Australian coast [Leroy et al., 2018a, Torterotot et al., 2020]. The almost continuous detection of SEIO pygmy blue whale songs our data collected in St. Paul and Amsterdam waters in March confirms the presence of individuals of this population in the area and indicates that the waters surrounding the islands are used as habitat during this part of the migration. These observations suggest that the population follows two distinct migration routes. It is unknown whether they all regroup in tropical Indonesian waters during austral winter or if the part of the population that goes by St. Paul and Amsterdam islands takes advantage of another distinct wintering ground. The western hydrophones of the OHASISBIO network seldom record SEIO pygmy blue whale songs [Torterotot et al., 2020] and the limit of their range is likely located east of the Walters Shoal seamounts, where no SEIO pygmy blue whale songs were recorded.

The SWIO pygmy blue whale songs have principally been recorded in the Western Indian Ocean [Best et al., 2003, Cerchio et al., 2018, Dréo et al., 2018, Torterotot et al., 2020, Stafford et al., 2011]. Although this population was the most detected at Walters Shoal, only 5% of the files contains their vocalizations. They were however previously recorded in May close to la Réunion island [Dréo et al., 2018] and south east of Walters Shoal [Torterotot et al., 2020]. There is no available recording to confirm their presence west of the Madagascar plateau. Walters Shoal might therefore be located on the limit of their distribution. The SWAMS and NEAMS sites in the OHASISBIO network are the one that record the fewest vocalizations from this population, indicating that the eastern limit of their distribution is situated close to this longitude [Torterotot et al., 2020]. Even so, the few detections of SWIO pygmy blue whale songs in our data collected around St. Paul and Amsterdam reveal that some individuals visit the islands in March.

P-calls have been previously detected in the sub-tropical Indian Ocean, but appear to be absent south of Kerguelen islands and at the equator. This sound meets the criteria that describe a blue whale song, and the seasonality of their detection in the Indian Ocean suggests an east-west migratory movement between the austral fall and spring [Leroy et al., 2017]. Their presence at the NEAMS and SWAMS sites coincides with the recording of SWIO and SEIO pygmy blue whales songs during the austral autumn [Torterotot et al., 2020]. P-calls detections in our data collected around St. Paul and Amsterdam confirm the presence of this undetermined species near the islands in March. On the contrary, the few P-calls detections in the West of the Indian Ocean during May [Leroy et al., 2017] matches with the absence of detection on our Walters Shoal dataset.

There is at least one other well-identified blue whale population inhabiting the Indian Ocean, commonly referred to as the Sri Lankan or Central Indian Ocean (CIO) pygmy blue whale. Vocalizations of this population have been detected around Crozet archipelago between December 2003 and April 2004, north of St. Paul and Amsterdam islands, between December and February 2006 [Samaran et al., 2010a, Samaran et al., 2013]. More recent recordings (2010 to 2016) report the acoustic presence of CIO pygmy blue whale calls north of Amsterdam island mainly in April and in November [Leroy et al., 2018a]. It is interesting to note that these vocalizations were not recorded at all by the glider in our study, further suggesting that this population is infelicitous to the northern Indian Ocean and migrates very little to higher latitudes, at least during the monitoring periods (ie March and May).

Some fin whale populations migrate long distances between high and low latitudes, but other populations are resident such as in the Mediterranean Sea, and the California gulf [Geijer et al., 2016, Rivera-León et al., 2019]. [Lydersen et al., 2020] have also shown that among migrating populations, some individuals remain at high latitudes during winter. However, their calls were only detected from August to December in the central West Fram and North of Spitzbergen [Ahonen et al., 2021], indicating that the individuals remaining at high latitude all year long might not be singing all the time. This seasonal change in vocal behavior was also observed in Antarctica [Širović et al., 2013]. This new information implies that this species can be hard to monitor only with PAM methods depending on the season and vocal behavior. In the Indian Ocean, fin whales feed down in Antarctica during the austral summer [Širović et al., 2004, Širović et al., 2009] and migrate northwards to subantarctic and subtropical locations during the austral winter [Leroy et al., 2018a]. Predominantly, their vocalizations are detected from March-April by the OHASISBIO array in the Southwestern Indian Ocean, with variability between the years [Leroy et al., 2018a]. A late arrival of fin whales in 2019 could explain why no fin whale vocalizations were recorded around St. Paul and Amsterdam islands by our glider. In our study, the few detections in Walters Shoal in May might also be explained by a delayed arrival in 2017 or by a lower vocalizations emission rhythm during this season.

D-call detection in the glider data around St. Paul and Amsterdam islands and Walters Shoal may provide an indication about the behaviour of blue whales in the region. Indeed, this type of vocalization, emitted by all blue whale populations, has already been detected during feeding behavior [Oleson et al., 2007a, Lewis et al., 2018]. Moreover, in the Indian Ocean, D-calls are mainly recorded in the south and around Antarctica on known feeding grounds [Torterotot et al., 2021]. The detection of D-calls, mainly around St. Paul island, suggests that this area might be utilized for feeding. Nevertheless, D-calls have also been recorded during socialization behaviors, including competition between several individuals for a female [Schall et al., 2019]l, which tempers the first interpretation of the presence of this type of vocalization in the recordings. Similarly, the emission of Atlantic fin whale 40 Hz calls was positively associated with prey biomass in the Azores, supporting that this call type is associated with a feeding behavior [Romagosa et al., 2021]. Our recording of 40 Hz calls at Walters Shoal could then indicate that fin whales feed during their migration in this sub-tropical area. Feeding during migration was already inferred from Atlantic fin whales tagged in the northern hemisphere [Lydersen et al., 2020]. However such as for the D-calls, 40 Hz calls were also recorded during social interaction between two individuals, suggesting that it could serve as a contact call as well [Wiggins and Hildebrand, 2020]. Compared to other seamounts and islands in the southwestern Indian Ocean, the Walters Shoal seamount showed seasonal high chlorophyll-a enrichment index values. These values peaked during the oligotrophic season from November to May [Hervé et al., 2020]. It is also recognize as a seabird foraging hot spot [Le Corre et al., 2012]. It could therefore be used by marine mammals as a food pantry while they undergo their long migration.

Some of the vocalizations detected in the St. Paul and Amsterdam mid-frequency dataset could not be formally identified, but looked similar to vocalizations emitted by other smaller mysticetes (Figure 9). One hypothesis is that some of these vocalizations could be emitted by humpback whales. They feed in Antarctica during the southern summer and migrate to warm tropical waters during the southern winter to breed and give birth [Clapham, 1996]. In the western Indian Ocean, the breeding grounds are very coastal and quite well identified (La Réunion island, Madagascar, Eparses islands) [Cooke, 2018]. Humpback whales were sighted at Walters Shoal seamount in summer (November, December), a period of high productivity [Best et al., 1998, Collette and Parin, 1991, Shotton et al., 2006]. Satellite tag localization data also revealed the visit of one individuals in September 2012 [Trudelle et al., 2016]. It is unsure whether this site is used for feeding or reproduction or both, depending on the period of the year. By analogy, the St. Paul and Amsterdam Islands may represent a feeding area for the population migrating through the eastern Indian Ocean to breeding grounds on the west coast of Australia [Bestley et al., 2019]. Some of these undetermined biological sounds detected in St. Paul and Amsterdam could also have been produced by Southern right whales (*Eubalaena australis*). Logbooks from the 19th century describe the capture of numerous Southern right whales in the waters near St. Paul and Amsterdam islands (between 30° and 40° S) [Richards, 2009]. More recently, five satellite tags were placed on Southern right whales as part of the Tohora project conducted by the University of Auckland. The whales, tagged around the Auckland Islands, south of New Zealand in August 2020 all headed west. The tag of one individual recorded for almost a year and showed that this whale approached the EEZ of St. Paul and Amsterdam during its migration [3].

The bioacoustic diversity of the low frequency dataset in St Paul and Amsterdam indicates that baleen whale calls were detected almost continuously along the glider's path. The high propagation range of these calls (Table 2) implies that the detection of these call type does not indicate the presence of blue whales in the direct vicinity of the glider, but more likely in a perimeter around the islands. The high bioacoustic diversity west of St Paul might be due to the presence of multiple whales offshore, an area identified as a blue whale migratory corridor [Torterotot et al., 2021].

[3] https://www.tohoravoyages.ac.nz/tracks-of-the-tohora/, consulted on September 27

5.3 Odontocete and pinnipede

Our data confirmed the significant presence of sperm whales and killer whales or pilot whales already described by numerous visual observations around the St. Paul and Amsterdam islands. The visual observation of killer whales and the absence of visual observation of pilot whales from the ship l'Austral during 2019-2020 (N. Gasco pers. comm.) suggests that the vocalizations recorded by the glider are emitted by the Amsterdam killer whale population, very regularly observed around the islands. Comparison of photo identification catalogs of killer whales in the entire southern Indian Ocean sector indicates that the Amsterdam population does not appear to be connected to any other area (P. Tixier, pers. comm.), making it an important conservation issue. Similarly to the killer whale populations studied in the Salish Sea [Ford, 1991], the identification of a specific acoustic repertoire produced by this population could help in monitoring their presence in the area.

The almost continuous presence of sperm whales around the St. Paul and Amsterdam Islands is documented by numerous visual observations made from the Austral, the Marion Dufresne or even the islands. In our dataset, the detection of clicks exclusively around the islands suggests that these areas are privileged habitats for sperm whales. Nevertheless, the absence of detection between the two islands does not mean that sperm whales are not present there at all. Moreover, since the glider mission lasted only one month, this phenomenon of acoustic presence mainly at the level of the islands is perhaps not significant. Sperm whales females and immature individuals often live in groups of about 20 individuals in tropical and sub-tropical waters [Rice, 1989]. In the Indian Ocean, a few studied on sperm whale groups were undertaken, mostly around Mauritius [Sarano et al., 2021], the Sri Lanka [Gordon, 1987] and the Seychelles [Whitehead and Kahn, 1992]. It is unknown whether the sperm whale group observed and recorded around St Paul and Amsterdam island is connected to any of these other groups. When socializing, female and immature sperm whales often make stereotypical patterns of about 20 clicks called codas [Watkins and Schevill, 1977]. Codas are specific to each group, therefore a thorough analysis of the sperm whale clicks detected in the data could bring insight on whether there is a connection between this group other Indian Ocean groups. Male sperm whales disperse from their natal group before their sexual maturity and can travel thousands of kilometers towards areas abundant in food and back to tropical waters for breeding [Rice, 1989]. Further investigation is required to determine whether the sperm whale clicks detected in our Walters Shoal data were emitted by solitary traveling or feeding males or by a social group.

Some vocalizations classified as indeterminate biological sounds (Figure 9 c)) have been identified as being emitted by Amsterdam fur seals (*Arctocephalus tropicalis*) (I. Charrier, pers. comm.). However, these sound look very similar to fish or crustacean sounds recorded in coral reefs [McWilliam et al., 2018].

In St Paul and Amsterdam, odontocete vocalizations were detected more sporadically than baleen whales's, with a high bioacoustic diversity occurring on very small portions of the glider's tracks. On the opposite, around Walters Shoal, odontocete vocalisations were detected almost continuously. As odontocete click and whistle propagation range is below 30 km (Table 2), the very low high-frequency bioacoustic diversity in-between St Paul and Amsterdam islands and the higher high-frequency bioacoustic diversity close to the islands suggest that the islands might attract odontocete.

6 Conclusion

This study supplemented the knowledge on marine mammals presence in two remote regions of the Indian Ocean, previously described either by satellite tag localization or by opportunistic visual observations. At both places, the bioacoustic activity is relatively high with 40% of the records positive for detection in Walters Shoal and over 70% around St. Paul and Amsterdam islands. Among the species already observed, acoustic data added significant value in identifying the species of large baleen whales. While visual observations only report the presence of unrecognized baleen whales, acoustics revealed the presence of multiple blue whale sub-species and acoustic populations - especially two poorly known and elusive pygmy blue whale populations - of fin whales and of an unidentified species producing the P-calls. The steady acoustic presence of endangered blue whale species, of a unique population of killer whales around st Paul and Amsterdam island over the recording period further supports the IMMA' status of the area and broadens the conservation issues. Although the bioacoustic activity around Walters Shoal was lower for baleen whales, the detection of blue and fin whale songs and social calls as well as the high odontocete acoustic reassert the importance of the area within the IMMA.

Even though the bioacoustic diversity metric fluctuates along the glider's path, a more consistent spatial and temporal sampling would be necessary in order to refine the privileged habitat areas around the islands and the seamounts. First, if the glider were to be redeployed in the same region, it would be interesting to repeat the same track to be able to compare the results with the deployment presented here. Future glider deployments could also focus on more limited areas, for example the southeast of St Paul island, with a much finer spatial sampling. This would allow to observe if the areas defined as hotspots in this study have consistently high bioacoustic activity and diversity or if this latter is too variable in time to be able to use it as an indicator to define a hotspot. A continuous monitoring across one year could also help define whether the species are only present seasonally, for example to rest during their migration, or if they occupy the area all year long. More widely, it would be interesting to compare the bioacoustic activity and diversity with that of oligotroph offshore remote areas surrounding these two regions. Finding that bioacoustic activity and diversity is higher around St. Paul and Amsterdam islands and Walters Shoal than in other regions would help determine to what extent they are marine mammal hotspots.

In addition, in order to refine the identification of the species present from to their vocalizations, parallel acoustic and visual observation campaigns (from boat, island or plane) could be set up. This would help to improve the distinction between killer whale and pilot whale vocalizations and to identify the species emitting the P-calls and the undetermined other vocalizations, assuming that their vocalizations were produced close to the island. Additionally, combining PAM and visual observation in a more systematic way in the area would allow us to better understand the functional role of this habitat for these species and provide knowledge on the link between general behavior and vocal behavior.

Ultimately, equipping the glider with a higher frequency hydrophone would allow to determine if beaked whales, who produce clicks in frequency ranges beyond this studies' sampling rate, are present in the surrounding areas. Indeed, seamount slope seems to be of importance for these species known to feed primarily on mesopelagic and deep sea fish and squid species [Kaschner, 2007].

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Conflict of interest statement

The authors (Maëlle Torterotot, Julie Béesau, Flore Samaran and Cécile Perrier de la Bathie) certify that they have NO affiliations with or involvement in any organization or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Declaration of interests

☒ 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.

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