Possible improvement of humpback whale *(Megaptera novaeangliae)* management in the Yarari Sanctuary based on Passive Acoustic Monitoring (PAM) data for habitat use

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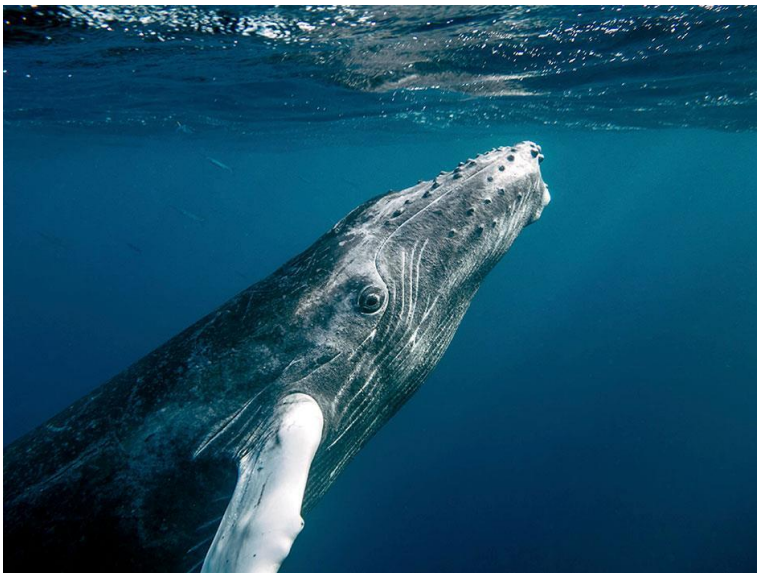

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Possible Improvement of humpback whale *(Megaptera novaeangliae)* management in the Yarari Sanctuary based on Passive Acoustic Monitoring (PAM) data for habitat use

A thesis study to see if humpback whale management of the Yarari Sanctuary can be improved based on data gathered via Passive Acoustic Monitoring on habitat use and behaviour.

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Date: February, 2019

IJmuiden, the Netherlands

Cover picture:

Acknowledgement

I would like to thank Meike Scheidat for offering me this thesis project and for helping and guiding me through the project. And for giving lots of useful feedback and tips while writing this report. I would also like to thank Bart Noort for helping me with the more technological aspect of this project, providing the Raven Pro license and giving information on the AMAR recorders. Further I would like to thank Denise Risch for helping me whenever I was not sure what kind of vocalization I had detected either humpback whale vocalizations or the vocalization of fish.
I also want to thank Evelien Jager and Tjibbe Stelwagen for giving feedback on my proposal and helping me when I was lost within management plans.

Mathilde Hoogerwerf.

IJmuiden, 11 January 2019

Abstract

This thesis research aimed to answer the question whether Passive Acoustic Monitoring (PAM) data of humpback whales can improve management of the Yarari Marine Mammal Sanctuary in the Dutch Caribbean. This study looks at data recorded on the Saba Bank from December 2016 until April 2017. The PAM data were analysed with the use of Raven Pro 1.5. Spectrograms were manually analysed for the presence of humpback vocalizations. Humpback whale vocalizations were detected from mid-January until the end of April. Throughout February and March vocalizations were registered every day. A sub sample of three weeks was analysed to look into how vocalizations were occurring over a 24 hour period. No diel pattern was identified with vocalizations being detected throughout the day. A literature study on the management plan was done for the Stellwagen Bank National Marine Sanctuary and the Dominican Republic Marine Sanctuary. Both plans took the potential threat of noise pollution, fisheries, vessel strikes and whale watching into account. In addition the Dominican Republic also took climate change into consideration. Aspects from the plans for these sanctuaries can be used to help inform the creation of a management plan for the Yarari. This study describes how PAM can be used to provide vital information needed for a long-term monitoring of cetaceans and to monitor the implementation and success of a management plan.

Samenvatting

Dit scriptie onderzoek heeft gekeken naar hoe Passief Akoestische Monitoring (PAM) data van Bultruggen het management plan van de Yarari Marine Mammal Sanctuary in de Caribische Zee kan verbeteren. Deze studie heeft gekeken naar data van opnames die genomen zijn op de Saba Bank van december 2016 t/m april 2017. Deze PAM-gegevens werden bekeken met behulp van Raven Pro 1.5. Hiermee werden spectrogrammen handmatig geanalyseerd op de aanwezigheid van Bultrug vocalisaties. Bultrug vocalisaties zijn waargenomen vanaf half januari t/m eind april. In februari en maart zijn bijna dagelijks vocalisaties waargenomen. Voor het patroon gedurende dag zijn drie weken onderzocht op vocalisaties die voorkomen gedurende 24 uur. Er is geen dagelijks patroon waargenomen. Een literatuur onderzoek werd verricht naar het management plan van de Stellwagen Bank en de Dominicaanse Republiek. Dit onderzoek heeft aangetoond hoe er het best gemanaged kan worden. Beide plannen namen dezelfde gevaren voor bultruggen in acht. Deze gevaren zijn geluid overlast, visserij en walvis toerisme. De Dominicaanse Republiek nam daarnaast ook klimaat verandering mee als potentieel gevaar. Deze aspecten kunnen gebruikt worden voor het creëren van het Yarari beheersplan. PAM is een bruikbare manier voor lange termijn monitoring van Bultruggen en het monitoren van de implementatie en het succes van het management plan.

Abbreviations and acronyms

AMAR	Autonomous Multichannel Acoustic Recorders
BES islands	Bijzondere Eiland Status (Special Island status (Bonaire, St Eustatius and Saba))
EEZ	Exclusive Economic Zone
PAM	Passive Acoustic Monitoring
SBMU	Saba Bank Management Unit
WCR	Wider Caribbean Region

Contents

1. Introduction

Humpback whale conservation

The humpback whales *(Megaptera novaeangliae)* were one of the first target species of the whaling industry. The populations depleted very rapidly, until the whaling ban in 1955 in the North Atlantic Ocean (Stevick et al., 2003). It remained an endangered species in the years after the ban, therefor in 1973, humpback whales were enlisted as an endangered species under the United States Endangered species act (Stevick et al., 2003). After decades of being hunted, the populations have shown recovery signs in the recent years. In September 2016 the humpback whales were delisted as an endangered species from the endangered species act of the United States (Heenehan & Stanistreet, 2017). This might affect the humpback population occurring in the Caribbean Sea as they migrate from US waters. In 2008 the IUCN red list noted them as least concern, based on the studies that have been done in various regions. These claims that the populations of humpback whales are healthy, are based on research done in the Dominican Republic, Hawaii and Australia (Ruegg et al., 2013). However, new dangers are rising, to marine mammals in general, such as anthropogenic noise. Concerns towards the effects of anthropogenic sounds on marine mammals are growing and there is a need for regulations limiting man-made sounds (Au et al., 2006). Possible effects of anthropogenic noise are: short- or long-term hearing damage, disruption of behaviour (e.g. feeding, mating and communication) and even lethal injuries (Risch, Corkeron, Ellison & Van Parijs, 2012). In order to study the effects of these new dangers on whales, knowledge is needed on the populations and behaviours in the present (Blair, Merchant, Friedlaender, Wiley & Parks, 2016; Lambert et al., 2011). Furthermore, in order to ensure the protection of the species, it is important to also protect their habitats (feeding, breeding and migration routes) (Debrot, Witte, Scheidat & Lucke, 2011).

Humpback whale monitoring

The monitoring of whales helps to keep track of abundance, distribution, (seasonal) occurrence, migration routes and behaviour. There are different ways to monitor these parameters. One traditional method is to conduct sighting surveys using vessels or aircrafts along pre-determined transects (Buckland et al., 2001). During sighting surveys only a fraction of animals are detected, because, even when visible, the whales can only be observed when they are close to or at the surface, and because observers might miss animals. The surveys can only be undertaken during daytime and when the weather is good. The results will be a fraction of the distribution and abundance of animals in one moment in time for a specific area. This means results can have a high variation between times if animals change their distribution. This is especially true for surveys that cover only a part of a population (Mellinger, Stafford, Moore, Dziak & Matsumoto, 2007).

Another technique is the so-called Passive Acoustic Monitoring (PAM). PAM is a technique which uses hydrophones to continuously record the vocalizations of whales. The hydrophones can either be fixed on a mooring, deployed from land or be towed from a ship. With mobile hydrophones towed behind vessels, larger areas can be surveyed. Whereas fixed hydrophones can stay moored in one place and keep recording for months at a time. This allows for the collection of much more detailed data on whale occurrence over time, compared to traditional sighting surveys. However, the downside of most PAM systems is that the data is only available after the retrieval of the hydrophone and it comes with a lot of data in one time, which takes substantial time to analyse. With the use of PAM it is possible to study the temporal occurrence of whales and their diel pattern. When an array of hydrophones is deployed it is also possible to determine the distribution of the whales (Baumgartner & Mussoline,

2011; Mellinger et al., 2007; Stimpert, Au, Parks, Hurst & Wiley, 2011). However, determining population sizes has so far only been done rarely (SAMBAH, 2016).

Vocalizations are of vital importance for humpback whales, and mostly happen in the winter during the breeding season to attract mates (Clapham, 2000; Helweg, Frankel & Mobley, 1992). The frequencies of humpback whale vocalizations are in a range between 30 through 5000Hz (Debich et al., 2013; Dunlop, Noad, Cato & Stokes, 2007). Humpback whales produce a variety of vocalizations, which can be divided into two categories, songs and social sounds. Songs exist of continuous repeated rhythmic patterns that can have a duration up to 30 minutes. Social sounds are sounds that have no pattern and are associated with social interaction and feeding. Male and female humpback whales are known to produce vocalizations in both winter and summer. The vocalizations differ per region and ocean basin (Björnsson, 2014; Dunlop et al., 2007; Fournet, Matthews, Gabriele, Mellinger & Klinck, 2018; Mercado, 2016; Parsons, Wright & Gore, 2008). Because humpback whales use vocalizations throughout the year, PAM is an useful technique to monitor the seasonal occurrence and distribution of the humpback whales.

Humpback whales of the Caribbean

The Wider Caribbean Region (WCR) is an important area for many marine mammal species that occur in the region including g the humpback whale. Humpback whales use the region primary as a habitat for mating and calving, which is a very important habitat for the preservation of the species (Darling, 2001; Parsons et al., 2008). But relatively little is known about the actual distribution and behaviour in the region. Most current information on marine mammals in the Dutch Caribbean comes from opportunistic sightings and strandings (A O Debrot, Tamis, De Haan, Scheidat & Van Der Wal, 2017; A O Debrot, Witte & Scheidat, 2011; Adolphe O. Debrot, Esteban, Bervoets, Hoetjes & Scheidat, 2013).

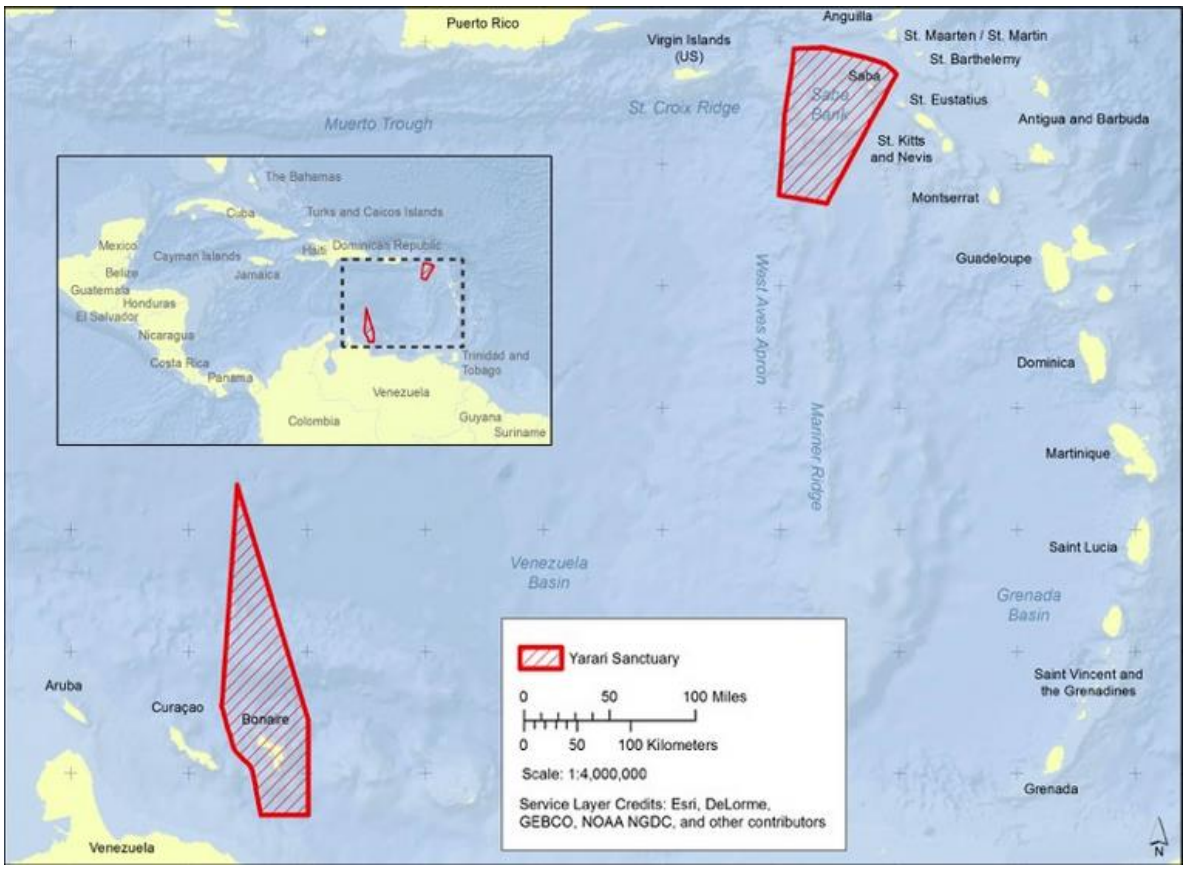

Figure 1 Map of the Yarari Sanctuary Debrot et al. 2017

This is also the case in the Yarari Marine Mammal and Shark Sanctuary, and especially around the leeward islands of Saba, St. Eustatius and St. Maarten.

The Yarari Sanctuary was established in September 2015, it is composed of two sectors. One sector surrounds Saba and the Saba Bank and the other sector covers the EEZ of Bonaire (figure 1) (A.O. Debrot et al., 2017; State Secretary of Economic Affairs, 2015). In September 2018 it was announced that the EEZ of St. Eustatius is also a part of Yarari. The aim of the Yarari Sanctuary is to protect all marine mammals and sharks within the sanctuary and to keep monitoring the marine mammals and sharks and do research on their occurrence, abundance and distribution (A O Debrot, Witte & Scheidat, 2011).

In October 2010 the Islands of Bonaire, St. Eustastius and Saba (BES islands) became special municipalities or public entities of the kingdom of the Netherlands. Unlike the municipalities in the Netherlands BES are not part of a province, therefore legislation which is normally exercised by provincial councils are now exercised by the Island Governments and the National Governments via the National Office for the Caribbean Netherlands (figure 2). Thus the Caribbean Netherlands has its own laws and regulations which are stated within the BES-law (Ministry of Economic Affairs, 2013).

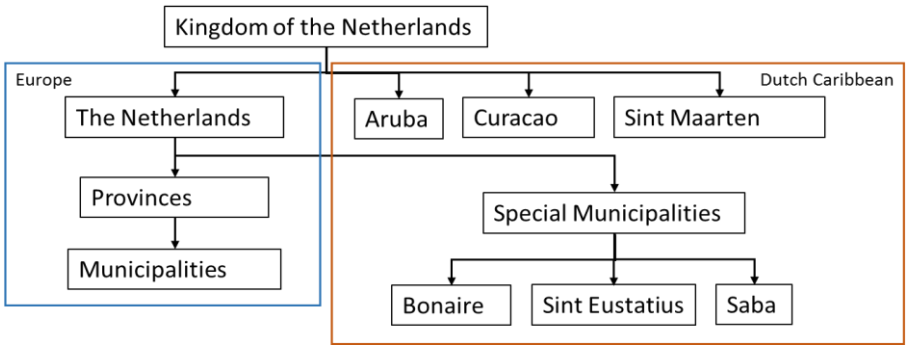

FIGURE 3 KINGDOM OF THE NETHERLANDS GRAPH

This study will focus on the Saba Bank part of the Yarari Sanctuary. The Saba Bank is protected by a Ministerial Decree based on the National act Nature Conservation framework BES. The Saba Bank Management unit was setup in 2012 by the Saba conservation foundation (Hoetjes & Wulf, 2012).

Besides the study discussed in this thesis, there was one other acoustic study (2016 to 2017) to investigate humpback whales in the Caribbean; the Caribbean Humpback Acoustic Monitoring Programme (CHAMP). This programme was setup after the delisting of the humpback whales from the US Engendered Species Act in 2016. This study is a collaboration between researchers, NGO's, governmental officials and others from Aruba, Bonaire, The Dominican Republic, Guadeloupe Martinique, Saint Martin and the United States (figure 3) (Heenehan & Stanistreet, 2017). The Netherlands was not officially part of this collaboration, and thus there was no consideration of the data need for the Yarari Sanctuary.

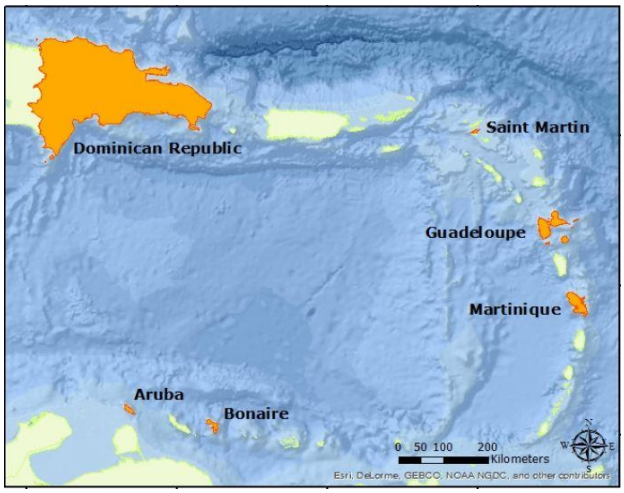

FIGURE 2 CHAMP COLLABORATION ALL COUNTRIES AND ISLANDS OF THE CHAMP COLLABORATION. (NOAA, 2018)

Humpback whales are frequently spotted around the windward Dutch Islands. To protect the habitat of the marine mammals of the Caribbean several countries surrounding the Dutch Caribbean have created sanctuaries. Most of these sanctuaries have signed the Sister Sanctuary agreement with NOAA. The Sister Sanctuary Program was first set up by NOAA and the Dominican Republic in 2007 (NOAA, 2011b). In May 2017 the Dutch Government signed a Sister Sanctuary agreement with NOAA for the Yarari Sanctuary. This means that the Yarai Sanctuary is now part of the Sister Sanctuary Program, which includes the Stellwagen Bank National Marine Sanctuary, the Marine Mammal Sanctuary of the Dominican Republic (Santuario de Mamíferos Marinos de la República Dominicana) and the French Antilles Agoa Marine Mammal Sanctuary (NOAA, 2011b, 2017). This makes the Yarari Sanctuary a valuable potential contribution toward the protection of marine mammals (Adolphe O. Debrot et al., 2013; NOAA, 2011b). Through the Sister sanctuary program it's possible to protect marine mammals and thus create the marine mammal protected areas network for the WCR (Wider Caribbean Region).

This study will use existing fixed PAM data from two locations on the Saba Bank, which was recorded from 2015 through 2018 to determine the occurrence of humpback whales in the Yarari Sanctuary. The data will be analysed on the occurrence per month and a further analysis on the diel pattern of the vocalization detected will be executed. This will be done to see if the humpback whales have a preference of time in the day put also a preference of season when the occur on the Saba Bank. Through knowledge on when and where humpback whales are most likely to occur, an advice can be provided on how management measures could perhaps be adjusted for improvement.

1.1. Problem description

With anthropogenic noise rising as a new potential danger for humpback whales (Hatch, Gontz, Clark & Wiley, 2006), more knowledge on the occurrence of humpback whales is needed. However, until recently occurrence information on humpback whales on and round Saba and the Saba Bank came from opportunistic sightings and interviews with local fishermans only. One of the main problems of monitoring cetaceans in the wild being that they spend long periods of time underwater and thus out of sight of observers. Another problem being that working at sea on vessels is generally expensive and highly dependent on good weather windows. PAM provides an opportunity to monitor cetaceans for longer periods in time. This could give more insights into which months and even during which time of day humpback whales occur. PAM monitoring can provide vital information needed for effective management, like:

- Long-term data allows the comparison of baselines (e.g. prior to change in the environment or changes of human use).
- Information on when animals use an area (occurrence) can be used to avoid potential negative human impacts. (e.g. planning of activities that produce noise; entanglement due to fisheries, shipping routes).
- Data on diel patterns in habitat use can highlight times of high vulnerability to noise activities, e.g. songs occur in a reproduction context and are thus an indicator for times that noise production should be avoided.

This data can lead to the improvement of management of the Yarari Sanctuary. But how can this information lead into management improvement? How does it happen in other marine protected areas? What could the possible improvements be? The results from this study will aim to inform the policy makers on the applicability of PAM as a long-term monitoring tool. It will also highlight the kind of information that can be gathered that can help inform decisions on management plans and risk

assessments. Two important variables within this study are occurrence and the diel pattern. Occurrence data will give insight into when humpback whales are present in the area. Diel pattern gives information on when humpback whales are vocally active in the area.

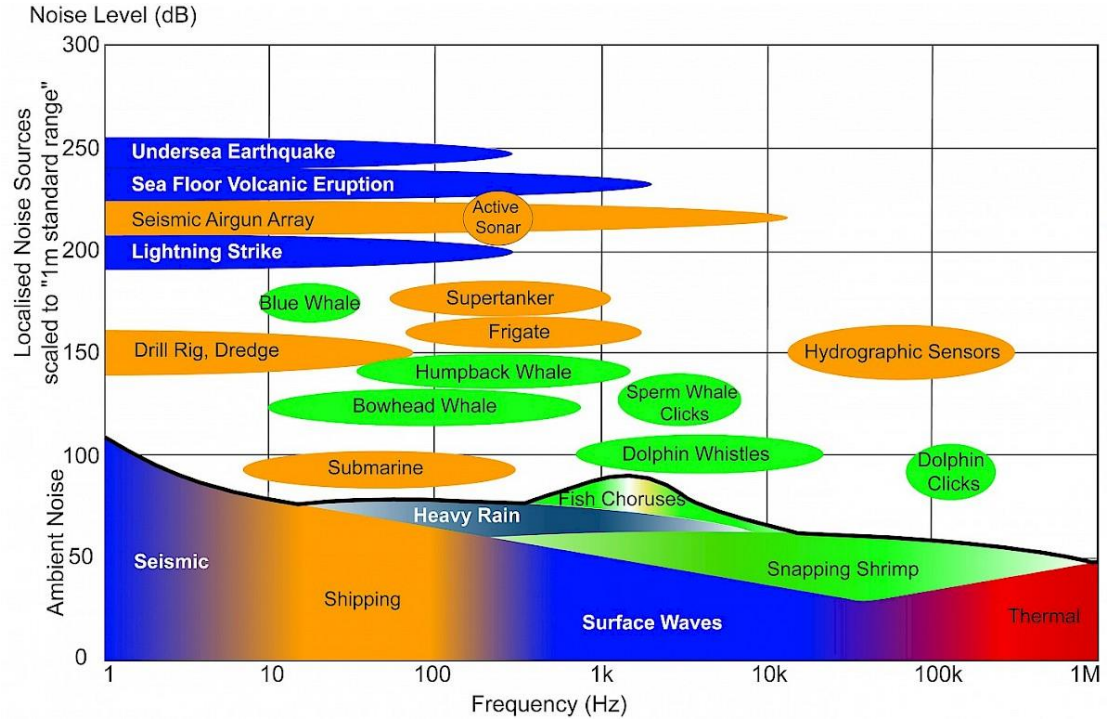

Figure 4 Frequency and decibel levels of various sounds in the marine environment (OSPAR Commission, 2019)

Figure 4 gives an illustration of various anthropogenic, natural and ambient sounds in the marine ecosystem and how these sounds overlap. There is a variety of sound underwater from various sources, there are natural sounds like rain, waves, wind, earthquakes and marine life (e.g. marine mammals and fish). Anthropogenic sources are human induced sounds like shipping, seismic research. Ambient noise are the sounds which can be heard as background noise, these sounds can consists of waves, rain, distant shipping and shrimp. Humpback whale vocalizations fall in the same range as various anthropogenic noise sources and some of these could mask the songs and social vocalization which are important to communicate with other whales. Effects of anthropogenic noise on whales are various and depend on the closeness of the sounds in contrast with the whales(Boyd et al., 2008; Hildebrand, 2004). Examples of these effects are hearing damage (short- /long-term), disruption of behaviour (e.g. feeding, mating and communication) and lethal injuries (Risch et al., 2012). The sources of the sounds do not need to be close to the humpback whale to have an impact as low frequencies propagate further through the water column then high frequencies (Frankel, 2018).

1.2. Aim

This study will inform the policy makers/managers on the applicability of PAM as a long-term monitoring tool at the Saba Bank, as well as within the Yarari Sanctuary in general. It will also provide an overview of how the data gathered can help inform decisions on the development of management plans.

1.3. Research question

Can the management of humpback whales in the Yarari Sanctuary be improved, when using Passive Acoustic Monitoring data, from the Saba Bank, using PAM as a source of information on humpback whale habitat use and behaviour in the local area? If so how can the data contribute to the management of the Yarari Sanctuary?

Sub questions

To answer the main question sub questions have been set up

1. What is the (seasonal and diel) occurrence of humpback whales round the Saba Bank?
2. How could monitoring data improve the Yarari Sanctuary management?

1.4. Readers guide

In the second chapter the materials and methods are described. This chapter is divided into two sections, one focuses on the data collection and analysis of the humpback whale occurrence data the second part focuses on the data collection and the analysis of using monitoring data to improve management. The third chapter shows the results that were found, this chapter is also divided into two sections. Again one for the humpback whales occurrence results and on the results from the literature study. The section on literature study firstly talks of the Saba Bank management, followed by Dominican Republic marine mammal management and lastly by the Stellwagen Bank National Marine Sanctuary management. The fourth chapter is the discussion, it starts with an discussion on the methods during this thesis, followed by the data selection. After the section on data selection, the discussion focuses on the PAM data and the hypothesis. The discussion then goes on to management, which focuses on the results found, but also on what makes good management for marine mammals. The fifth and final chapter is the conclusion/ recommendation, this chapter answer the main question and gives an overview on how PAM can provide information to managers.

2. Materials and methods

2.1. Humpback whale occurrence data

2.1.1. Data collection

This study looked into PAM data recorded with the two Autonomous Multichannel Acoustic Recorders (AMAR). These acoustical loggers were placed on two different locations on the Saba Bank from 2015 through 2018 (figure 4). AMAR276 was placed at a depth of 33m and AMAR 274 was placed at a depth of 15m. These acoustical AMAR loggers recorded continuously 24 hours a day, 7 days a week for 4 to 5 months. The bandwidth of the AMAR logger was 10Hz – 24 kHz with a resolution of 24 bits. These locations were chosen because these location were easy to reach from Saba and they are not too deep and difficult to reach for the divers that place the acoustical recorders.

FIGURE 5 AMAR LOCATION ©B. NOORT

Before the analysis of the data could begin, a review of the data base was necessary. This was needed to check if all the data exist and no errors occurred during recoding. Another reason was to see the extent of the data, to allow a guess on how much data could be analysed in two months. All the available months and years of data recorded are presented in table 1. Because of a difference within the deployments of the loggers, this research was focussed on the data with the longest continuation of recordings. Which is from December 2016 till October 2017. The plan for the analysis was to firstly go through all of the AMAR 276 data and then do the AMAR 274 data. However, due to time constraints there was only time to analyse AMAR 276.

TABLE 1 AVAILABLE AND ANALYSED DATA FROM AMAR 276. THIS TABLE SHOWS WHAT TYPE OF ANALYSIS WAS DONE WITH THE AVAILABLE DATA IN THAT WEEK.

Months	Week	Type of analysis	
		Occurrence	Diel pattern
December 2016	28-11 / 04-12		
	05-12 / 12-12		
	13-12 / 19-12		
	20-12 / 26-12		
	27-12 / 01-01		
January 2017	02-01 / 08-01		
	09-01 / 15-01		
	16-01 / 22-01		
	23-01 / 29-01		
February 2017	30-01 / 05-02		
	06-02 / 12-02		
	13-02 / 19-02		
	20-02 / 26-02		
March 2017	27-02 / 05-03		
	06-03 / 12-03		
	13-03 / 19-03		
	20-03 / 26-03		
	27-03 / 02-04		
April 2017	03-04 / 09-04		
	10-04 / 16-04		
	17-04 / 23-04		
	24-04 / 30-04		

2.1.2. Analysis

Different researches aimed at the analysis of marine mammal vocalisations have used different software. Heenehan & Stanistreet 2017 used Raven Pro to view spectrograms of the data between frequency ranges of 0-600 Hz. They also used the Low Frequency detection and Classification system (LFDCS) to identify hours with high number of detections of humpback whale song for some days. Baumgartner & Mussoline, (2011) described and tested the LFDCS. Debich et al., (2013) used a computer algorithm based on the generalized power law detector as described from Helble, Ierley, D'Spain, Roch & Hildebrand, (2012). It is also possible to use the Raven Pro batch detector to detect humpback whale vocalizations (Charif, Waack & Strickman, 2010). However, because the vocalizations of the humpback whales differ per region, automated detectors need to be adjusted per case. Since that would take a lot of time it was decided to do the detections manually.

The data from AMAR 276 has been analysed for the months of December(2016) until April (2017) to monthly occurrence, diel pattern (3 weeks) (Table 1). Raven Pro 1.5 (Bioacoustics Research Program) was used for the analysis of the data, this was done manually. The reason for using Raven Pro is because, Wageningen Marine Research has this software available and it is relatively simple to learn to use in a short amount of time. This software shows the recordings in spectrograms as seen in figure 6. By looking at spectrograms the analyst did not have to listen to every minute, instead can scroll through the spectrograms in search of patterns that are characteristic for humpback whale vocalizations. The files of each day (24 hours) were analysed in spectrograms showing 30 minutes of data, a day existed of 48 files. Firstly all days were analysed on vocalization presence, when a vocalization was detected this meant a presence for that day. Therefor the results of the monthly occurrence is based on 1 detection per day. A total of 151 days were analysed on humpback whale vocalization presence. When a characteristic humpback pattern was detected, the pattern was listened too, to confirm if it was indeed a humpback whale. When a humpback whale vocalization was detected and confirmed, the date and the time of the file are noted in an excel file. Secondly, when all the data was analysed, three weeks were chosen, based on the monthly occurrence, to be analysed for a diel pattern. All hours of these weeks were analysed and when a detection was made this means at least one humpback whales was present in this hour. With all the detections noted in the excel file, graphs were made for the seasonal occurrence and the diurnal pattern. Only one observer went through the data, for the consistency (Fournet, Matthews, Gabriele, Mellinger & Klinck, 2018). The results of the analysis were compared with existing knowledge of humpback whale sightings and the previous pilot study in order to see if there were either more detections and if the detections are in similar seasons.

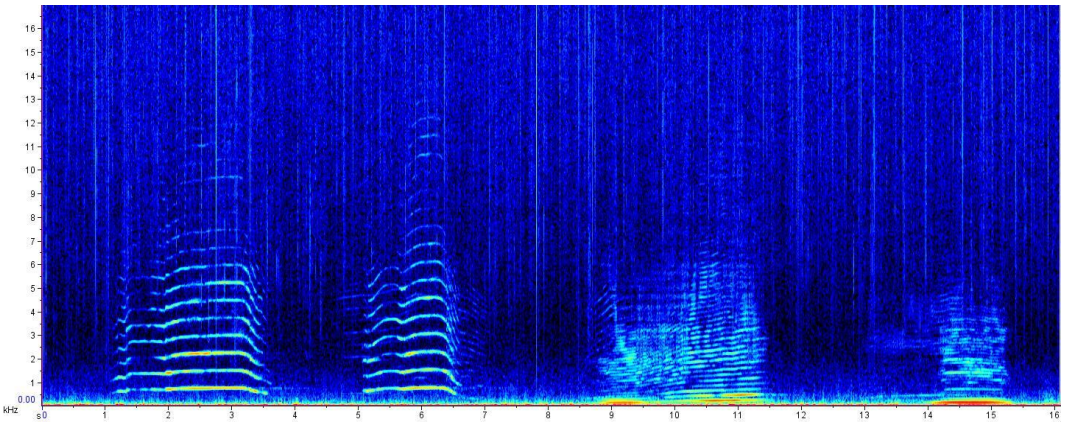

FIGURE 6 SPECTROGRAM EXAMPLE OF HUMPBACK WHALE VOCALISATION

2.2. Using monitoring data to improve management.

2.2.1. Data collection

In order to assess whether acoustical data can help in the implementation of marine park management, a literature study was done. This literature study used internet to search for papers, management plans and information on various marine parks and their use of PAM. Google Scholar was used to find the research papers and google was used to find the websites of marine parks/sanctuaries. When more knowledge was required for example when papers of websites did not provide with enough information or when further questions occurred, contact was made with marine park management researchers and other researchers to gather more specific information.

2.2.2. Analysis

This literature study focusses on several components, in order to answer the second sub question on how the management could be improved.

- What is the current management and it's measures for the Yarari Sanctuary?
- What are the human uses and threats to marine mammals?
- How could acoustical data improve management?
- What could be appropriate improvement of management measures within the sanctuary?

The current management situation surrounding the Saba Bank was assessed and the management plan of the Stellwagen bank and the Dominican republic. This literature/case study focussed on the Stellwagen Bank National Marine Sanctuary. This Sanctuary was chosen because it's a marine sanctuary since 1989. This marine sanctuary provides much information on how to manage a marine mammal sanctuary, what measures are taken, what is important for the protection of marine mammals. Another reason is that the Caribbean are the breeding grounds for the humpback whale population of the Stellwagen Bank.

Besides the Stellwagen Bank management plan this study also looked into the management plan of the Marine Mammal Sanctuary of the Dominican Republic, this sanctuary is also in the Caribbean. It is likely that humpback whales that occur in the Yarari also use this area. Furthermore a case-study was conducted to see how the Stellwagen marine national park and the Dominican republic national marine mammal sanctuary use acoustic- and survey-data to improve their management. And what management measures did they use based on the acoustic- and survey-data.
The combination of the literature study and the case-study, was used to feed into a discussion of appropriate ways to improve the management and which measures could be useful for the humpback whales in the Yarari Sanctuary, and in particular if PAM data proves useful within the sanctuary. This was done by making a mind map of the Stellwagen Bank management plan to gather the information that was needed to answer the sub-question.

3. Results

3.1. Humpback whale occurrence

3.1.1. Monthly occurrence

Figure 7 shows the occurrence percentage of detections in the months of Decembers till April. There were no detections in December, from mid-January the detections started and increased to a coverage of 52%. With a 100% February has detections every day throughout the month and 90% of March had detections. April showed a reduction in detections to 60%. The detection through these months can be seen as a bell shape were humpback vocalization detections increase in January and decrease in April. This indicates a constant presence of humpback whales in the surroundings of the Saba Bank from January till April.

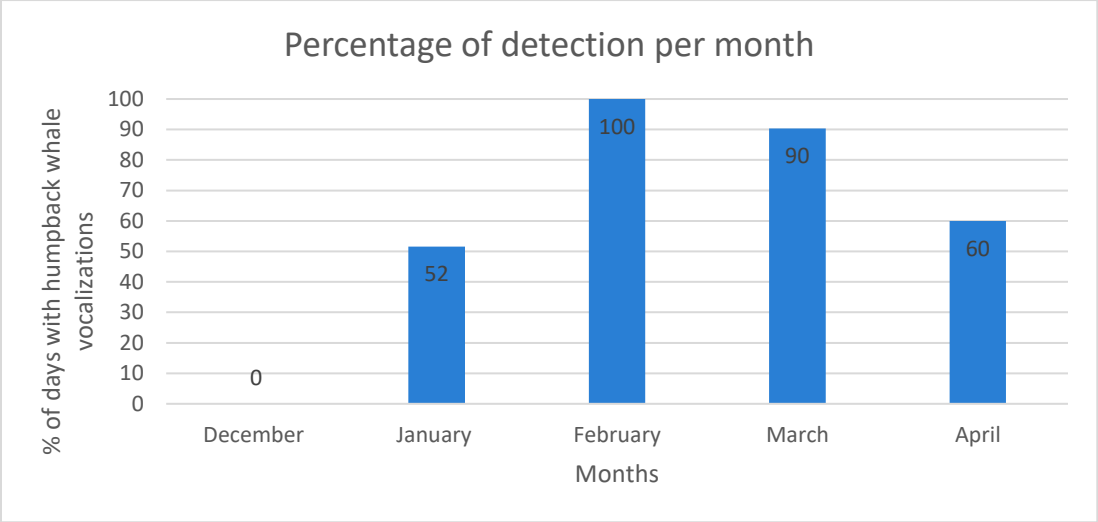

FIGURE 7 PERCENTAGE OF POSITIVE DAILY VOCALIZATION PRESENCE PER MONTH.

3.1.2. Diel pattern

For the three week sample period 16-22 January, 06-12 March and 24-30 April the diel pattern was analysed (table 2). This analysis does not suggest a diel pattern, there is no clear evidence that humpback whales vocalize more during the day or night. In the first 4 days of January the vocalizations are sparse but are detected during the day and night. The last 3 days of January show vocalizations during almost every hour. The near constant (day/night) vocalizations can also be seen during the entire week in March. The week in April only has vocalization during 2 days, on the 25th of April the vocalizations occur mostly during night time, while the detections on the 28th of April are mostly during daytime.

TABLE 2 DIEL PATTERN OF HUMPBACK WHALES RECORDED. THE TIMES COLOURED IN ORANGE PRESENT DAY TIME AND THE BLUE COLOURS PRESENT NIGHT TIME. THE GREEN BLOCKS ARE THE HOURS WITH POSITIVE DETECTIONS.

Date / Hour	16-Jan	17-Jan	18-Jan	19-Jan	20-Jan	21-Jan	22-Jan	06-Mar	07-Mar	08-Mar	09-Mar	10-Mar	11-Mar	12-Mar	24-Apr	25-Apr	26-Apr	27-Apr	28-Apr	29-Apr	30-Apr
0:00	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
1:00	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
2:00	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
3:00	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
4:00	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
5:00	0	0	0	0	1	1	1	1	1	1	0	1	1	1	0	0	0	0	1	0	0
6:00	0	1	1	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
7:00	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
8:00	0	0	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
9:00	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
10:00	0	1	0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
11:00	0	1	0	0	1	0	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
12:00	0	1	0	0	1	0	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0
13:00	0	0	0	0	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
14:00	0	1	0	0	1	1	0	1	1	1	1	1	1	1	0	0	0	0	0	0	0
15:00	0	1	0	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
16:00	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0
17:00	0	0	0	0	0	1	1	1	1	0	1	1	1	1	0	1	0	0	0	0	0
18:00	0	0	0	0	0	1	1	1	1	0	1	1	1	1	0	1	0	0	0	0	0
19:00	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	1	0	0	0	0	0
20:00	1	0	0	1	0	1	1	1	1	1	1	0	1	1	0	1	0	0	0	0	0
21:00	1	0	0	0	0	1	1	1	1	1	1	0	1	1	0	1	0	0	1	0	0
22:00	1	0	0	1	0	1	1	1	1	1	1	1	1	1	0	1	0	0	1	0	0
23:00	1	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	1	0	0

3.2. Management

3.2.1. Current Management Saba Bank (Yarari)

There is no management plan for the Yarari Sanctuary as yet, it is still in development. In the meantime the Saba Bank Management unit governance model is used to manage Yarari (A.O. Debrot et al., 2017). The management plan of the Saba Bank Special Marine area(2008) does not include any management regarding marine mammals.

Human uses and threats Saba Bank

The Saba Bank is used for fisheries, tourism (fishing, diving) and for maritime transport as well as an anchorage. All these human uses have different potential effects on humpback whales. Fisheries within the Dutch Caribbean EEZ are regulated under the BES fisheries law, 2014. This law does prohibit to catch marine mammals, the use of marine mammals as bait and the use of gillnets longer than 2.5km. This means that certain fisheries that impact cetaceans such as longlines, tuna purse seines and drifting gill nets are poorly regulated (A.O. Debrot et al., 2017; Lundvall, 2008). The main cause for human influenced mortality of marine mammals world-wide are entanglement and bycatch (Reeves, McClellan & Werner, 2013). Marine debris and contaminants are a cause as well, cetaceans could ingest marine debris such as plastic, metal, glass and lost fishing gear. Contamination includes sewage, industrial discharges, as well as waste from ships and oil spills. The effects of ingesting marine debris and contaminants could be lethal or indirect lethal (A.O. Debrot et al., 2017). Another cause for injury or mortality is vessel strikes, it is likely that vessel strikes in the Caribbean region are underreported (A.O. Debrot et al., 2017). A relative newer concern for marine mammals is climate change, for the Dutch Caribbean this means the increase of air and sea surface temperature, increase of sea level and ocean acidity and an increase in frequency and the intensity of storms and hurricanes. There are three suspected responses of marine mammals to climate change: redistribute to avoid changes, adapt to changes, go extinct (A.O. Debrot & Bugter, 2010; IWC, 2010). Disturbance of behaviour can be caused by various sources, like noise and whale watching. The main sources of anthropogenic noise in the Caribbean comes from shipping, naval sonars and seismic surveys. These behavioural disturbances can cause increase of speed, changing from resting to travelling and displacement (leaving habitat) (A.O. Debrot et al., 2017). Figure 8 shows the potential different threats to humpback whales by humans in the Saba Bank.

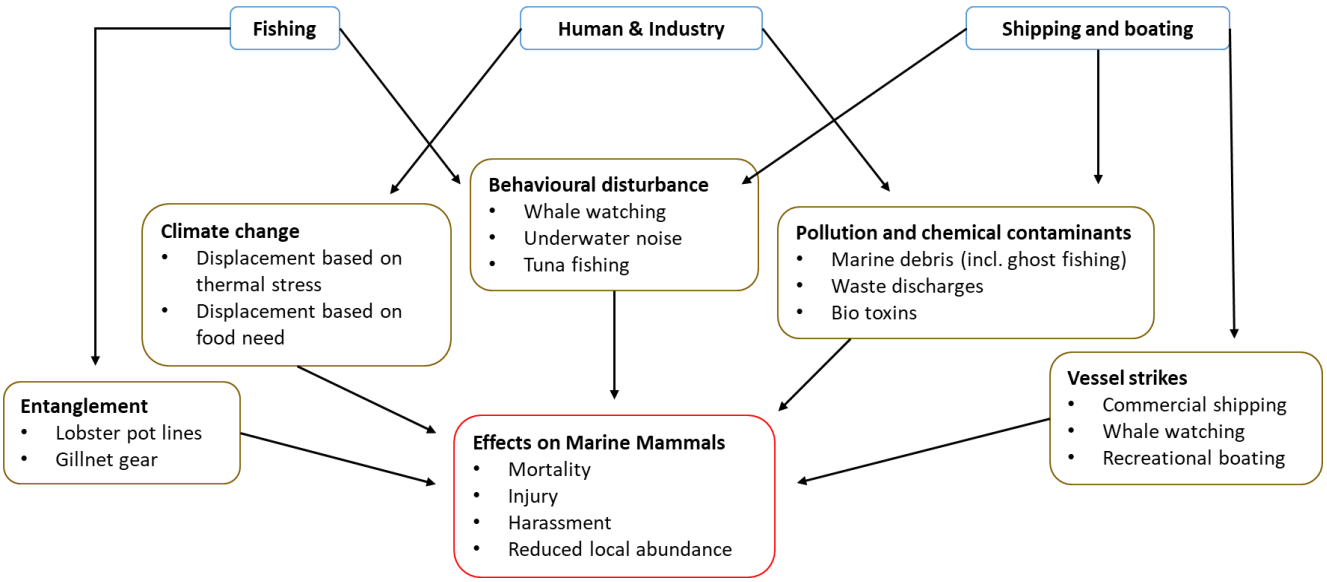

FIGURE 8 POTENTIAL EFFECTS OF HUMAN ACTIVITIES IN THE SABA BANK ON MARINE MAMMALS

3.2.2. The Stellwagen Bank National Marine Sanctuary, USA

The Stellwagen Bank Sanctuary is located (figure 9) in the Gulf of Maine at the north east coast of the USA, the bank stretches from Cape Ann and Cape Cod at the mouth of Massachusetts Bay. Boston and Gloucester are two important ports that lay at the Gulf of Maine. Both ports are important for import and export of products, this brings large ships like tanker ships, container ships and gas carriers. Besides the various types of vessels that pass the Gulf of Maine there are other threats to marine mammals caused by human activities. Such as fishing, whale watching, entanglement and marine pollution. Figure 10 shows the potential different threats to humpback whales in the Stellwagen Bank (NOAA, 2010).

FIGURE 9 LOCATION OF THE STELLWAGEN BANK NATIONAL MARINE SANCTUARY (BOSTONIA, 2008)

The Stellwagen Bank National Marine Sanctuary uses marine passive acoustical monitoring for various applications and researches. There are acoustic detection monitoring programs focused on vocally active species (e.g. fish, marine mammals), assessment of noise impacts and underwater sound propagation modelling to inform biological observation and mapping of human induced impacts. The management plan considers acoustic masking from anthropogenic noise as a threat to marine mammals, especially low-frequency specialists like humpback whales. In 2007 a multi-year passive acoustic project started which focusses on evaluating potential impacts of chronic low-frequency noise on whale communication and behaviour. These researches are done by the Northeast Fisheries science centre and Cornell University's Bioacoustics Research Programs by installing an array of hydrophones which continuously record all low-frequency (10 to 1000HZ)(Hatch et al., 2006; Lucke, Geelhoed, Scheidat, & Debrot, 2014).

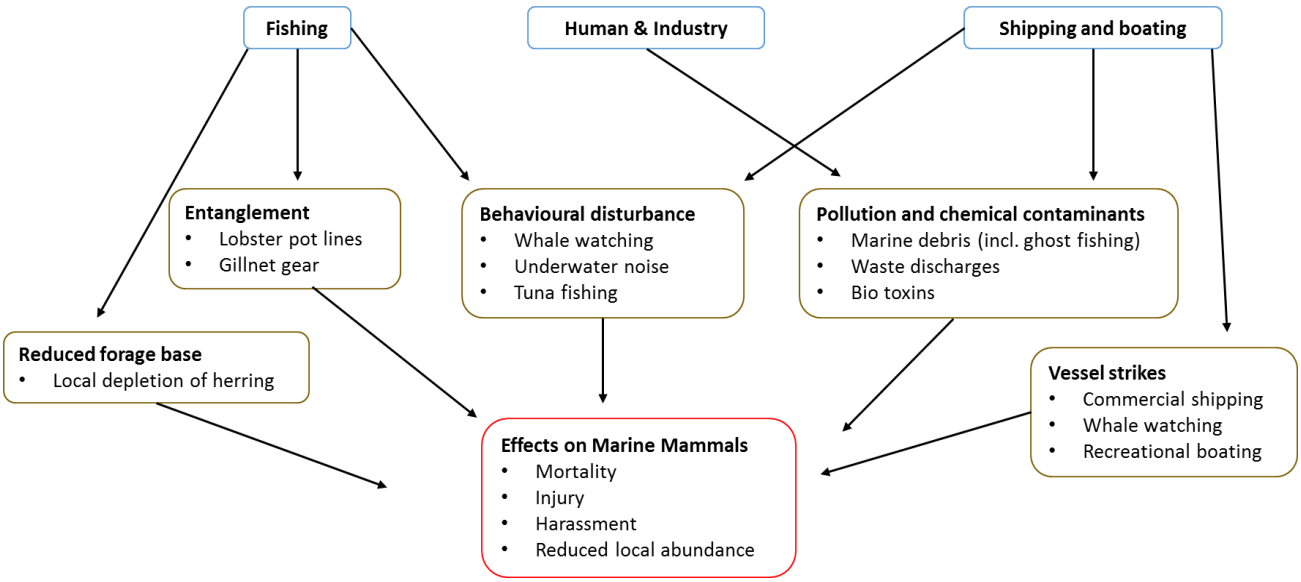

FIGURE 10 POTENTIAL EFFECTS OF HUMAN ACTIVITIES IN THE STELLWAGEN BANK ON MARINE MAMMALS

Marine mammal specific management

In order to protect marine mammals in the Stellwagen Bank marine sanctuary three action plans are described in the Management plan of the Stellwagen Bank marine sanctuary(NOAA, 2010).

- Marine mammal behavioural disturbance action plan
- Marine mammal vessel strike action plan
- Marine mammal entanglement action plan

Each of these action plans have been separated in several objectives. These objectives exists out of different strategies on how to tackle the objective. All of these objectives are relevant for this study. The first objective use acoustic monitoring.

Marine Mammal Behavioural Disturbance Action Plan

The Marine mammal behavioural disturbance action plan looks into ways to reduce the risk of behavioural disturbance and harassment of marine mammals with the following human activities: Whale watching, tuna fishing, noise pollution and aircrafts. There are three objectives:

1. Reduce marine mammal behavioural disturbance and harassment by vessels.
2. Reduce marine mammal behavioural disturbance and harassment by noise
3. Reduce marine mammal behavioural disturbance and harassment by aircraft

The desired outcomes of this action plan are that by 2011, implemented a noise-monitoring program covering 50-85% of the sanctuary. Ten Automatic Recording Units (ARU's) will be deployed for at least 12 months. Furthermore by 2012, a whale watching management program has been developed and implemented that reduces the risk of behavioural harassment. And by 2013 most fieldwork and analyses will be completed. The data analyses will provide a continuous record and understanding of whale behaviour to vessels and noise.

Marine Mammal Behavioural Vessel Strike Action Plan

The Marine Mammal Vessel strike action plan looks into way to reduce vessel and marine mammal collisions. Vessel strikes have been known to cause injury and mortality to whales and cause damage to vessels. This action plan is divided in three objectives:

1. Reduce risk of vessel strikes between large commercial ships and whales
2. Reduce the risk of vessel strike through speed restriction on vessels
3. Support and develop research programs to reduce the risk of vessel strike

The desired outcomes of this action plan are that all large ships (>300ton) will be monitored while crossing the sanctuary, including their location, speed and time. New routes will be proposed for large ships to reduce the risk of ship strikes with whales with 50%. Speed restrictions will be put in place.

Marine Mammal Entanglement Action Plan

The marine mammal entanglement action plan looks into way to reduce the risk of entanglement of marine mammals, sea turtles and sea birds in fishing gear. Entanglement can have immediate effects including mortality and injuries, however entanglement can also have a long-term effects including deteriorating health, behavioural disruptions or decreased reproductive abilities. This action plan is divided in three objectives:

1. Aid disentanglement efforts
2. Reduce marine mammal interaction with the trap/plot fisheries

3. Reduce marine mammal interaction with the gillnet fisheries.

The desired outcomes of this action plan that by 2012, 85% of detected entangles whales will have vessels or aircraft standing by until a disentanglement team arrives. The vessel or aircraft will keep track of the whale. Furthermore by 2012 all fixed fishing gear of fisherman that are being used in the sanctuary, will have to be gear that minimizes entanglement risk with marine mammals.

3.2.3. The Marine Mammal Sanctuary of the Dominican Republic

FIGURE 11 LOCATION OF THE MARINE MAMMAL SANCTUARY OF THE DOMINICAN REPUBLIC (ECO-HISPANIOLA, 2018)

The marine mammal sanctuary of the Dominican Republic was designated in October 1986 and expanded in 1996 to what it now is. The Sanctuary exists of the Banco de la Plata, Banco del Panuelo and the Banco de la Navidad, part of the Samana bay and the waters connecting these banks (figure 11). The sanctuary is believed to be a critical habitat for humpback whales especially from January till April. During these months the humpback whales use the area as a reproduction, mating and calving area. It is estimated that 85% of the North Atlantic humpback whale population use the sanctuary (UNESCO, 2018).

The main human activities in the sanctuary are fisheries and whale watching. The main threats to humpback whales in the sanctuary are entanglement in fishing nets (Fundacion Dominicana de estudios marinos, 2015).

The Marine Mammal Sanctuary of the Dominican Republic mainly uses PAM to acoustically map the noise and marine traffic within the sanctuary. Baseline information on occurrence in the sanctuary was done via photo-id and observers. Acoustic detection is used to monitor all noise in the sanctuary to gather baseline information on anthropogenic noise and the impacts they might have on marine mammals. Because of whale watching vessels and cruise ships, a concern arose to the impacts of the low frequency noises from these vessel, to the communication between whales. This concern lead to a project to analyse the low-frequency noise levels within important breeding habitats and the impacts on whales (Lucke et al., 2014).

Management plan Dominican Republic (Fundacion Dominicana de estudios marinos, 2015)

This management plan has five objectives which are considered important for effective management of the sanctuary.

1. Strengthen and promote an institutional, regulatory and legal framework in accordance with existing national and international guidelines
2. Develop, at a local and regional level, a sense of appropriation of the sanctuary, promoting a responsible behaviour of the users of its resources, managers and the general public
3. Reduce degradation and promote the recovery of the natural and the cultural resources of the sanctuary, promoting its sustainable use and compliance with national and international regulations
4. Use existing information and generate new data as a basis for the adaptive management of the sanctuary through research and monitoring projects
5. Ensure the availability of the financial resources required for the management of the sanctuary

Objective four is the most relevant objective regarding this study and uses acoustic monitoring. However, this objective is very broad, especially when looking at what they want to achieve with this objective. The priorities for the humpback whales are on

- Assessing their population status (abundance/density)
- Investigate the habitat use of whales
- Evaluate the impact of anthropogenic activities on whales
- Carry out a habitat preference and characterization studies as a basis for future marine spatial planning
- Create a baseline to monitor possible effects of climate change in the sanctuary
- Identify humpback whale movements via satellite tracking
- Acoustically map the sanctuary on anthropogenic noise
- Monitor the intensity of marine traffic in the Bay of Samana
- Gather information on fishing activities (number of vessels, fishing gear used, fishing effort)
- Monitor the water quality including on metals and toxic substances
- Study the socioeconomic impact of whale watching

The plan does not further indicate how the implementation is done.

4. Discussion

Method

The acoustical data set was analysed manually. Automatic detection is in principle possible using algorithms, but these have to be designed specifically in order for an automated detection to work. The manually detections done in this study can be used to create and test such an algorithm, allowing a future analyses to be faster. The focus during the manual detection was on vocalisations visible in the spectrogram and audible when listening to the files. It was not always straightforward to detect vocalisations, background noise like boats, natural sounds and anthropogenic sounds could mask the presence of the vocalisations. This also means that it might be possible that some of the vocalisations were missed. Swartz et al., (2003) found that when comparing visual and acoustic data some singing whales were accompanied by other humpback whales that were not vocalizing, indicating that the number of singing whales detected represents a minimum number of individuals. One can assume that the results presented in this thesis are a minimum estimate of humpback whale vocalisations. The literature study went relatively subtle, the management plan of the Stellwagen Bank provided a lot of information. The management plan of the Dominican Republic proved to be a little more difficult to read because it has only been published in Spanish. Via the use of google translate, it was possible to dissect the management plan and identify and analyse the important chapters and paragraphs for this study.

Data selection

When initially writing the research proposal it was considered possible to go through the 11 months available of the year 2016 in 2 to 3 months' time. However, it was quickly discovered that this was not feasible and after taking a closer look into the data set it was decided to stop at the end of April. This was done because there was a three week gap in the month May due to the retrieval of the hydrophone and redeployment of the hydrophone. As the results show that in the end of April there is still humpback whale presence, it would be interesting to see if this presence is still there in May and onwards.

Due to time constraints it was not possible to research the diel pattern during all of the 4 months. It was decided instead to do an in-depth diel pattern analysis of vocalization for three weeks. This sub-sample was selected using weeks with humpback whale vocalizations, spread out over the study period, the first week with detections in January, a week in March (middle of the weeks with presence) and the last week of April. With the data analysis taking a large amount of time, the available time to work on the literature study and case study was reduced. This is why the literature selected was focussed on review documents and management plans and less on primary research papers.

PAM data

The seasonal occurrence pattern that was observed during the analysis indicate that humpback whale vocalizations occur from mid-January till April. With most detections (near continuous) in February and March. Arrival in the Saba Bank would be expected, based on a previous study and opportunistic sightings, between February and in April (Risch & de Haan, 2016). However, humpback whales have been seen arriving at the breeding grounds of the Wider Caribbean Region in early January (Mattila, Clapham, Vásquez & Bowman, 1994). Most breeding grounds of the humpback whales are banks that are between 15 and 60 meters deep (Whitehead & Moore, 1982). Mother calf pairs are most commonly found at depths up to 20 meters (Betancourt, Herrera-Moreno & Beddall, 2012). The Saba Bank has an average depth between 20 and 30 meters (Wiltink, 2016), which can suggest that the Saba

Bank could be a suitable area for humpback whale mother calf pairs. To confirm if indeed mother calf pairs use the Saba Bank visual sightings are needed (Zoidis et al., 2008).

When humpback whales pass through the Saba Bank on their way to the breeding/feeding grounds, an increase in the occurrence of vocalizations in January and later in April would be expected. That would be consistent with animals moving through the area on their migratory routes to breeding grounds. However, the results of this study show that the highest number of vocalizations were detected in February and March, during the peak of the reproductive season. This indicates that the area around the Saba Bank is used as a breeding area and not as a migratory corridor. More research to other years is needed to see if this is a recurring phenomenon and if yes, if the same animals return to the Saba Bank. It is certain that the humpback whales occurring in the Caribbean come from the North Atlantic as has been confirmed by various photo id studies YoNAH (Years of the North Atlantic Humpbacks) and MoNAH (More North Atlantic Humpbacks)(NOAA, 2011a). YoNAH provided detailed information on the abundance, population structure and migratory movements of humpback whales in 1992 and 1993. MoNAH was in 2004 and 2005 focused on the humpback whale population of the Stellwagen Bank and the Silver Bank in the Dominican Republic (Clapham, 2000; NOAA, 2011a). With the peak of vocalization being during the reproductive season, it could indicate that humpback whales stay in the area of the Saba Bank, and could indicate that the Saba Bank also serves as a reproduction area.

Through other studies it was expected that humpback vocalizations would primarily occur at night, as this had been observed in other areas (Huang, Wang & Ratilal, et al., 2016; Kowarski et al., 2018; Lammers et al., 2005). However, this study into the diel pattern did not indicate that there was a difference between day and night activity. Because only three weeks were analysed for the diel pattern the results within this study cannot be seen as conclusive, and more research is needed to provide more certainty. During the week in March, at the height of the reproductive season, humpback whale vocalizations were detected around the clock. This shows first of all that humpback whales were acoustically active more or less continuously in the study area and could indicate that it has more importance than previously thought as a place where acoustic reproductive behaviour (song) is displayed and breeding takes place. Various researches have been done to investigate the diel patterns of humpback whales, one research found no impact of daylight on singing behaviour (Sousa-Lima & Clark, 2008). However, other researches have proposed that an increase of singing during the night could be used as a mating tactic, whereas during day time other mating tactics such as the forming of competitive groups is more preferable (Au, Mobley, Burgess, Lammers & Nachtigall, 2000). Sousa-Lima & Clark (2008) found that light is unimportant in explaining the diel pattern of humpback whale vocalizations, they did find in raw data that during the day, the passing boats can have an effect on the vocalizing behaviour of humpback whales, with them becoming quieter.

The results of this study suggest that PAM is a useful method long-term monitoring of humpback whale presence and habitat use. The results within this study are, however, not conclusive more research to other years is needed. Swartz et al. 2003 found that when applying both acoustic and visual methods, that visual sightings only represented a fraction of the number of acoustic detections of vocalizing whales. This was partially due to bad weather conditions, which are prevalent in the area, showing but that PAM is a useful technique to effectively monitor humpback whales.

This study only looked at occurrence data and diel pattern but there are more studies that could be done with this data set. One of these studies could be a more in depth characterization of the vocalization. While going through the diel patterns analysis, different types of vocalizations were encountered. Below are some examples shown as spectrograms (figure 12 and 13). These various types of vocalizations could be used for song characteristic studies in the future. This could give more insights into the behaviour of the individual humpback whales who are making the vocalizations. When a vocalization is a song, this indicates that a lone male is either searching for a mate or is marking his territory. When the vocalizations are social sounds this could either indicate a mother and calf or a group of adults (Clapham, 2000; Dunlop et al., 2007; Zoidis et al., 2008).

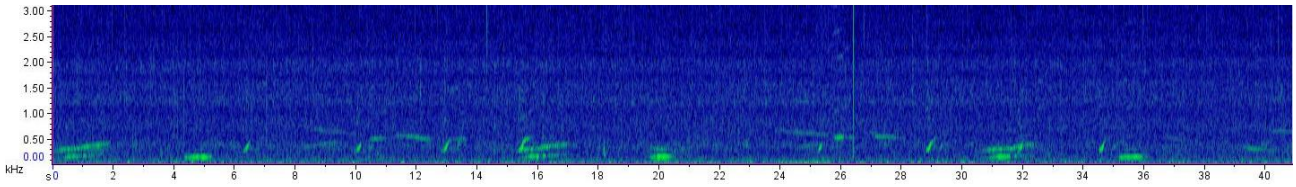

Figure 12 example of low frequency vocalizations. Y axis frequency X axis time in seconds.

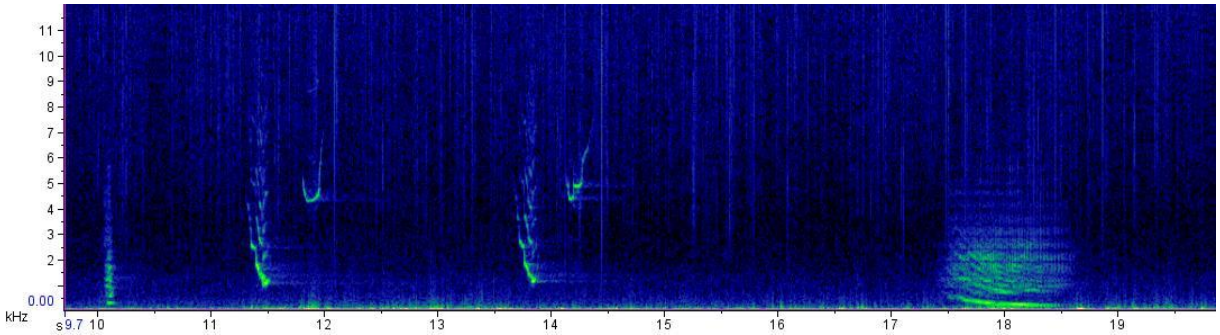

FIGURE 13 EXAMPLE OF THREE DIFFERENT VOCALIZATIONS. Y AXIS FREQUENCY X AXIS TIME IN SECONDS.

Another study that could be done is to investigate the presence of anthropogenic noise in the area. Appendix I gives examples of spectrograms with anthropogenic noise that were encountered during this study. Mapping anthropogenic noise can give could insights to the extent of the human induced noise within the Yarari Sanctuary and how this changes over time.

Management

At the moment there is no management plan for Yarari, the management falls under the existing management framework of the Saba Bank national park. This management plan does however, not mention marine mammals. There are some laws in place, regarding marine mammal protection, via the BES fisheries law, but this is only protection regarding entanglement in fishing gear. There are a number of potential threats towards marine mammals in the area, which have been identified by A O Debrot et al., (2017). A comparison with two other sanctuaries, Stellwagen Bank and the Dominican Republic, was done to investigate their management strategies and to get a clear picture on how the Yarari Sanctuary could benefit from their experience. The two sanctuaries that have been treated within this study have two different approaches on how to manage a marine mammal sanctuary. The Stellwagen Bank Sanctuary has clearly defined aims and objectives on what and how they want to manage their sanctuary, they have also done research to the potential threats to humpback whales in the sanctuary. Whereas, the Dominican republic, have done the same but misses details on how the objectives are met. Both these sanctuaries use acoustic monitoring of whales, it is also used for the

mapping and monitoring of anthropogenic noise. These studies are focused on low-frequency noise and the impacts these sounds have on whales in their feeding (Stellwagen Bank), breeding and nursery grounds (Dominican Republic). The results from these studies are shared with the other sanctuaries. Another aim of these studies is to inform managers of the potential dangers. Since the Yarari Sanctuary does not have a management plan as yet, what makes good management for marine mammals? There are different opinions on the effectiveness of marine protected areas specially for marine mammals. Not all marine parks or sanctuaries are as effective, as hoped. The cause of this can be that the designated area is too small, or not enough research was done before designating the area as an protected area, sometimes there are simply not enough resources for proper enforcement (Evans, 2018; Wilson, 2016). At the moment there are not enough resources available in the Yarari to ensure adequate implementation of a management plan and for gathering information on marine mammal occurrence and the potential negative impacts they face (A.O. Debrot et al., 2017). For example, current information on marine mammals in the Saba Bank is derived from interviews with fisherman, aerial surveys and PAM work, is not adequate enough to determine density of species or distribution patterns (Geelhoed, Janinhoff, Verdaat, Bemmelen, & Scheidat, 2015; Scheidat, Boman, Davaasuren, Geelhoed, & Graaf, 2016). In order to create proper management it is important to get all the parameters right. Hoyt (2011) listed the basic requirements for setting up a protected area

- ‘’Defined purpose with specific goals;’’
- ‘’Scientific background research into critical habitat requirements of cetaceans and other species, as well as the marine ecology and an inventory of the area’’
- ‘’ early multidisciplinary input to choose, plan, implement and review the protected area’’
- ‘’a good relationship with local communities and stakeholders’’
- ‘’reasonable boundaries in view of the species, ecosystems and ecosystem processes that are being protected’’
- ‘’creation and sufficient funding for staff and operations including research, a management plan, monitoring and enforcement’’
- ‘’a comprehensive ecosystem-based and socioeconomic management plan’’
- ‘’legal recognition as well as public acceptance’’
- ‘’ an educational programme which is interactive and continuous for those who will use, travel through or visit the protected area’’
- ‘’ attention paid to the big picture’’
- ‘’management of pollution, both marine and land based’’
- ‘’Reassessment and re-evaluation at periodic intervals with stakeholder input’’

(Hoyt, 2011) also listed criteria for determining the critical habitat of cetaceans.

- ‘’areas regularly used by cetaceans for feeding, breeding, calving, nursing and social behaviour’’
- ‘’migration routes and corridors and related resting areas’’
- ‘’areas where there are seasonal concentration of cetaceans species’’
- ‘’areas of importance to cetacean prey’’
- ‘’oceanographic processes that support continued productivity of cetacean foraging species (upwelling, ocean fronts)’’

- ‘’topographic structures favourable for enhancing foraging opportunities for cetacean species (seamounts, canyons)’’

All of these points above should be taken into account, to create effective sanctuary management of cetaceans. In addition, it is also important to protect all the habitats of the species, including the migration corridors and feeding grounds. For the North Atlantic population of humpback whales this is partially monitored via the sister sanctuary programme established in 2006 between Stellwagen Bank and the Dominican Republic. The Yarari is also part of this Sister Sanctuary Program since 2017. This program has the potential to protect humpback whales on an international level.

5. Conclusion/recommendation

This study aimed to investigate how and if PAM in the Yarari Sanctuary can be an adequate monitoring tool to inform decisions for management plans. The results indicate that PAM can be used as a monitoring tool for management. More analyses including other months and years should be done to confirm these initial findings as described in this thesis, as these results are based on a data set of one year. The results of the occurrence analysis gave new insights to the extent of when and how long the humpback whales stay in the area of the Saba Bank. Their daily presence in February and March at the height of the breeding period, in combination with continuous 24 hour long vocalizations at that time provide strong evidence that the Saba Bank area is used by humpback whales as a reproductive area. When reproductive behaviour, such as song, is displayed, it is likely that there are also mother calf pairs present. Because the gestation period is 11 months, humpback whales that breed in this area, are likely to also calf here. Successful reproduction is vital for the survival of a population or a species. Management of the Yarari Sanctuary in particular around the Saba Bank need to take this into account to make sure that humpback whales are particularly protected.

There are multiple uses of PAM for management, PAM can provide information on occurrence and diel pattern like in this thesis, but also for distribution data, noise mapping (anthropogenic) and vocalization characterization (table 3). Large-scale distribution information can be collected, requiring a coordinated network of PAM and cooperation with other sanctuaries and marine parks in the WCR. This could provide valuable data allowing the monitoring of the migration corridor to the feeding grounds as well. A more detailed analyses of the vocalization characteristic can give insight into who is vocalizing, e.g. if it is a male or female or a group of whales. And finally as PAM records all sounds in the ocean, it can also be used to detect anthropogenic noise (noise mapping). As noise is a potentially serious threat to cetaceans, quantifying the presence of vessels as well as seismic sounds would help with effect studies of marine mammals to anthropogenic noise. If an automated detection algorithm specific to humpback whale is developed, data analyses would be much faster and more cost-effective. In addition, the presence of other species, such as minke whales, could also be investigated.

TABLE 3 OVERVIEW OF INFORMATION THAT PAM DATA CAN PROVIDE FOR MANAGEMENT

Data from PAM	Application to management of the sanctuary
Occurrence data	Baseline data on when animals are in the area. Changes of this data indication natural shifts or impact of human activities.
Distribution data	Using an array of PAM provides information on how the North Atlantic humpback whale population is distributed in the Wider Caribbean region and if this distribution changes.
Diel pattern	Data on times when animals are most active acoustically, which indicates an importance related to reproductive behaviour. Also shows if anthropogenic sounds influence the diel pattern.
Anthropogenic noise mapping	Different anthropogenic noise sources can be identified and mapped. The change of this, e.g. in frequency or in the type of noise, can be used to defer potential threats for marine mammals and other species.
Vocalization characterization	Can be used to investigate how song patterns change over time, in particular in reaction to anthropogenic noise sources.

Both the Stellwagen Bank and the Marine Mammal Sanctuary of the Dominican Republic use PAM for the monitoring of anthropogenic noise and use this information to inform managers. Besides the information on PAM there is still much to be learned from both these sanctuaries for Yarari. At the moment there is no management plan in place for the Yarari Sanctuary. To be able to create a proper and effective management plan it is advised to look at important parameters, such as human threats towards marine mammals in the area (e.g. fisheries, marine pollution), human uses of the area (shipping routes), involvement of the local community and stakeholders and making sure that there is enough funding for enforcement, research and long-term monitoring. Lessons from the sister sanctuaries should be taken into account, in particular how conservation aims can be defined and monitored within a management plan.

In conclusion, this study has found that PAM is in particular valuable for Yarari to gather information on humpback whale occurrence and behaviour, as well as background anthropogenic noise, which can serve as a baseline for a management plan. The rest of the acoustic data should be analysed to confirm the initial findings described in this thesis. Once the management plan is in place, the data collected can be used to monitor both anthropogenic sounds and sounds created by marine life, as has been done in both Stellwagen Bank National Marine Sanctuary and the Marine Mammal Sanctuary of the Dominican Republic.

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Appendix

I. Anthropogenic noise

Besides the different types of vocalizations, anthropogenic noise was also encountered during the analysis, figure 14, 15 and 16 show different examples of anthropogenic noise. The noise in figures 14 and 16 could mask humpback whale vocalization. The sound of figure 15, in this example, does not mask vocalizations but is an example of an anthropogenic sound which could mask the vocalization when the analyst would listen to the files.

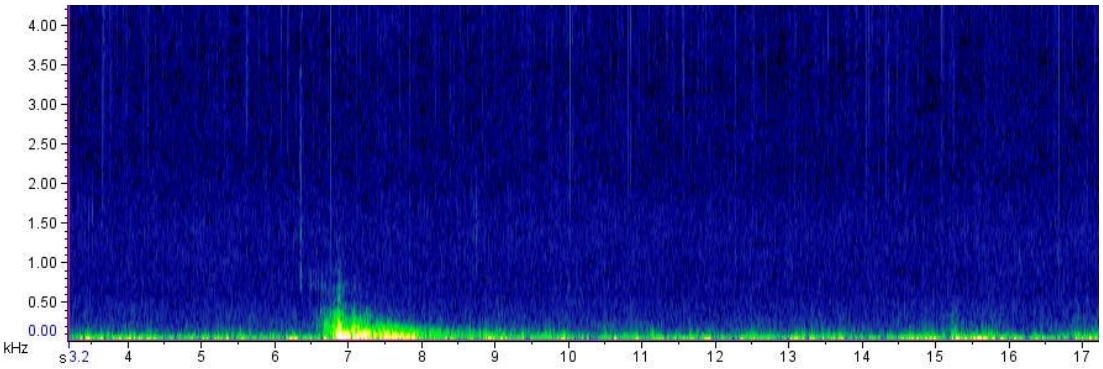

FIGURE 14 SPECTROGRAM OF SEISMIC NOISE. Y-AXES FREQUENCY IN KHZ ON X-AXES TIME IN SECONDS

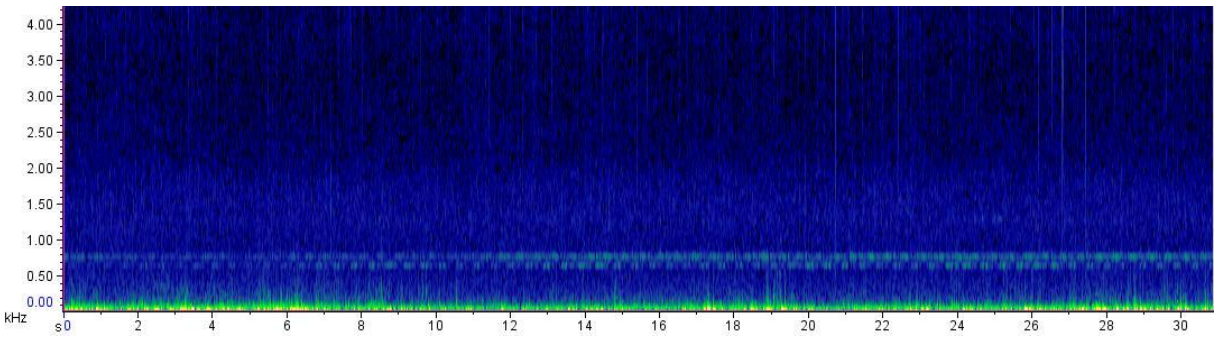

FIGURE 15 SPECTROGRAM OF YET UNIDENTIFIED NOISE

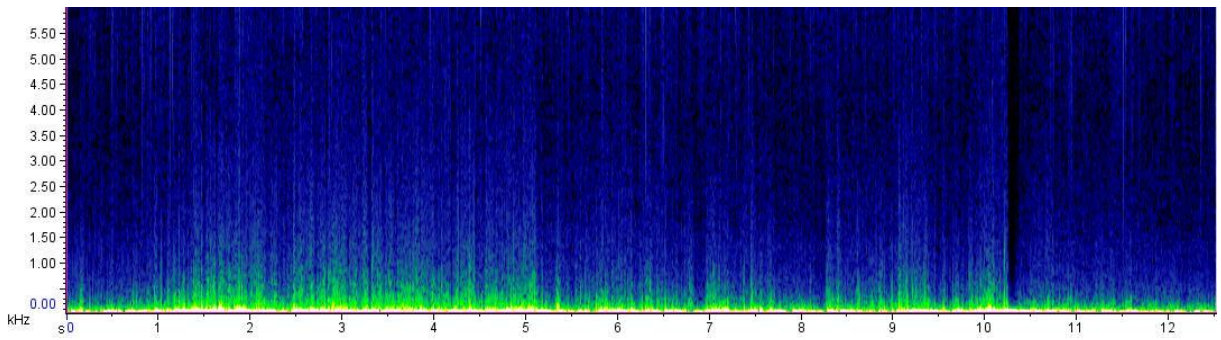

FIGURE 16 SPECTROGRAM OF BACKGROUND NOISE