Humpback and minke whale acoustic presence with reference to fish sounds and ambient noise levels at Saba Bank, Caribbean Windward Dutch Islands

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Summary

The Antillean Island chain is a known breeding and calving ground for North Atlantic humpback whales (*Megaptera novaeangliae*). However, while most research efforts for this species have focused on the largest aggregation of whales, located on Silver Bank, off the northern coast of the Dominican Republic, there are still significant knowledge gaps with respect to humpback whale movements along the Antillean Island chain. Even less is known about the spatio-temporal distribution of other marine mammal and fish species in the region. This report summarizes analysis results of acoustic data (10-8000 Hz effective analysis bandwidth recorded at a 25% duty cycle), recorded on the north east of Saba Bank from October 2011 to April 2012. The results show the consistent presence of humpback whales in the vicinity of Saba Bank during their winter breeding season, occasional presence of minke whales and the presence of sound producing fish assemblages. Humpback whale song occurred from the end of December to the end of the recording period in April. From February to April humpback whale song was recorded on more than 89 % of all recording days, though it occurred most frequently in March. All recording days in March showed song presence, with an average of 8.5 ± 2.8 (mean ± SE) hours of recorded song per day. In contrast, for minke whale (*Balaenoptera acutorostrata*) 48 pulse trains (n = 32) were detected less frequently between February to April 2012. A variety of unidentified fish sounds were present throughout the recordings. Although the occurrence of these sounds was not quantified, notable fish choruses (e.g. grouper spp. *Epinephelinae*) consisting of one to two distinct pulsed calls in the frequency range of 100 - 600 Hz were documented from October to December 2011 in particular. The results of this pilot project highlight the feasibility of using passive acoustic monitoring (PAM) to explore year-round marine mammal and fish presence and distribution in otherwise understudied and remote field sites.

1 Introduction

Despite an apparent high species diversity, comparatively little is known about cetacean distribution and seasonality in the Wider Caribbean Region (WCR). Research efforts have focused on concentrations of humpback whales north of the Dominican Republic during their winter breeding and calving season (Mattila et al. 1989, 1994, Clapham et al. 1993).

Until recently dedicated cetacean studies at other times of the year or in other areas such as the windward Dutch Islands, including Saba Island, have been rare and a comprehensive overview of marine mammal occurrence in this region has been missing. Recently Debrot et al. (2013) compiled all known sightings for this area and documented at least six cetacean species. Humpback whales appear to be most commonly encountered, although Debrot et al. (2013) add the caveat that due to their size and approachability, there might be an availability bias, leading to more reports of this iconic species, as compared to other lesser known and/or less visible species.

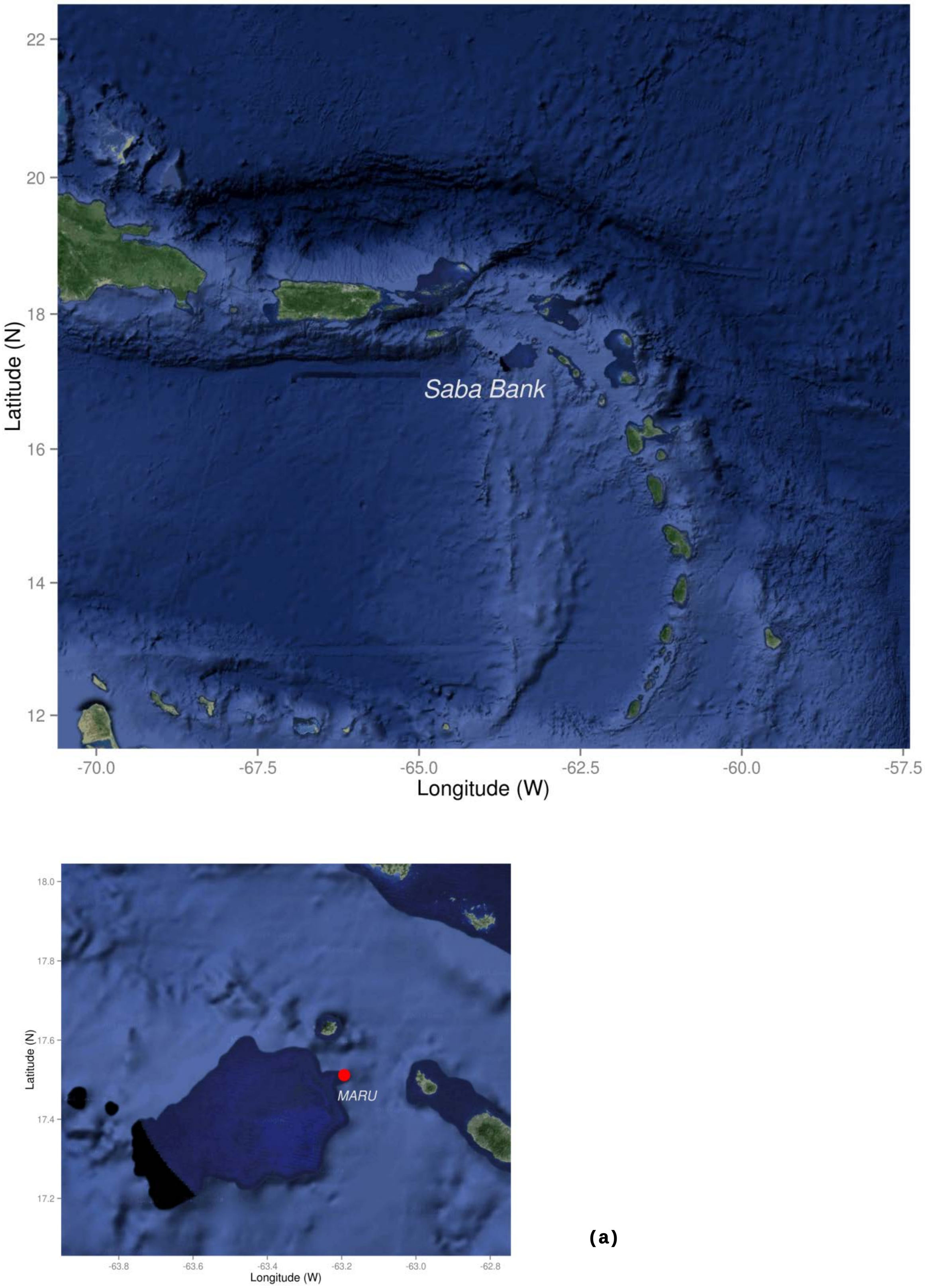
Although humpback whale populations worldwide have shown signs of recovery in recent years, concerns remain for populations in understudied areas and where detailed knowledge about population structure is missing (Valsecchi et al. 1997, Ruegg et al. 2012). As mentioned earlier, research efforts for this species have focused on high density areas north of the Dominican Republic and to a much lesser extent on inter-island movements and wider habitat use (Kennedy et al. 2013).

It is widely recognized, that in order to protect highly mobile species such as humpback whales effectively, it is necessary to establish a network of protected habitats, covering feeding and breeding habitats as well as main portions of their migration (Hooker & Gerber 2004, Agardy et al. 2011). Both, the Dominican Republic, as well as France have established marine protected areas (MPAs) in the northeastern Caribbean, in relatively close proximity to Saba Bank. In US waters of the Caribbean around Puerto Rico and the Virgin Islands, marine mammals are protected by the Marine Mammal Protection Act (1972). In order to strengthen these initial initiatives and increase the general conservation status of cetaceans in the region and increase connectivity between MPA networks, the whole Dutch EEZ should be declared an MPA for cetaceans (Debrot et al. 2011). In the meantime, on September 1, 2015, the two EEZ sectors attributable to the islands of Saba and Bonaire, lying respectively in the northern and southern sectors of the Dutch Caribbean EEZ, were designated as the **Yarari marine mammal and shark sanctuary** via ministerial decree by State Secretary of Economic Affairs, Sharon A. M. Dijkstra. The remaining EEZ sectors attributable to Aruba, Curaçao, St. Eustatius and St. Maarten will hopefully soon follow suit.

With its obvious advantages in sampling remote areas and in bad weather conditions for extended time periods, passive acoustic monitoring (PAM) provides an effective tool to study and monitor cetacean distribution year-round. As such PAM can not only provide information on migration timing and habitat use (Risch et al. 2013, 2014), but may also give insight in long-term changes in ambient noise levels and related impacts of increasing noise levels on marine mammals (Rice et al. 2014). In addition, PAM may provide valuable information on the seasonal occurrence and distribution of a variety of soniferous fish species (Hernandez et al. 2013), as well as enable the rapid evaluation and monitoring of changes in biodiversity at a given site using newly developed bioacoustic indexes (Sueur et al. 2008, Staaterman et al. 2014, Kaplan et al. 2015, Nedelec et al. 2015). As such PAM is an increasingly important tool for site evaluation and long-term monitoring of MPAs and marine soundscapes in general.

This report summarizes results of a pilot study to explore the feasibility of using long-term PAM for low-frequency cetacean and fish monitoring at the Dutch windward islands, specifically Saba Bank. The focus here is the analysis of humpback and minke whale presence at the site, with reference to ambient noise levels and any other bioacoustics signals in the recorded frequency band (10-8000 Hz).

This work was carried out by IMARES Wageningen UR with funding from the Ministry of Economic Affairs for the purposes of Policy Support Research (BO-11-019.02-005).



(a)

Figure 1. (a) *Map of the Caribbean Islands Chain, showing the location of Saba Bank and* ***(b)*** *Location of the marine autonomous recording unit (MARU) at the north eastern edge of Saba Bank and to the south west of Saba Island.*

2 Materials and Methods

2.1 Study area

The study area consists of the waters west of the island of Saba, with the largest part being covered by the Saba Bank (***Figure 1***). Saba Bank is a large submarine atoll with a surface area of about 2000 km² and an average depth of 25 m (Hoetjes and Carpenter 2010).

2.2 Passive acoustic monitoring

Passive acoustic data were collected for a period of 6 months (from 27 October 2011 to 28 April 2012) at the north eastern edge of Saba Bank (***Figure 1***) with the recorder moored about 4-5 m above the seafloor at a maximum water depth of about 30 m. Recordings were made using an autonomous recording unit (MARU, ***Figure 2***) (Calupca et al. 2000), which was equipped with an HTI-94-SSQ hydrophone (High Tech Instruments; type specific sensitivity: -168 dB re 1 V/µPa), connected to a pre-amplifier and A/D converter with 12 bit resolution, resulting in an estimated effective system sensitivity of -152 dB re 1 V/µPa. The unit was set to record at a sample rate of 16000 Hz and a schedule of 30 minutes of recordings every 2 hours in order to extend overall recording duration. This duty cycle resulted in 6 hours of recordings per day and daily results as presented within this report refer to this daily fractional recording period. Data were high-pass filtered above 10 Hz. The effective analysis bandwidth was 10 to 8000 Hz.

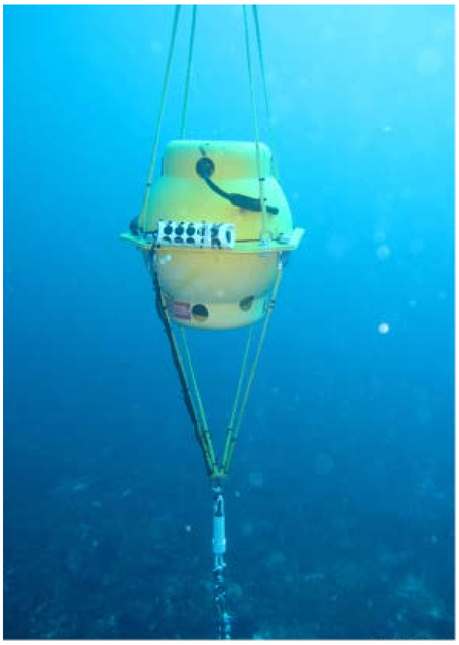


Photo: IMARES

Figure 2. *Autonomous recording unit (MARU) as deployed on Saba Bank 2011-2012.*

In order to assess data quality and identify potential recording gaps, acoustic data were initially reviewed visually and aurally by creating spectrograms (fast Fourier transformation [FFT] size: 1024 points, 95 % overlap, Hanning window) using the sound analysis software XBAT (Figueroa & Robbins 2008). In a second step automated detectors were applied to identify the occurrence of humpback and minke whales on an hourly basis. Humpback whale song and minke whale pulse trains were used to detect species presence, while detection of individual animals was not looked at in this analysis. While it is theoretically possible to give a minimum estimate of individual animal presence based on overlapping vocalizations, it is not possible to consistently locate individuals with just one recording unit and due to this limitation it was decided to assess species presence rather than to attempt an estimation of number of individuals here. While checking detection results for humpback and minke whales, data were also reviewed opportunistically and at random intervals for other biological sound types. In addition, the same day each month was selected to assess and indicate variability of ambient noise levels throughout the season. Ambient noise levels were assessed in 1/3rd octave bands.

2.2.1 Humpback whale song detections

An automated template detector was constructed in XBAT. Principally, the detector is based on spectrogram cross-correlation of an example event (the template) and the sound file (Figure 3). Several templates can be arranged in presets. Multiple presets were constructed using different humpback whale song notes until the resulting detector missed less than 10 % of hours with humpback whale song (song positive hours) within a test data set which consisted of 6 randomly selected days for each available recording month (n = 36 days), comprising roughly 20 % of all recording days.
Automated humpback whale detections were manually reviewed and verified using XBAT and false positive detections were removed from the data set. Humpback whale song presence was subsequently summarized as hours with detection per day and week.

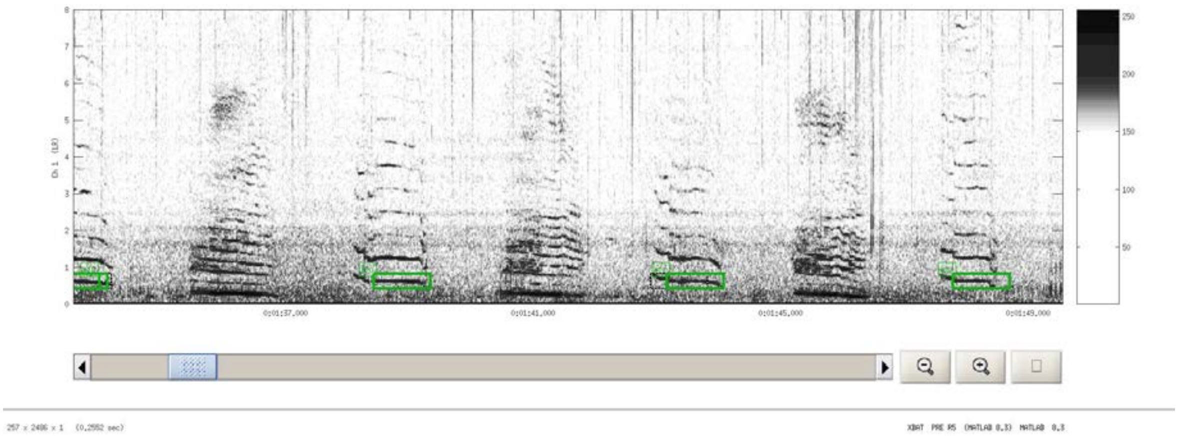


Figure 3. *Example of acoustic detections using the data template detector in XBAT on humpback whale song recorded at Saba Bank in January 2012. (Spectrogram with FFT size: 1024 pt, 95 % overlap, Hanning window).*

2.2.2 Minke whale pulse train detection

North Atlantic minke whales are known to produce up to seven types of low-frequency pulse trains, which can be assigned to three major categories (slow-down, constant and speed-up pulse trains), based on varying inter-pulse interval structure (IPI) (Risch et al. 2013). An automated custom-written detector for these sounds had been developed in earlier work (Risch et al. 2014). The automatic detection using this software consists of a multi-stage process based on spectrogram intensity binarization, energy projection, feature extraction and classification (Popescu et al. 2013). While the detection stage is designed for general pulse train detection, a Rippledown Rule (RIDOR) learner (Gaines & Compton 1995) is trained to identify minke whale pulse trains, taking into account, but not distinguishing among, the different types of pulse trains. The overall false negative rate (FNR) of the detector was previously assessed to be 27 % (647 out of 2428 true positive (TP) detections), with 181 false positive (FP) detections in 120 hours (or 29,847 signal slices) of evaluated data (Risch et al. 2013). While the estimated FNR of 27% was accepted, all detected pulse trains in this study were verified manually using the MATLAB (Mathworks, Natick, MA) based custom software program SEDNA (Dugan et al. 2011). As opposed to hourly humpback whale song presence, minke whale pulse trains were detected and results presented by enumeration of individually detected vocalizations.

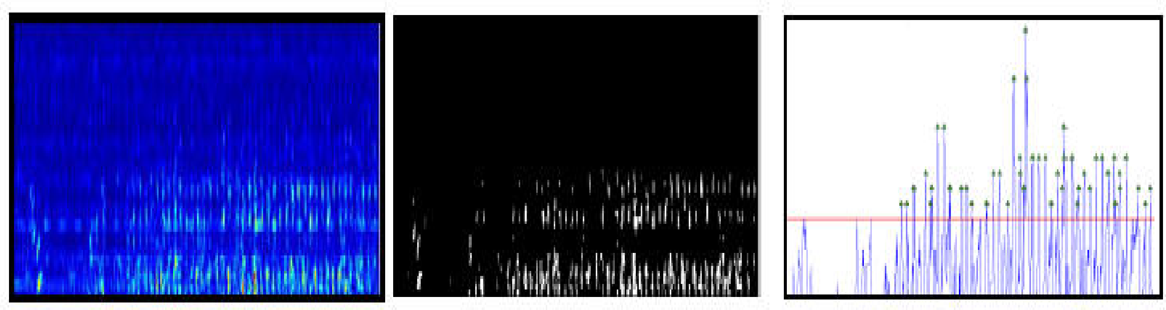


Figure 4. *Example of acoustic detections using the custom-written minke whale pulse train detector, showing the three stage detection process consisting of spectrogram conditioning, image binarization and final detection output after applying the energy projection function. Figure M. Popescu*

2.2.3 Fish sounds and ambient noise analysis

Pulsed sounds, produced by fish such as grouper *spp.*, were frequently identified in this data set and their occurrence was noted but not quantified. Several examples of the most commonly observed call types were saved for future more in-depth analysis and comparison to data from other researchers studying the underwater soundscape of Caribbean fish assemblages.

Preliminary low frequency ambient noise analyses were carried out using Matlab based PAMGuide scripts (Merchant et al. 2015). In order to explore changes in noise levels between months, 1 fixed day per month was selected for ambient noise analysis. For all noise analyses, power spectrum density levels in 1 Hz bins were calculated across selected data files using a 1 s Hanning window with zero overlap. In order to produce more reliable measures of random signals and in order to save storage, the temporal resolution of the power spectrum was averaged to 10 s using the Welch method, and upper and lower frequency limits of the analysis were set to 10 Hz and 1 kHz, respectively. All noise level data, calculated with above settings, are presented in 1/3rd octave bands and as RMS sound pressure levels (SPL) [dB re 1 µPa/Hz].

3 Results

3.1 Humpback whale song

Humpback whale song (Figure 5) was recorded from the end of December 2011 to the end of the recording period in April (Figures 6 and 7). Overall, humpback whale song was detected on 56.2 % of recording days (n=104). While song was detected on only the last day of December, 67.7 % of days in January and 89.7 %, 100 % and 89.3 % of days in February, March and April, respectively showed humpback whale song detections. As can be seen from Figure 6, the number of song positive hours per day varied between months. The maximum number of song positive hours in a day was 12 hours in March and 11 hours in January, February and April. The average number of song positive hours per day (mean ± SE) for respectively December, January, February, March and April were: 0.1 ± 0.5, 3.2 ± 3.4, 5.5 ± 3.8, 8.5 ± 2.8 and 5.1 ± 3.7.

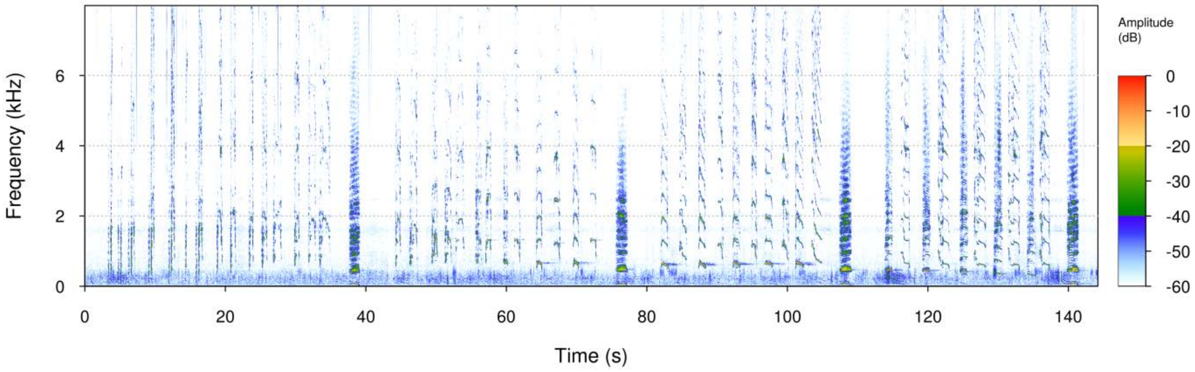


Figure 5. *Example spectrogram of a portion of clean humpback whale song showing several themes recorded on 01 January 2012. Sample rate: 16 kHz, FFT size: 2048 pt, overlap: 95 %.*

Although individual singers could not be localized from a single unit deployment, and distance to singers was thus not possible to obtain, some song detections, like the example in Figure 5 were recorded at high received levels, suggesting that the recorded singer has been in relatively close proximity (< 1 km) to the recording unit.

Figure 7 illustrates the general increase in song positive hours starting at the end of December, with a peak in the end of February, followed by a plateau in March and a decrease towards the end of April.

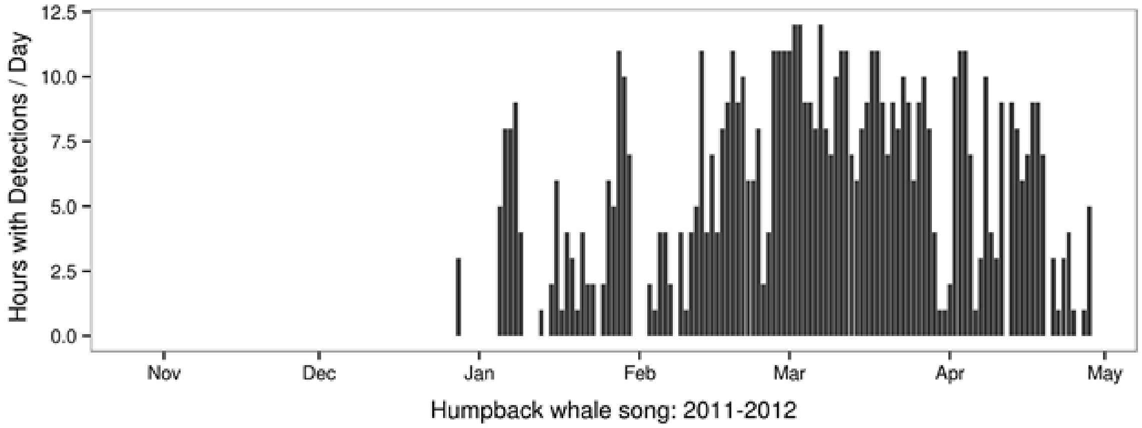


Figure 6. *Humpback whale song occurrence expressed as hours with detections / day at Saba Bank October 2011-April 2012.*

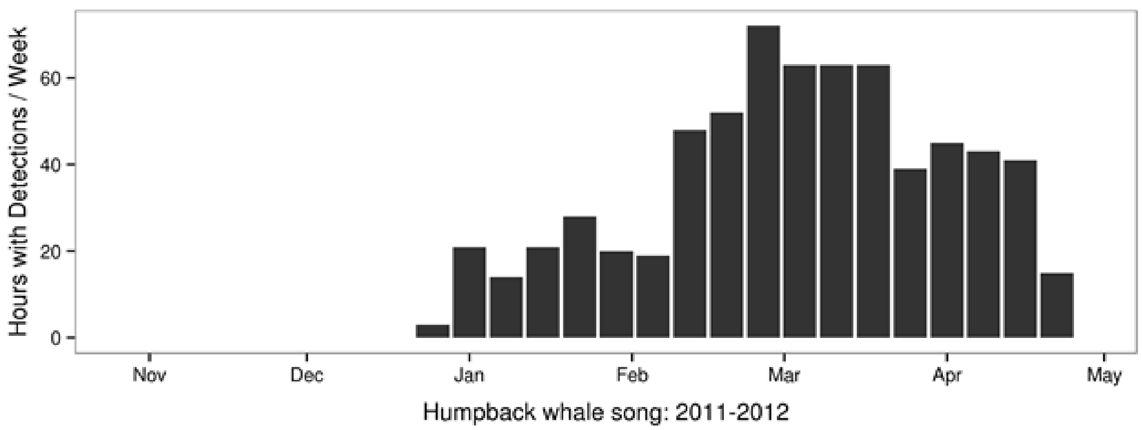


Figure 7. *Humpback whale song occurrence expressed as hours with detections / week at Saba Bank October 2011-April 2012.*

3.2 Minke whale pulse trains

Minke whale pulse trains (Figure 8) were recorded from February to April 2012 (Figures 9 and 10). Only 48 pulse trains were detected in the whole data set. Of all received calls the inter-pulse interval (IPI) decreased throughout the duration of the call (Figure 8). Most pulse trains (n = 32) were detected in March, while only 2 detections were made in April and 14 in February (Risch et al. 2014).

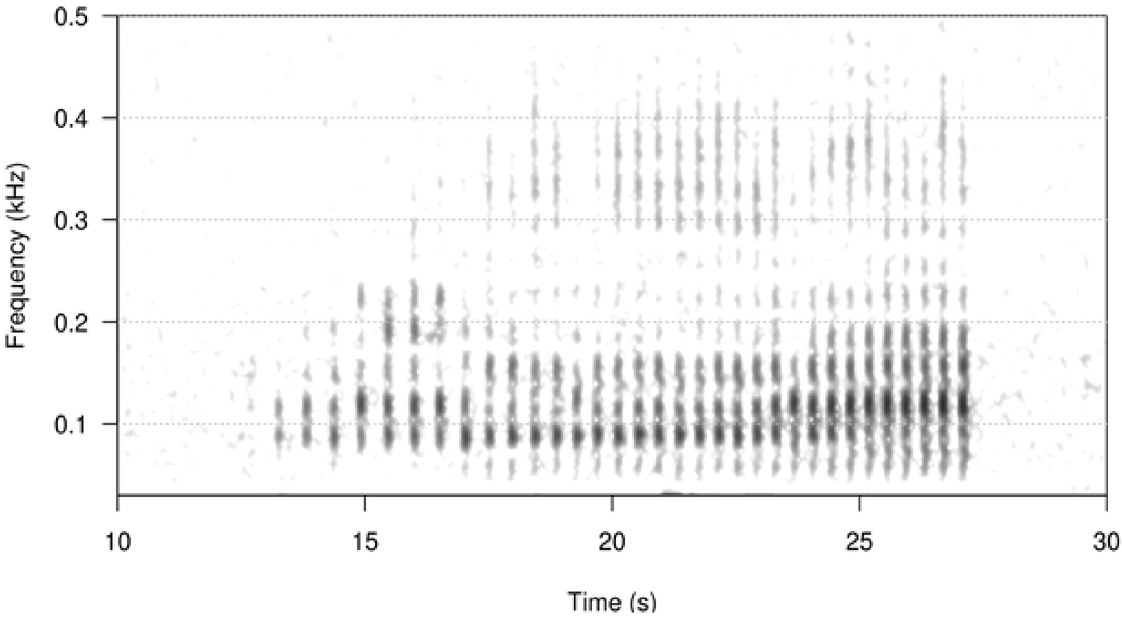


Figure 8. *Example spectrogram of a typical minke whale speed-up pulse train. Sample rate: 2 kHz, FFT size: 512 pt, overlap: 75 %.*

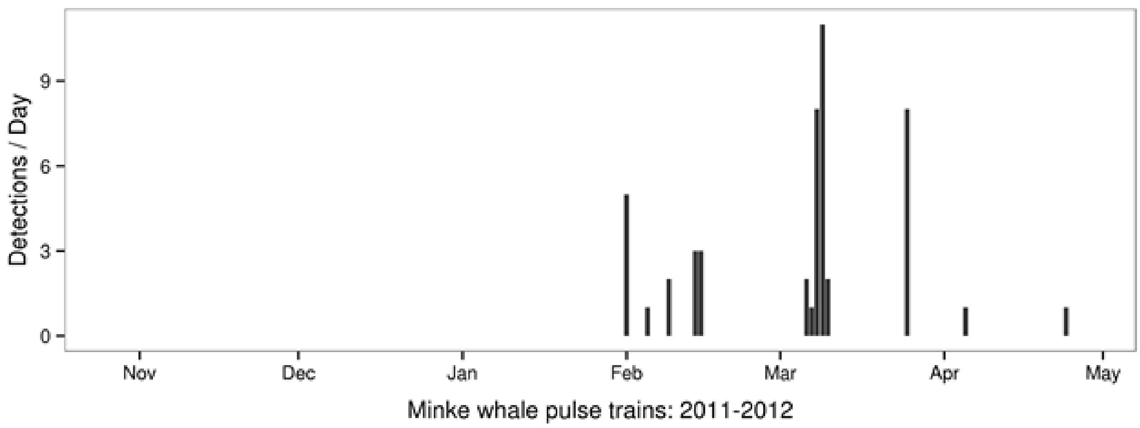


Figure 9. *Minke whale pulse train occurrence expressed as hours with detections / day at Saba Bank October 2011-April 2012.*

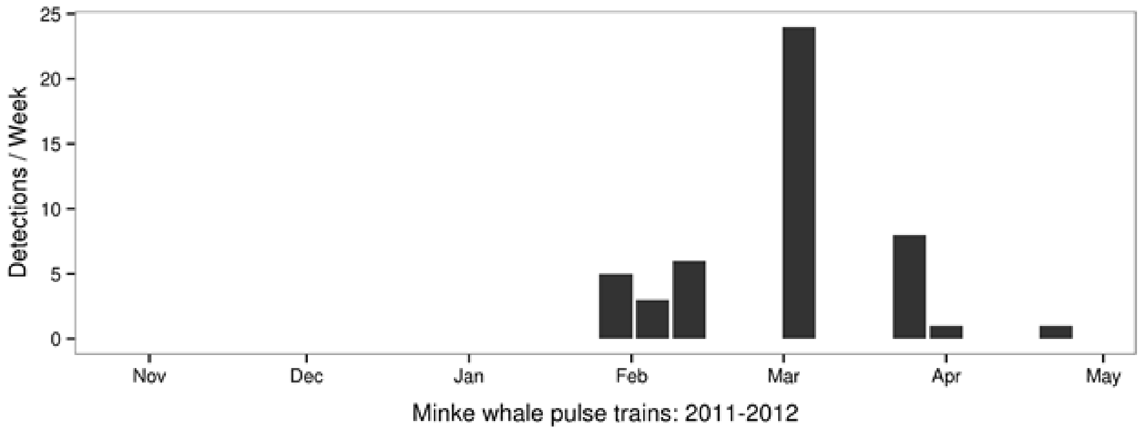


Figure 10. *Minke whale pulse train occurrence expressed as hours with detections / week at Saba Bank October 2011-April 2012.*

3.3 Fish and other low-frequency sounds

A variety of other sound types, some of which presumably produced by unidentified fish species were recorded throughout this project. The most prominent and most often recorded of these sounds were pulsed sounds of varying inter-pulse interval (IPI) and peak frequencies between 100 and 600 Hz (Figure 11 b, c), most likely produced by grouper spp. (11 b) and squirrelfish (*Holocentridae*) or damselfish (*Pomacentridae*) (11 c). Although it was outside the scope of this report to identify the species producing these sounds or quantify their temporal contribution to the overall soundscape, most of them were recorded in the first half of the recording period (October to December), sometimes in dense choruses.

Some lower frequency down-sweep calls (Figure 11 a, e) from about 200 to 50 Hz over 200-500 ms and sometimes produced in sequences from 3 to 10 calls at a time, were recorded too, although less frequently. The origin of these signals is unknown.

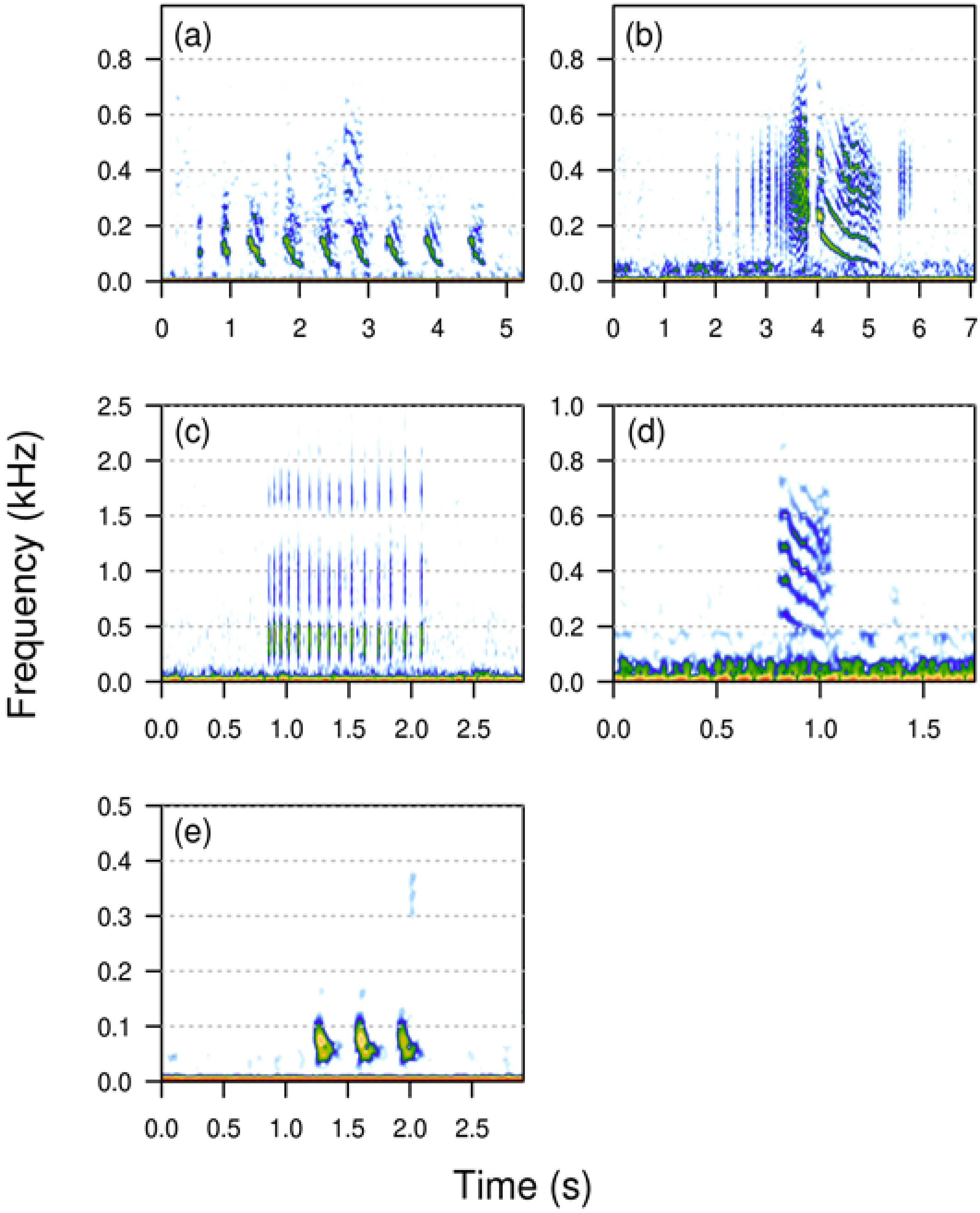


Figure 11. *Example spectrograms of various unknown sounds, likely produced by various fish species. Most frequently recorded call types are shown in panels (b) and (c). Sample rate down-sampled: 2 kHz (a,b,e); full recording sample rate: 16 kHz (c,d); FFT size: 256 pt (a,b,e), 512 pt (c), 1024 pt (d); overlap: 95 % (a,c,d,e), 99 % (b).*

3.4 Background noise levels

Low-frequency (10-1000 Hz) ambient median noise levels were similar between all sampled days with median 1/3 octave band sound pressure levels (SPL) between 75 and 95 dB re 1µPa (Figure 12). Highest noise levels were measured in October and lowest median noise levels were measured in April. High noise levels on October 28th 2011 may be the result of elevated ambient noise in relation to high winds during the end of the North Atlantic hurricane season. In fact, hurricane category 2 storm Rina was observed in the western Caribbean islands from October 23rd – 28th, 2011. The observed lack of strong variability in ambient noise levels suggests that background noise conditions should not have significantly influenced detection probability of marine mammal vocalizations over the full recording period.

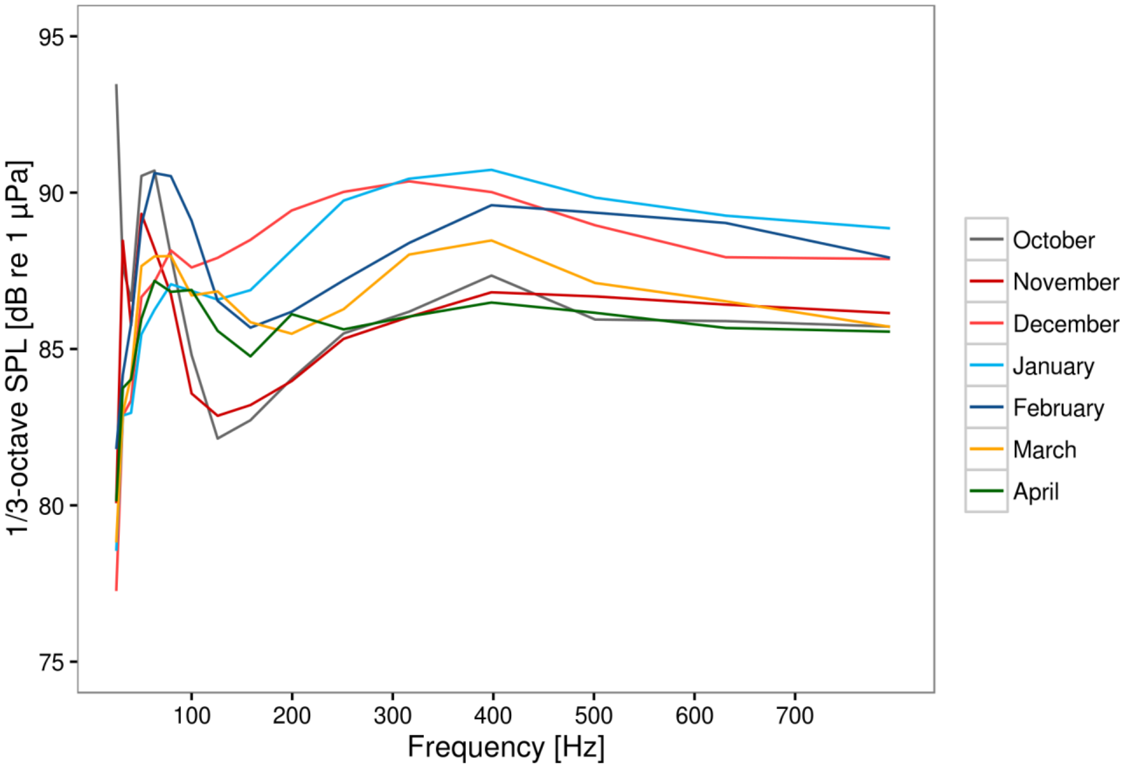


Figure 12. *Median 1/3 octave band (10-1000 Hz) Sound Pressure Levels (SPL) by month.*

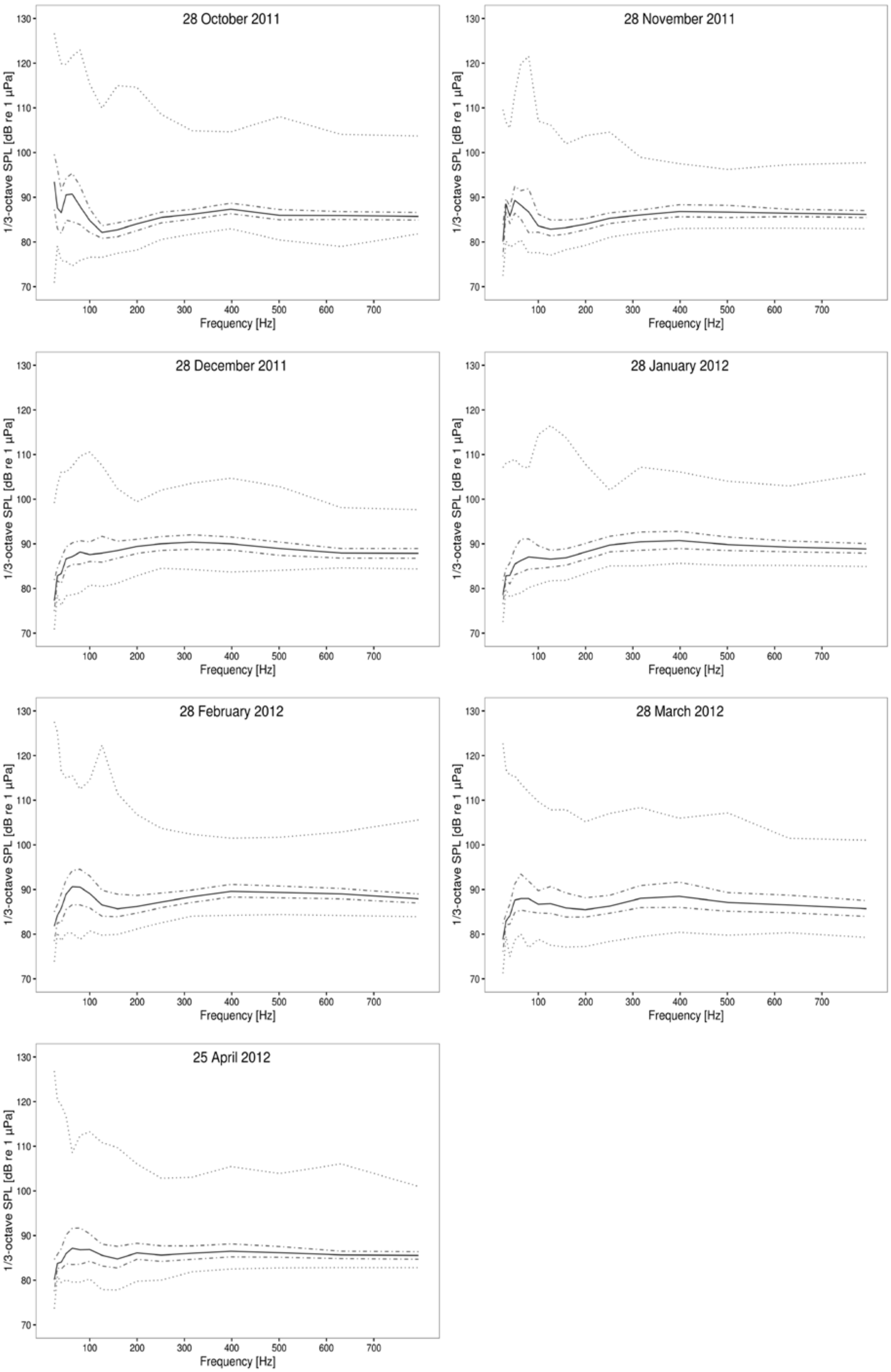


***Figure 13**. Median (solid line); Maximum, Minimum (dotted line), 25th and 75th Percentiles (dot-dashed line) of 1/3 octave band (10-1000 Hz) Sound Pressure Levels (SPL) for one day per month from October 2011 to April 2012.*

4 Conclusions and future work

This pilot-study corroborates recent visual sightings and satellite tagging studies showing that areas other than the well-studied high density breeding sites located at the north coast of the Dominican Republic provide important and consistently utilized habitat for humpback whales in the Caribbean region (de Boer & Willems 2015, Debrot et al. 2013, Kennedy et al. 2013). Humpback whale song was recorded on more than 85% of all days from February to April 2012, showing consistent usage of this area during the height of the winter breeding season. Some occurrences of high amplitude song indicates relative close proximity of singers to the recording unit at the edge of Saba Bank, confirming the actual usage of this location as part of the extended humpback whale winter breeding habitat.
Furthermore, although present much less frequently, this study confirms the Wider Caribbean Region (WCR) as a winter habitat for minke whales (Risch et al. 2014). The relatively low presence of recorded minke whale pulse trains can be explained by the placement of the recording unit in the relatively shallow waters of Saba Bank, affecting long-range propagation of low-frequency sounds. In addition, several previous studies have suggested a more off-shore distribution of minke whales during winter months (Clark & Gagnon 2004, Risch et al. 2014).
Results of this study also show the presence of several different fish species assemblages at Saba Bank, and highlight the opportunity to use passive acoustic monitoring (PAM) as a tool to monitor changes in ambient noise levels, anthropogenic noise impacts as well as develop new methods for rapidly surveying marine biodiversity using acoustic data.
Future analyses of this and future datasets could be extended to explore the presence of fish choruses as recorded during this project in more detail, as well as the presence of high frequency cetaceans such as dolphins, by employing automatic whistle detection. Bio-acoustic indices could be used to explore their association with different species assemblages at this site and their use in monitoring change in biodiversity and species presence (Sueur et al. 2008, Lillis et al. 2014, Kaplan et al. 2015).
Lastly, ambient noise levels deviated strongly over the recorded period with 15 dB taken from the median results. In the future large-scale patterns and contributions of anthropogenic sources, such as commercial shipping and high speed tourist boats as well as seismic exploration and military sonar exercises and their respective propagation ranges should be quantified in detail from these recordings. Additionally, the area of should be extended with multiple acoustic recorders to provide insight how these sources affect the spatial distribution of vocalising marine mammals.
Overall, this pilot project demonstrated the feasibility to deploy and successfully recover moored, autonomous acoustic recorders during the Caribbean winter and at the edge of the hurricane season. The acquired data can fill existing knowledge gaps on the distribution and seasonal occurrence of marine mammals and fish in these more remote areas of the Wider Caribbean Region (WCR). Providing a low-coast addition to visual sighting surveys and satellite tagging studies, PAM should therefore be extended in order to cover a larger spatial area and longer time periods, to explore species presence during summer months for example. To monitor the abundance and usage over a wider area, future projects should also tie in with similar efforts by other countries, as well as recent initiatives to protect cetacean habitat in the WCR, such as NOAA's sister sanctuary program (http://stellwagen.noaa.gov/sister/pdfs/ss_fs_e.pdf). Since marine mammals belong to highly mobile species, effective monitoring is dependent on employing a suite of different methods and a network of recording stations in order to fully understand movement patterns and site usage on a spatial scale which is relevant to species conservation.

Acknowledgements

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5 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

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The scientific quality of this report has been peer reviewed by a colleague scientist and the head of the department of IMARES.

Approved: Meike Scheidat
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