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INTERNATIONAL WHALING COMMISSION

Acoustic monitoring of blue whales (*Balaenoptera musculus*) and fin whales (*Balaenoptera physalus*) in the Mozambique Channel off the northwest coast of Madagascar

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Abstract

Migratory baleen whales of the Southern Ocean, particularly Antarctic blue (*Balaenoptera musculus intermedia*), pygmy blue (*Balaenoptera musculus brevicauda*) and fin (*Balaenoptera physalus*) whales, move each year into subtropical and tropical waters during the Austral winter, presumably for breeding; however, information for each is highly limited regarding migratory timing, population distribution, and potential breeding habitat. Previous evidence indicated the presence of blue whales off northwest Madagascar, ca. latitude 13.3ºS, including a pair encountered in 1,800m depth water off Nosy Be, and distant recordings of Madagascar pygmy blue whale song-type from shallow water in December 2014 and 2015. These discoveries prompted an acoustic monitoring project in the deep waters off northwest Madagascar during 2017, in part funded by the IWC SC. Passive acoustic recorders were deployed during four 4-month deployments from December 2016 to April 2018, and two 6-month deployments from April 2018 to March 2019, anchored just off the shelf break at depths ranging from 225-275m. Manual review of spectrograms from the 28 month recording period revealed extensive documentation of SWIO (Madagascar) pygmy blue whale and Antarctic blue whale song-types and fin whale song, in addition to humpback whale and Antarctic minke whale song (not reported on here). SWIO pygmy blue whale song was present bi-modally with peaks of singing activity during May-July (Austral late autumn/early winter) and October-January (Austral late spring/early summer). This pattern suggests a migratory corridor between summer feeding and winter breeding habitat south and north of Madagascar, respectively. Antarctic blue whale song was present throughout the Austral late autumn/winter from May to September (overlapping with the first peak of SWIO pygmy blues), suggesting a winter breeding season aggregation. Sri Lanka blue whale song-type, and a blue whale song-type attributed to the Arabian Sea population (Oman song-type) were detected for short periods between January and May. Fin whale song was present during the late Austral winter, from early August to mid-September. The timing of fin whale song suggests a later arrival than Antarctic blue whales and a lower rate of occurrence and occupancy, potentially representing the northern extent of breeding habitat. Geophysical seismic surveys were detected nearly continuously during a seven month period from October 2017 to May 2018, and have the potential to disturb these sensitive populations of baleen whales.

Introduction

This report presents to the IWC Scientific Committee results of a study on blue whale presence off Madagascar. The project uses Passive Acoustic Monitoring (PAM) to document the presence and seasonality of blue whales and other baleen whales in the deep water habitat off the northwest coast of Madagascar, where they have been previously documented. The IWC Scientific Committee awarded a small fund during SC66 to the project for the purchase of acoustic releases, allowing existing recording equipment to be placed on the shelf slope; all operating and salary costs were sourced elsewhere. This document thus serves as a final report to the IWC SC for the award of these funds. The initial goal of the

work was to extend monitoring previously conducted during 2015/2016 in shallow shelf habitat (at a depth of ca. 40m) into deep water, after the detection of Madagascar-type pygmy blue whale song during six days in December 2015 at a location positioned near the shelf break edge (reported in SC/66b/SH/33, Cerchio et al. 2016). The work commenced in December 2016 and a progress report was presented to the IWC Scientific Committee documenting results from the first 11 months of monitoring (SC/67B/SH14, Cerchio et al. 2018). This document reports on 28 months of acoustic monitoring off the shelf in deeper water at the same location.

Migratory baleen whales of the southern ocean, including pygmy blue (*Balaenoptera musculus brevicauda*), Antarctic blue (*Balaenoptera musculus intermedia*), and fin (*Balaenoptera physalus*) whales, move each year into subtropical and tropical waters during the Austral winter, presumably for breeding; however, information for each is highly limited regarding migratory timing, population distribution, and potential breeding habitat. Blue whales in the Southern Hemisphere are currently divided into four subspecies; three of these are represented in the southern Indian Ocean, including the Antarctic blue whale (*B. m. intermedia*), the "pygmy" blue whale (*B. m. brevicauda*), and the "North Indian Ocean" blue whale (*B. m. indica*). Populations of blue whales globally have been distinguished by stereotyped song-types, often referred to as "acoustic populations" (McDonald et al 2006). In the Indian Ocean there is one song-type from Antarctic blue whales, and at least four regional pygmy or NIO blue whale song-types (McDonald et al 2006, Stafford et al. 2011, Samaran et al 2013a, Cerchio et al. in review). Antarctic blue whales are distributed around Antarctica during the summer and migrate to as-yet poorly documented regions in lower latitudes during winter (Branch et al. 2007). Acoustic monitoring in a few locations in subtropical waters of the central Indian Ocean indicated a strongly seasonal temporal distribution, inferring winter breeding habitat (Stafford et al. 2004, Samaran 2010, 2013a, Leroy et al. 2016). Pygmy blue whales are distributed in tropical to temperate latitudes not much further south than 54ºS (Branch et al. 2007). In the SWIO, a population is defined by the "Madagascar" song-type, heard from the Madagascar Plateau to the central Indian Ocean (Ljungblad et al. 1998, McDonald et al. 2006, Samaran et al 2013a). There is a likely summer feeding region on the Madagascar Plateau, for which abundance was estimated at 424-474 (Best et al. 2003). There were also large numbers of winter catches north of Madagascar between 0º - 10ºS, and recent spring sightings off Kenya, suggesting a potential breeding area; although it is not clear if these represent the Antarctic, SWIO pygmy, or North Indian Ocean subspecies (Branch et al. 2007, Barber et al. 2016).

Cerchio et al. (2016) reported evidence for the presence of blue whales in the northern Mozambique Channel off northwest Madagascar, including a pair encountered in 1,800m depth water off Nosy Be, and distant recordings of Madagascar song-type from shallow water in December 2014 and 2015 (Figure 1). Prior to this, socio-ecological interview surveys with local fishermen had indicated reports of blue whales from several locations along the west coast of Madagascar, from Ifaty in the southwest, latitude 23.2°S, to Nosy Be in the northwest, latitude 13.3°S (Cerchio et al. 2012, 2014).

Fin whales are distributed around Antarctica in the Southern Ocean and like blue whales exhibit seasonal breeding and migratory movement into as-yet poorly defined lower latitudes. Fin whales globally produce a song consisting of a series of short (ca. 1sec) down-sweep pulses in the 30-15Hz bandwidth (Watkins et al 1987, xxxx). Analysis of fin whale recordings from the Southern Hemisphere suggest geographic variation in fin whale song, defined by a secondary spectral energy peak at varying frequencies above 80Hz; it was speculated that this geographic variation may indicate population identity and structure (Gedamke 2009). Limited PAM data in the Southern Hemisphere indicates that fin whale singing and presence in sub-tropical waters is highly seasonal and correlated with breeding season, inferring seasonal migration into low latitudes during the Austral winter (Samaran et al 2013b).

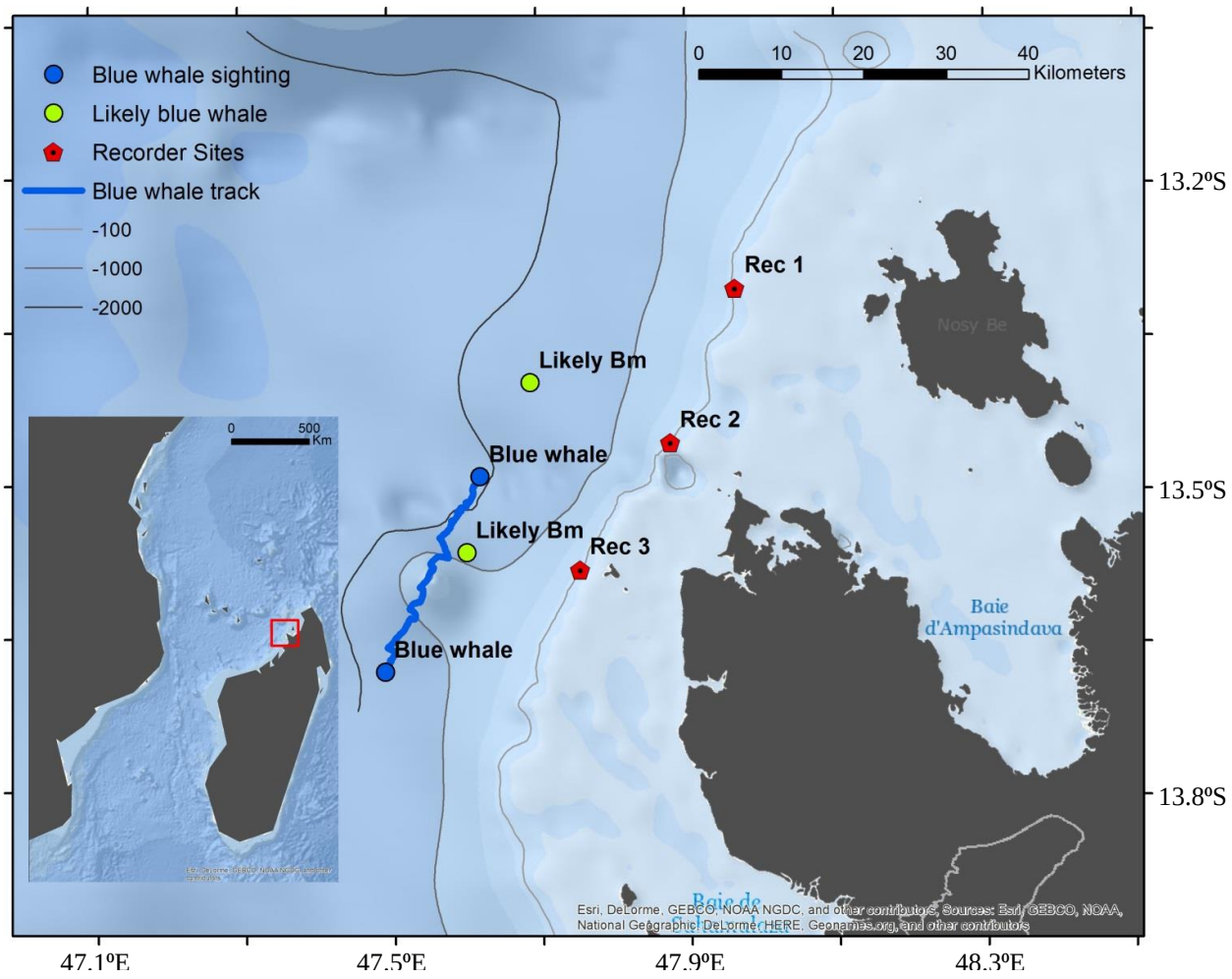

Figure 1. Map of field site showing Nosy Be (base of small boat work) and positions of three acoustic recorders deployed during 2017 immediately off the shelf break at 225-275m depth. Illustrated are the position and track of a pair of blue whales encountered and followed over a 4-hour period on October 11, 2012, and additional positions of two likely blue whale sightings during 2012 offshore surveys. These data document the proximity of blue whales within 25km of the Madagascar coast and within 15km of recorder positions. Inset shows the positon of the detail map relative to Madagascar and the east African coast.

Methods

Passive acoustic monitoring was conducted off the Nosy Be region of northwest Madagascar over a period of 28 months using two different recording protocols described below. Archival recorders used were SoundTrap 300STDs with external battery pack (oceaninstruments.co.nz), which provides up to 76day battery-limited continuous recording endurance. The SoundTrap recorder has a flat response from 20Hz-60kHz (+/- 3dB) with a 34dB re 1 µPa noise floor and a full scale response of 174.1 dB re 1 µPa including system gain. During the first 16 months (10 December 2016 to 9 April 2018), four approximately 4-month deployments were conducted. Recorders were placed at three locations each separated by 20km, just past the shelf break from north to south: Rec Site 1, Sakatia-DW (13.28ºS, 48.01ºE), at 227-250m bottom depth; Rec Site 2, Ankazoberavina-DW (13.45ºS, 47.91ºE), at 277-280m bottom depth; and Rec Site 3, Iranja-DW (13.59ºS, 47.78ºE), at 272-278m bottom depth (Figure 1). The

central recorder of the three (Ankazoberavina-DW) was placed just 420m offshore of the site of the shallow recorder that had detected blue whale song in December 2015 at a depth of 38m, indicating a very steep drop-off. Recording parameters were a sample rate of 24kHz (for an analysis bandwidth of 12kHz) and a 50% duty cycle recording 30min every 60min, yielding a 139day (4.6month) estimated maximum recording period per deployment. The 24kHz SR was chosen because it is the lowest rate available on the SoundTrap, and does not limit endurance due to storage space (i.e., endurance is entirely determined by battery limitations and therefore maximises temporal sampling performance of recorder). During the last 12 month period (11 April 2018 to 18 Mach 2019) one recorder was placed at the Rec Site 1, Sakatia-DW, for two approximately 6-month deployments. Recording parameters were a sample rate of 24kHz and 96kHz (after increasing storage capacity of the SoundTrap) and a 33% duty cycle recording 20min every 60min, yielding a 192day (6.4month) estimated maximum recording period per deployment. The units were deployed attached to a locally constructed anchor with an acoustic release, the Vemco Ascent system (http://ascent.vemco.com) and a hard deep-water float. The PAM rigs had a system maximum depth rating of 500m, so 250-300m was conservative, and recorders were floated approximately 5m off the sea bottom.

Upon retrieval, the Soundtraps were downloaded and the archival acoustic files decompressed into wav files (a lossless compression algorithm is used by the SoundTrap software that provides on average 3x compression dependent on broadband noise amplitude, Johnson et al. 2013). The resulting 24kHz or 96kHz 16bit wav files were then down-sampled to 2kHz sample rate to reduce size and increase manageability of the data set for low-frequency analysis. The chosen 2kHz sample rate has been found convenient to assess presence and distribution of a wide range of baleen whale vocalizations, from low-frequency blue and fin whales to mid-frequency minke and humpback whales.

Manual browsing of spectrograms was conducted for review of baleen whale vocalizations and logging for hourly presence. Although manual browsing spectrograms and logging of individual vocalizations for large data sets can be prohibitively time consuming, we have found that a rapid browse in order to log simple presence is an effective means to provide an overview of the data for moderate size datasets as in this study. The results are informative and the process is indispensable for exploration of the dataset and detecting unusual, previously unknown, or unexpected vocalization types or other acoustic signals, which may be missed by automated detectors targeting specific vocalizations. Raven Pro 1.5 (Bioacoustic Research Program, Cornell University) was used to generate continuous spectrograms of multiple consecutive 30min or 20min samples, allowing several hours of data to be scanned on a single screen. Manual scans were conducted for low frequency blue and fin whales, using a 0-65Hz bandwidth, 30min or 20min per spectrogram line (depending on duty cycle protocol), 4096pt FFT, 50% overlap, and Hanning window. In order to document hourly presence, the presence of each species' song encountered was logged once for every sample. Song was scored as present when the analyst could perceive in the spectrogram individual song units, irrespective of the faintness of the signals, or how low of a Signal-to-Noise (SNR) ratio; thus the results may be considered an indication of the presence of the species within the region, likely within a few 100km of the recording site (however, propagation modelling to estimate detection range has not been done). In addition to baleen whale song, geophysical seismic surveys were detected during the period from October 2017 to June 2018 and also logged. For each sample in which they were detected, the amplitude of the airgun blasts was subjectively scored on a scale from 1 to 4 according to the perceived potential to mask vocalizations: SS1, low, unlikely to mask vocalizations, but distant airgun blasts perceptible; SS2, moderate, may mask low SNR vocalizations; SS3, high, likely to mask low and some moderate SNR vocalizations; SS4, severe, near complete masking in target bandwidth, unlikely to detect any but the highest of SNR vocalizations. Only Rec Site 1, Sakatia-DW, is reported here as it was the only site where recording occurred for the entire monitoring period.

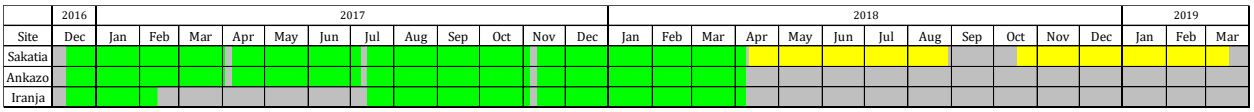

Figure 2. Schematic of recording effort at three sites off Northwest Madagascar during 28 months from 10 December 2016 to 18 March 2019; complete 24hr recording days are indicated in green (at 50% duty cycle, 30min every 60min) and yellow (at 33% duty cycle, 20min every 60min), and grey represents periods of no data. Recorder malfunction at the Iranja site on 14 February 2017 resulted in a truncated deployment 1 and loss of deployment 2 during recorder repair for that site. Premature battery failure at the Sakatia site on 30 August 2018 resulted in a truncated deployment 5, and a 50day gap in recording. Otherwise gaps between deployments for recorder download and refurbishment were 2 to 4 days.

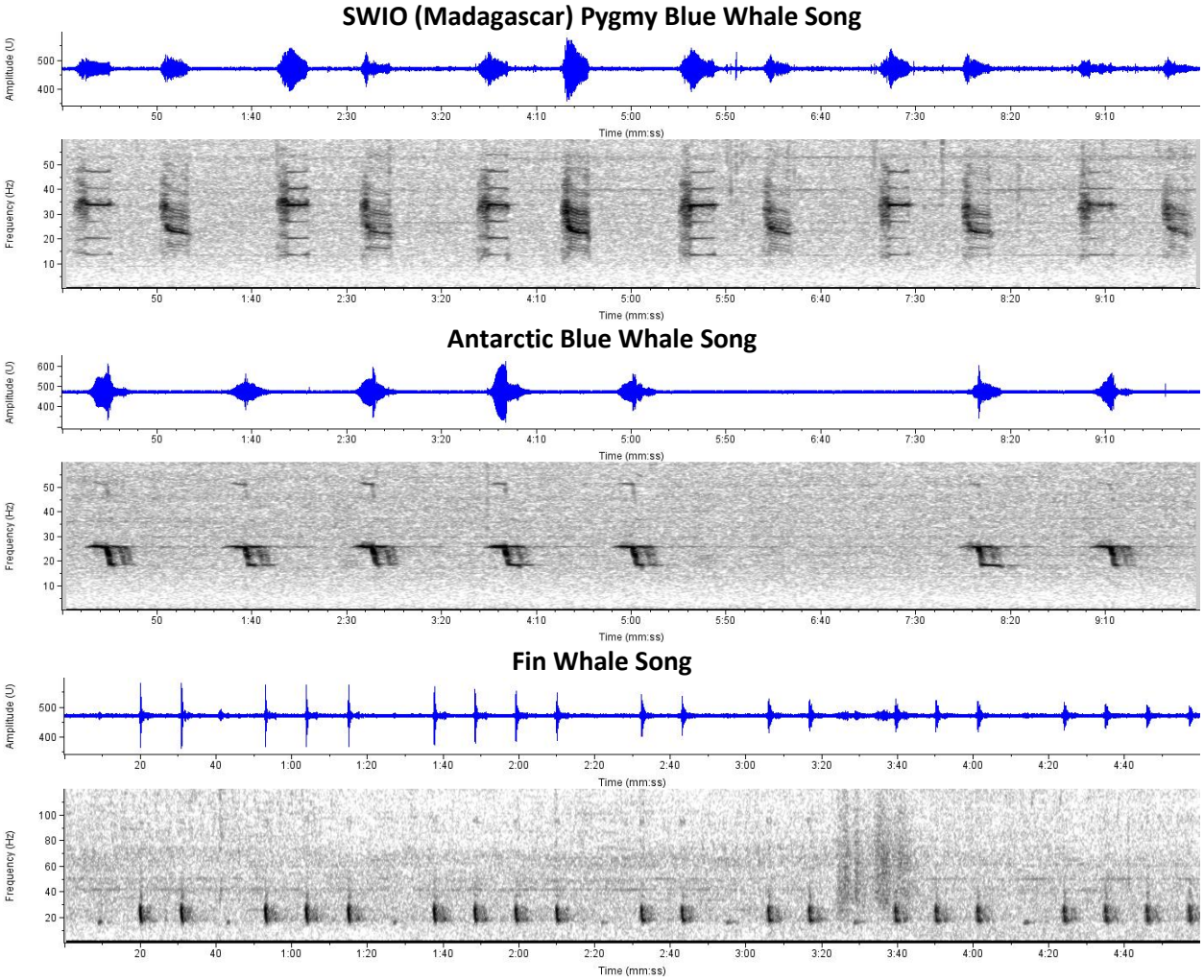

Figure 3. Example spectrograms and waveform envelops (in blue) of high signal-to-noise ratio recordings of blue and fin whale song recorded off Sakatia-DW (Rec Site 1, Figure 1). Represented, top to bottom, is Antarctic blue whale song, Madagascar pygmy blue whale song (2kHz SR, 8192pt FFT, 95% overlap, Hann window), and fin whale song sequence (2kHz SR, 2048pt FFT, 95% overlap, Hann window).

Results and Discussion

Recording Sample

Four deployments of the three recorders were successfully completed during: 10 December 2016 to 3 April 2017 (114 days); 7 April to 9 July 2017 (93 days); 12 July to 6 November 2017 (117 days); and 10 November 2017 to 9 April 2018 (150 days); and two deployments of one recorder were completed during: 11 April to 14 October 2018 (186 days) and 19 October 2018 to 30 March 2019 (162 days) (Figure 2). In all but three cases, recorders contained complete datasets and were still recording upon retrieval (Figure 2). A total of 17,702hr of recording was collected during 1,572 recorder days for all sites combined. For Rec Site 1, Sakatia, a total of 8,016hr of recording was collected during 765 recorder days, and reviewed for the results reported here.

Initial review of data revealed extensive documentation of both Antarctic and pygmy blue whale song-types (Figures 3 and 4), and fin whale song (Figure 3). In addition, Antarctic minke whale, humpback whale and Omura's whale song was also detected (not shown or reported on here). For particularly the Antarctic blue, SWIO (Madagascar) pygmy blue, and fin whales, the highest signal-to-noise ratio (SNR) songs are shown (Figure 3); the singer in each case was likely within 10km or a few 10s of km of the recorder, given the received signals' clean, non-degraded quality, high amplitude and clear presence of sidebands (SWIO blue) and harmonics (Antarctic blue). Most detections reported in the hourly presence analysis were lower SNR of much more distant animals, however it is likely that many if not most were within 100 or 200km, which will eventually be tested with propagation modelling.

Southwest Indian Ocean Pygmy Blue Whale Song (Madagascar Song-type)

SWIO Madagascar song-type blue whale song was initially detected on all recorders in a cursory browse of the first few months of data. Frequently multiple individuals were audible in a chorus of song. The systematic manual browse revealed that song was present throughout the year, with yearly bi-modal peaks of singing activity during May-July, correlating with the Austral late autumn/early winter, and October-January, correlating with Austral late spring/early summer, and sporadic detections in the intervening periods (Figure 4). This bimodal pattern was present during all monitored years, with five distinct peaks representing two autumn/winter peaks (2017 and 2018 seasons), and three spring/summer peaks (2016/2017, 2017/2018 and 2018/2019 seasons). During the heights of the peak periods, song was detected nearly 24 hours/day for several days in a row. This pattern suggests a clear migration signal and therefore a migratory corridor in the northern Mozambique Channel.

The May-July peaks in song occurrence would presumably be attributed to animals migrating north in the Austral autumn/winter coming from a summer feeding area south of Madagascar and moving towards a winter breeding area to the north of Madagascar. The October-January peaks presumably represent the return southward passage of animals as they move from a breeding area back to the south. The summer feeding area would likely be the Madagascar Ridge/Plateau, as documented by Best et al. (2003). Best et al. (2003) reported on surveys from 7-18 December 1996 on the Madagascar Plateau/Ridge, and documented 110 individual pygmy blue whales from 25º-35ºS, 40º-45ºE, estimating population abundance at 424 (CV=0.42). Although Madagascar song was still heard during December off northwest Madagascar, in all years occurrence was on the decline, and thus the timing is broadly congruent with a migratory passage to the Madagascar Plateau. The winter breeding area may be off the Seychelles and the west Indian Ocean between 5ºN-10ºS, as indicated by Soviet whaling catches during November 1964 (Mikhalev 1996, 2000, Branch et al. 2007), and/or off Kenya and the east African coast as suggested by recent geophysical survey sightings during September and October (Barber et al. 2016). Mikhalev (1996, 2000) reports that pygmy blue whales were taken by Soviet whalers during November 1964 in equatorial waters near the Seychelles between 2Nº-5ºS, 50º-55ºE, whereas no whales were encountered in that region during operations in April 1965. Pregnant females taken in the Seychelles/Equatorial catches had

mostly small foetuses, congruent with a Southern Hemisphere breeding cycle (Mikhalev 1996, 2000), which further supports that this aggregation belonged to the SWIO pygmy blue whale population and that this region represented breeding habitat. Barber et al. (2016) collected sightings data from geophysical surveys off the coast of Kenya from 9 September 2014 to 15 January 2015; 38 individual blue whales were sighted primarily between 2º-5ºS, 43º-45ºE, all between 13 September and 18 October, ceasing in mid-October presumably due to the whales leaving the area. The timing of Barber et al. (2016) sightings correlates well with a southward migration out of that region and into the northern Mozambique Chanel between October and January, as documented by our acoustic records. Thus we believe there is strong evidence linking the summer assemblage on the Madagascar Plateau/Ridge with the equatorial winter assemblage stretching from the coast of Kenya to the Seychelles, and the use of the Mozambique Channel as a migratory corridor.

Timing and singer density of the migratory passages varied to some extent during the 28 month period (Figure 4). During 2017, the northward migration commenced in late April/early May, peaking in late May/early June, and then declined by late July; during 2018 the trend is similar but shifted slightly later in the year with comparatively less singing activity in the first half of May, the peak lasting into July, and then not declining until mid-August. For the southward migration, we did not document the start of the 2016/2017 migration since recording started in early December, but it appears that it was peaking in mid-December and declines by early January; the 2017/2018 commences in mid-October, appears to peak in from early November to mid-December, and declines by early January, similar to the previous year. In 2018/2019, our data is somewhat limited by the recording gap from early September to mid-October; however, the pattern is anomalous compared to the other peaks with overall far less activity, almost no activity in late October and cessation by mid-December. This is incongruent with the strong singing pulse during the northward migration in the previous season (May-August 2018) and suggests that the southward migration may have occurred either further offshore, or along the east coast of Madagascar. The sporadic detections in between the peaks, at times for most hours during a several day period, particularly after the southward migrations (e.g., 25 February–1 March 2017, and mid-January to late-February 2018) suggest that the migration is prolonged or there are regular stragglers throughout the year.

Antarctic Blue Whale Song

Antarctic blue whale song was present yearly during a single period, throughout the Austral late autumn/winter from May to September, overlapping with the SWIO pygmy blue whales northward migration (Figure 4). The timing of the two documented peaks varied considerably between 2017 and 2018. In 2017, the first Antarctic blue whale song was recorded on 21 May, and peaked rapidly in early June. The daily occurrence is not as consistent as for SWIO pygmy blue song, with several gaps of no detected song ranging from 6 to 15 days throughout a 3.5 month period from early June to mid-September with the last occurrence for the year being 12 September. In 2018, the peak was offset by a full month earlier, with the first occurrence on 16 April, several strong peaks in activity for a shorter 2 month period between mid-May and mid-July, and the last occurrence for the year being 31 July. Also the frequency of occurrence in terms of number of hours per day present does not reach the levels observed for SWIO pygmy whales. This suggests that there may be fewer Antarctic blue whales visiting this area, or that they are further offshore, although the SNR of some examples (as in Figure 3) indicates that individuals of both subspecies at times come very close to the shelf break. Furthermore, during peak occurrence periods, choruses of multiple individuals were not uncommon. Therefore, the presence during the autumn/winter suggests that the northern Mozambique Channel may host a breeding season aggregation.

The unimodal occurrence of Antarctic blue song each year suggests that the population utilizing this region may not move much further north than northern Madagascar, or at least that the northern Mozambique Channel is part of a winter destination or range. Branch et al (2007) observed that while it is accepted that Antarctic blue whales migrate into lower latitudes during winter for calving and mating,

there is little evidence in the Indian Ocean to define these regions or infer what proportion of the population migrates. Several previous acoustic studies have documented the presence of Antarctic blue whales in latitudes lower than 45°S with winter distributions. Stafford et al. (2004) reported the detection of Antarctic blue whale song off the Chagos Archipelago (Diego Garcia) at 6°-7°S, 71°-72°E, during the austral winter months of May-July, however note that few detections were made and that the population may not migrate that far north in appreciable numbers. Samaran et al, (2013) and Leroy et al. (2016, 2018) detected Antarctic blue song at six different locations in the central/western Indian Ocean, ranging from 26°-46°S, 53°-83°E, each detected throughout the year but peaking during winter from May-August; Leroy et al. (2016) reviewed data but did not document any Antarctic blue whale song at the most northern site examined at approximately 4°S. Barber et al. (2016) state that the live sightings of blue whales off Kenya at 2º-5ºS could be either pygmy or Antarctic blue whales; however, their sightings during mid-September to mid-October all occur after Antarctic blue whale song ceases off northwest Madagascar, presumably because the animals have departed on their southern migration. Therefore, the whales off Kenya are unlikely to be Antarctic blue whales, and the evidence we present combined with other acoustic studies suggests that the winter distribution may be predominantly south of 10ºS.

Other Blue Whale Acoustic Populations (Sri Lanka and Oman Song-types)

In addition to SWIO pygmy and Antarctic blue whale song, two other low-frequency song types were heard at low SNR (Figure 5). Sri Lanka-type blue whale song was also recorded, first heard on 11 December 2016, the day after deployment, on the Ankazoberavina-DW (Rec Site 2), and was consistently detected for at least two days (Figure 4). During the systematic browse of the Sakatia-DW (Rec Site 1) data, this event was not detected; however a second event was detected during 15-16 January 2018. In each case it appeared to be a single animal and very distant so at the edge of perception on the manual browse. Primarily the second and third units of the Sri Lanka song, at approximately 60Hz and 100Hz respectively, could be clearly discerned. This suggests that although very infrequent, Sri Lanka song-type acoustic population travel south into the Mozambique Channel; vagrancy of whales from this acoustic population has also been documented off the coast of Angola in the tropical South Atlantic (Cerchio et al. 2010).

An additional song-type was recorded that to the best of our knowledge is a previously unreported blue whale song (Figure 5). This song has also been documented in the Arabian Sea off Oman (northern Indian Ocean) and off the Chagos Archipelago (Cerchio et al. in review). It was only ever recorded off Madagascar at low SNR, although there exist higher SNR examples from Oman and Chagos (see SC/68B/ForInfo/xx). Due to the characteristics of the song closely matching that of typical blue whale song, and the close temporal association of recordings with sightings of blue whales off Oman, Cerchio et al. (in review) attribute the song to a blue whale, and label it the Oman song-type. The song was recorded off the northwest Madagascar in both 2017 and 2018 during early April to late May 2017, and each time detected in a few bouts last for several days, always of a single distant singer at low SNR (Figure 4). Cerchio et al. (in review) report that the song-type is much more prevalent in the Arabian Sea and western Chagos (Diego Garcia North) recording sites, and propose that this acoustic population is the Arabian Sea blue whale population that was heavily targeted by Soviet whaling in the 1960s (see SC/68B/ForInfo/xx for discussion).

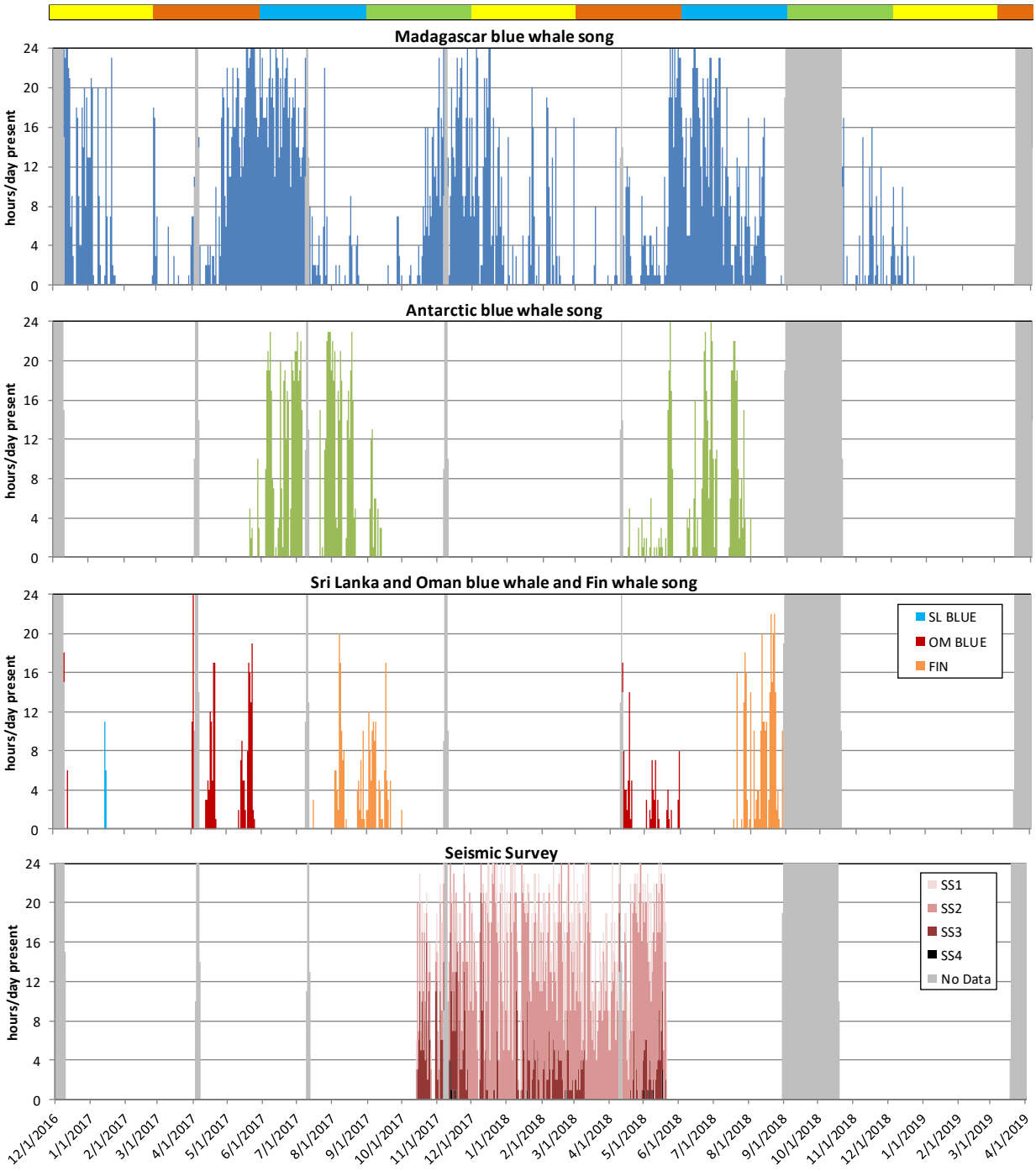

Figure 4. Hourly occurrence of low frequency baleen whale song and seismic survey detected on Sakatia-DW site (Recorder 1). Data represent 28 months of monitoring, from 10 December 2016 to 18 March 2019; grey bars represent hours and days of no data before, between and after deployments. For each day, bars represent the number of hours in which whale song was detected based upon a manual browse of spectrographic data from 0-60 Hz. Represented from top to bottom are presence of: Madagascar pygmy blue whale song; Antarctic blue whale song; Sri Lanka blue/Oman blue/fin whale song; and seismic survey airguns, with amplitude coded on a subjective scale from low (SS1) to severe (SS4). Astronomical seasons are indicated in the top bar representing the Austral summer (yellow), autumn (orange), winter (blue) and spring (green).

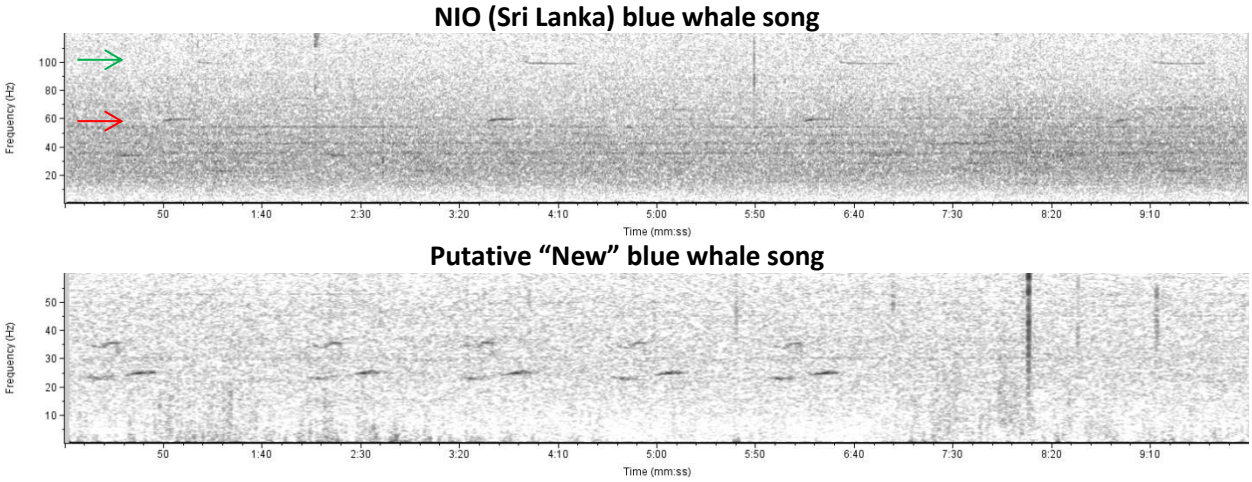

Figure 5. Low SNR detections of Sri Lanka type blue whale song (upper panel) recorded off Ankazoberavina-DW (Rec Site 2) on 13 December 2016, with the 60Hz (red arrow) and 100Hz (yellow arrow) units of four consecutive phrases evident; and a previously undescribed song of a putative blue whale recorded off Sakatia-DW (Rec Site 1) on 2 April 2017, illustrating five consecutive phrases of approximately 45sec duration, and energy between 21Hz and 36Hz. (2kHz SR, 8192pt FFT, 95% overlap, Hann window).

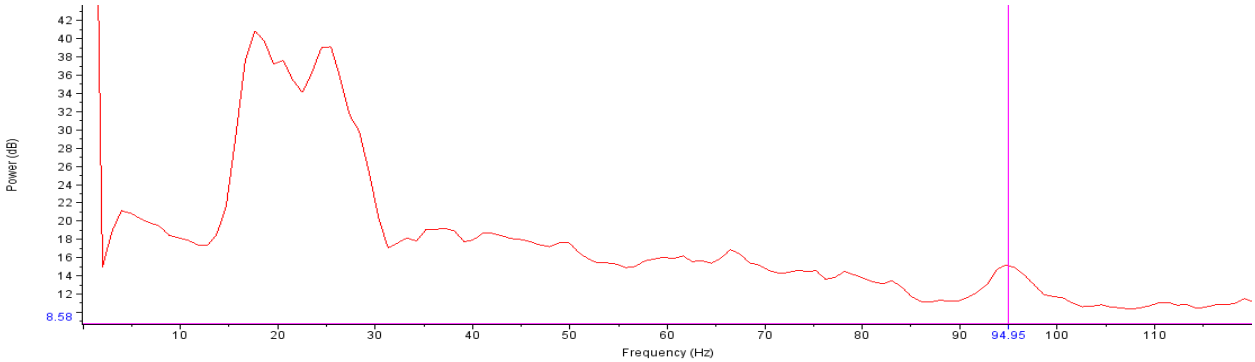

Figure 6. Average Power Spectral Density vs. frequency plot of a 6min sequence of detected fin whale song, showing energy spread of the main pulse component between 15-30Hz and the secondary peak at 94-96Hz.

Fin Whale Song

Fin whale song was present during the late Austral winter, from early August to mid-September in 2017, and shifted slightly early in 2018 during mid-July to late August (although due to the recording gap in 2018, it is not known if fing whale song occurred in September or early October) (Figure 4). At times high SNR series of 20Hz pulses were recorded, which included a single secondary peak at 94-96Hz (Figure 6); this appears to be distinct from the three different song types described by Gedamke (2009) that each differed in the frequency of this secondary higher frequency peak. It is possible that this song type may represent the same as previously detected off Western Australia and Antarctica (at ~75-80°E) with a peak at 99Hz (Gedamke 2009), but after several years of progressive decrease in frequency; further analysis and direct comparisons are necessary to clarify. The timing of fin whale song suggests a later arrival than Antarctic blue whales and a lower rate of occurrence and occupancy, potentially representing the northern extent of breeding habitat. Also the temporal shift in occurrence from winter 2017 to earlier in winter 2018 is similar to the pattern observed for Antarctic blue whales.

Seismic Surveys

Geophysical seismic surveys were documented nearly continuously for a seven month period between 13 October 2017 and 20 May 2018 (Figure 4). Airgun blasts were detected on 212 days of this 220 day period (96.4% of days), and during 3,791 of 4,426 hour samples (85.7% of hours). It is not known where the seismic surveys were occurring or how far from our recorders; however, at times they were close enough to completely mask the bandwidth between 10-60Hz (subjective amplitude category SS4), such that all but the highest SNR whale vocalizations would have been masked. The most severe masking (SS4) occurred highly infrequently in only 18 samples (0.5%); moderate masking (SS3), for which low SNR and some moderate SNR vocalizations were likely masked, occurred in 606 samples (16.0%); minor masking (SS2), for which low SNR may have been masked, occurred in 2,315 samples (61.1%); and faint airgun pulses (SS1), which were unlikely to mask vocalizations, occurred in 856 (22.6%) of samples. Although some vocalizations were likely missed due to the masking effect of these airguns (particularly in the 16.1% of samples with SS3 and SS4 categories), we do not believe that the overall trends were altered. More consequentially, these surveys were insonifying this habitat for an extended period of time, overlapping entirely with the 2017/2018 southward migration and the start of the 2018 northward migration of Endangered Madagascar pygmy blue whales, and with the start of the 2018 winter breeding season of Critically Endangered Antarctic blue whales. Given the well-documented potential for behavioural disturbance of baleen whales by seismic survey blasts, we believe that there is reason for concern for these recovering populations, particularly Antarctic blue whales, which remain at less than 10% of the pre-exploitation abundance.

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