Comparing passive acoustic data of Aural and Sono.Vault recordings off Elephant Island for September 2013

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ABSTRACT

In this study, we compare marine mammal acoustic presence data from two passive acoustic recording devices, Aural and Sono.Vault that recorded simultaneously off of Elephant Island northwest of the Western Antarctic Peninsula, to evaluate the effect of sampling rate and recording duty cycle on acoustic observations. Passive acoustic recordings sampled with two different sample rates (2.5 kHz and 16 kHz) and two recording duty cycles (five minutes per hour vs continuous) were compared. The aim of the study was to explore how a standard-used sampling rate and duty cycle compares to continuous recordings in terms of information about marine mammal acoustic presence. Applying a recording duty cycle can enable a longer recording period while at the same time effectively reducing data analyzing time. The analysis shows that there is no large difference in the results, when comparing duty cycled Aural data sampled with a frequency range of 16 kHz versus 2.5 kHz. Only killer whales (*Orcinus orca*) were detected more often in the data with higher sample rate, due to their high frequency vocalizations. The comparison of continuous Sono.Vault versus subsampled Aural data with a frequency range of 2.5 kHz displays that, as expected, with the continuous recording of Sono.Vault species are detected more often than in the sub-sampled recording of Aural. As a conclusion for this research site a sample rate of 2.5 kHz is suggested to be sufficient. To obtain reliable results on the occurrence of species, recordings may be continuous, although higher duty cycles than the one investigated here may also produce good results, but need to be investigated.

Key words: passive acoustic recording, marine mammals, Sono.Vault, Aural

1. Introduction

During the commercial whaling era in the 20th century, many marine mammal populations declined (Clark & Lamberson 1982, Trathan & Reid 2009, Branch & Williams 2006). Still today anthropogenic influences (e.g. drilling, military operations, fishing, vessels and tourism) are leading to losses of marine mammal habitats and populations in our oceans (Clapham *et al*. 1999, Thomas *et al*. 2016). Some species are already categorized as "endangered" (i.e. blue whale (*Balaenoptera musculus*) or sei whale (*Balaenoptera borealis*)) or "near threatened" (i.e. Antarctic minke whale (*Balaenoptera bonaerensis*)) by the IUCN (2018). Therefore, it is important to have a closer look at the needs of these animals, especially the territories they are using, to, for example, install marine protected areas. Since marine mammals are widely spread and often appear in great depths, it is challenging to examine their behavior like feeding, mating or breeding. In the majority of cases, temporal patterns like migration behavior and use of different habitats throughout the year (e.g. feeding, mating and breeding), are still unclear (e.g. for Antarctic blue whales, Thomisch *et al*. 2018). In addition research sites in remote areas, such as the Southern Ocean are difficult to reach; Only very few ships can access the Southern Ocean south of 60°, particularly during austral winter, when the Antarctic continent is surrounded by pack ice (Gordon 1981),

Elephant Island is an island in the north of the Western Antarctic Peninsula, at the boundary of the Antarctic Circumpolar Current in the Southern Ocean (61° 7′ S, 55° 11′ W, Fig. 1). Visual surveys reported in the past that baleen whales, like Antarctic blue (*Baleanoptera musculus intermedia*), fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*) and Antarctic minke whales appear off Elephant Island (Santora *et al*. 2010, Scheidat *et al*. 2011, Burkhardt & Lanfredi 2012, Joiris & Dochy 2013). Also toothed whales, like sperm whales (*Physeter macrocephalus*) and killer whales (*Orcinus orca*, in the following: orcas). Furthermore, seals, like leopard (*Hydrurga leptonyx*), crabeater (*Lobodon carcinophaga*), Ross (*Ommatophoca rossii*) and Weddell seals (*Leptonychotes weddellii*) were observed regularly off Elephant Island as well (Thomas *et al*. 1980, Bengtson *et al*. 1990, Casaux *et al*. 1997, Secchi *et al*. 2001, Thiele *et al*. 2004, Širović *et al*. 2006, Meister 2017). Many of the reports are based on visual surveys. However the light conditions above water are too dim during austral winter that visual surveys do not allow a year round monitoring. Sighting distances and light conditions under water discard all year-round underwater video recording, too. Therefore, in areas as Elephant Island, passive acoustic recording has logistic advantages over visual observations and enables monitoring of marine mammal species based on their vocalizations (Mellinger *et al*. 2007, Thomas & Marques 2012). Passive acoustic recording is an alternative to conventional sampling techniques. Hydrophones can be placed in various depths and left to record autonomously in remote areas and provide continuous long-term

Fig. 1: Antarctica with adjacent oceans. The red dot north of the Western Arctic Peninsula marks Elephant Island (Haran *et al.* 2005, graphic changed).

recordings. Advantages are that the recording is omnidirectional and covers a large area. It covers a wide range of sounds from low frequency moans, such as those of Antarctic blue whales, to high frequency echolocation clicks of orcas, but is non-invasive. Further, data collection is weather and light condition independent and since it is an autonomous sampling technique, it has a low cost/efficiency ratio. However, disadvantages are that it only captures information on presence of soniferous (i.e. sound-producing) species and individuals. Moreover the data storage and battery life are limiting factors to the recording time. Therefore it is necessary, when recording over a long period, to apply a subsampling scheme. This means that the recorder is set to a certain recording scheme (i.e. five minutes once or more times an hour) over a certain time span. While the advantage is to save data storage and battery life, since it is not recording continuously, the disadvantage is a lack of data in between two recordings. This could be trivial, but could also lead to a loss of important information.

In 2013 the Alfred Wegener Institute for Polar and Marine Research (AWI, Bremerhaven, Germany) deployed two types of autonomous recording devices (Aural and Sono.Vault) off Elephant Island (Boebel 2013). These recorders were simultaneously deployed at the same location and recovered in 2016. This deployment allowed direct comparison of the data from the two device types to assess how differences in sample rate and duty cycle impact presence/absence information on marine mammals.

2. Material and Methods

2.1. Passive acoustic data acquisition

For the comparison, passive acoustic data from September 2013 was collected off of Elephant Island (Fig. 1) for which two autonomous hydrophones, Aural (Multi-Électronique (MTE) Inc., Quebec, Canada) and Sono.Vault (Develogic GmbH, Hamburg, Germany), were deployed. The Aural recorder was equipped with two lithium battery packs each containing 64 LS33600 batteries and with two 320 GB hard drives. It was positioned at a depth of

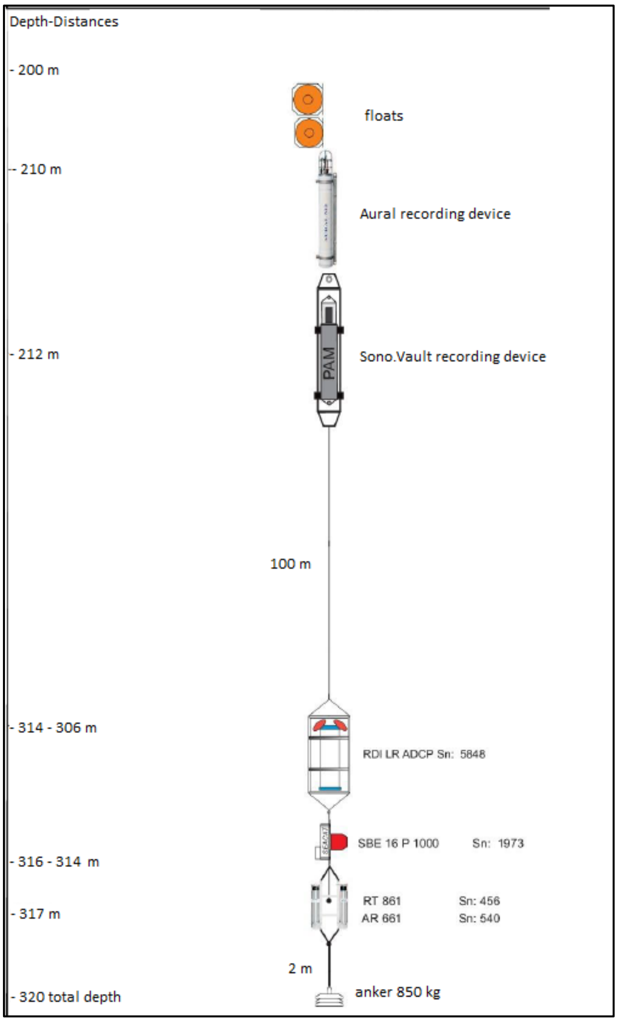

Fig. 2: Mooring scheme of mooring AWI 251-1, deployed from 16 January 2013 to 10 February 2016. The recording devices were placed in 210 m (Aural) and 212 m (Sono.Vault) depth (Source: Alfred-Wegener-Institute, Bremerhaven, Germany. Graphic changed).

212 m (total water depth 320 m, Fig. 2) and recorded in subsampling modus with a sampling rate of 32 kHz for five minutes every hour (Boebel 2013). A sampling frequency of 32 kHz allows recording with a maximum frequency of 16 kHz (Nyquist frequency). The Sono.Vault recorder was also equipped with LS33600 batteries and had a total storage capacity of 1.1 TB (35x 32GB SDHC). It was positioned in 210 m depths (Fig. 2), had a sampling frequency of 5.3 kHz and recorded continuously with a maximum frequency of 2.5 kHz (Boebel 2013, Rettig *et al*. 2013). The continuous recording of Sono.Vault goes at the expense of the overall recording duration, which was limited to 10 months during this deployment.

2.2. Data analyses

For the analysis, every second day of September 2013 was analyzed (starting with the 1st of Sept. 2013). The data of both acoustic recorders was analyzed consecutively and finally compared. To analyze the data, I used Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, NY, USA). The spectrograms seen in Raven were analyzed visually and aurally and scanned for vocalizations of marine mammals. Only the acoustic presence of marine mammal species was detected, not the number of individuals. A species was considered present if at least one call was evident. Detected vocalizations were compared with already existing sound samples of the Alfred Wegener Institute (Bremerhaven, Germany)**,** spectrograms shown in other publications and sound-examples uploaded in online databases[1] (e.g. NEFSC.NOAA.gov, Macaulaylibrary.org, Whalewatch.com) associated to marine mammal vocalization. The data was not subsampled additionally. For the statistics, Excel 2010 (Microsoft Corporation, Redmond, WA, USA) and R 3.5.2 (R Core Team, Vienna, AUT) were used. To be able to compare the data, results were sorted in three categories: Aural 16 Hz (fully recorded frequency range), Aural 2.5 kHz (only recordings in the frequency range 0 to 2.5 kHz were considered) and Sono.Vault 2.5 kHz. The results for Aural 16 kHz and Aural 2.5 kHz and the results for Aural 2.5 kHz and Sono.Vault 2.5 kHz were compared. To be able to compare the hourly recording of Aural (24 rec./d: one 5min file x 24hrs) with the continuous recording of Sono.Vault (144 rec./d: six 10min files x 24hrs), all species appearing in one hour of the continuous recording of Sono.Vault were summarized into one result for this hour (24 rec./d).

<u>3. Results</u>

First, the same data collected with different sample rates of Aural (16 kHz, 2.5 kHz) were compared. Secondly, data from Aural 2.5 kHz and Sono.Vault 2.5 kHz with the same sample rate, but collected with different duty cycles, were compared. I was able to detect blue (B), fin (F), humpback (H) and minke whales (M), as well as orcas (O). Furthermore, leopard (L), crabeater (C) and Ross seals (R) were detected. Former analysis of passive acoustic recordings from this location also found sperm whales (S)

[1]See Internet References.

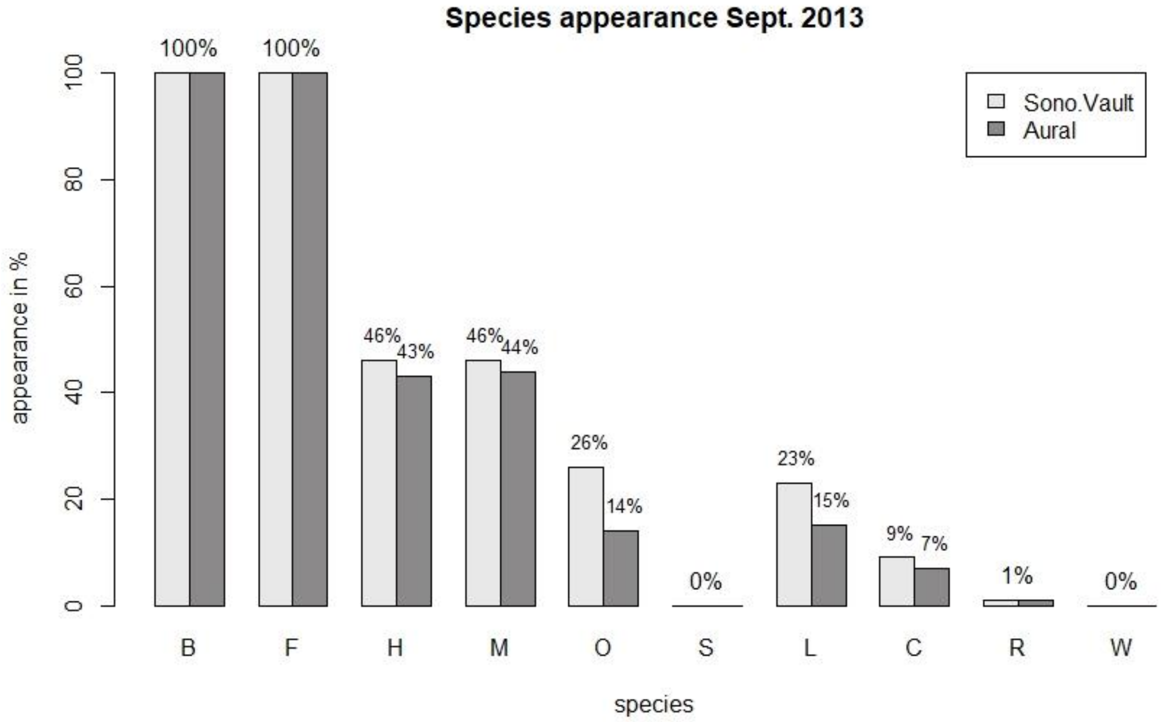

Fig. 4: Species appearance over the whole month of Sept. 2013, comparing Aural and Sono.Vault with a range of 2.5 kHz, shown in percent. The y-axis shows the species concentrated on in the analysis. The x-axis shows the appearance of a species over the whole month in percent (%). Blue- and fin whales were present all the time during the whole month, minke and humpback whales about half the month. The detected presence of orcas differs strongly between Sono.Vault and Aural. There were 12% more orcas seen, when analyzing the Sono.Vault recordings. For the seals, leopard seals appeared the most and show 8 % difference between the two recording devices. Again followed by crabeater seals. Ross seals were only detected 1% of the month, as also seen in Aural. Sperm whales and Weddell seals could also in Sono.Vault not be detected at all.

and Weddell seals (W) acoustically present (Meister 2017). During this study, which only subsets of the data analyzed, these species were not detected.

3.1 Comparing Aural 16 kHz with Aural 2.5 kHz

As seen in Fig. 3, differences in acoustic presence between the Au16 and Au2.5 data sets were only observed for orcas. For the higher frequency range (16 kHz) 3% more orcas were detected. Sperm whales were not detected in either of the frequency ranges. Blue and fin whales showed an appearance of 100% during the whole month. 100% means that they were detectable in every recording, so every hour of every day. For the seals, leopard seals were detected the most and in the same amount in both frequency ranges. Subsequently crabeater seals appeared the most. Ross seals were detected only 1% of the month and Weddell seals could not be detected at all.

3.2 Comparing Aural 2.5 kHz with Sono.Vault 2.5 kHz

Comparing Aural and Sono.Vault with both 2.5 kHz, differences between these two were much more obvious (Fig. 4). Some species appeared as often in Sono.Vault as in Aural (B, F, S, R, W), whereas other species had a higher appearance rate in Sono.Vault than in Aural (H, M, O, L, C). The continuous presence of blue and fin whales could also be seen in Sono.Vault like in Aural. Also sperm whales and Weddell seals were not detected at all. Furthermore, humpback and Antarctic minke whales appeared during approximately half of the month, but were detected more often in Sono.Vault than in Aural. The largest differences occurred between the Sono.Vault and Aural results for orcas (12% difference) and leopard seals (8% difference). For orcas, the detection rate in Sono.Vault was even higher than in Aural 16 kHz.

4. Discussion

4.1 Comparing Aural 16 kHz with Aural 2.5 kHz

The differences in the results when analyzing Aural 16 kHz or 2.5 kHz, were very small (Fig. 3). Every species was seen in both frequency ranges equally often, except orcas. Orcas can generate various sounds like whistles, clicks and pulse calls (Ford 1989). The sounds are located in frequency ranges between 250 Hz and 85 kHz (Diercks *et al.* 1973, Ford 1989), depending on the sound. Frequency levels of clicks and whistles are very divers, but it is not unusual that the minimum frequency of these sounds exceed 2.5 kHz (Ford 1989), that they are only detectable in ranges that are higher than 2.5 kHz like in Aural 16 kHz. The other nine species produce sounds in lower frequency ranges. Examples are the Z-calls of Antarctic blue whales that range from 18 to 30 Hz (Ljungblad *et al*. 1998) or the 89-Hz-pulse of fin whales (Širović *et al*. 2009). Higher calls like the ones of leopard seals occur between 200 Hz and 4 kHz (Van Opzeeland *et al*. 2010) but are still mostly detectable in a range between 0 and 2.5 kHz, so were able to be detected in Aural 2.5 kHz and Aural 16 kHz. When having a look at the continuous presence of Antarctic blue and fin whales, it is important to mention, that a detected presence of a species does not mean that individuals were necessarily close to the hydrophone. Water conducts sounds about five times faster than air, without losing information (Bradley & Stern 2008). Sounds, especially of lower frequencies like of blue and fin whales, can be transported in water well over hundred kilometers (Širović *et al*. 2007, Bradley & Stern 2008, Miller *et al*. 2015). Nevertheless, detecting blue and fin whales in September is still rather unusual since it is austral winter/spring in Antarctica at that time, when the species are generally thought to still be at lower latitudes and more temperate or even tropical waters for breeding (Mackintosh 1966). For humpback whales, it is already suggested that females, which do not expect a calf, overwinter at their feeding grounds in the Southern Ocean (Brown *et al*. 1995). The resulting sex-bias towards females again might attract male humpback whales to overwinter in the Southern Ocean, too (Brown *et al*. 1995, Van Opzeeland *et al*. 2013). This is suggested since high-frequency sounds occurred as humpback whale songs during austral winter, which are mainly produced by males (Darling & Bérubé 2001).

4.2 Comparing Aural 2.5 kHz with Sono.Vault 2.5 kHz

The continuous presence of blue and fin whales was also seen in the comparison of Sono.Vault and Aural 2.5 kHz. Both showed an appearance of 100% which means that both species appeared in every hour of every second day in September 2013. Same results for both recording methods were seen for sperm whales and Ross and Weddell seals: Sperm whales and Weddell seals could not be detected at all during the whole month. Ross seals were seen 1% of the month, both in Aural and Sono.Vault. For the rest of the detected species, Sono.Vault showed in every case higher appearance rates than Aural. This is not surprising: Sono.Vault recorded continuously throughout the whole month, without any subsampling scheme. Every recording was analyzed and every species seen in a whole hour was included in the presence information. Since Aural only recorded five minutes every hour, species that did not appear in this time span, where not counted as present for the whole hour. Having this in mind, it was expected, that the differences between these two recording methods would be much stronger. Detected appearances for humpback and minke whales only differed by 3% (H, rounded) and 2% (M, rounded). For crabeater seals the difference was also only at 2%, which are about seven hours of presence more over the whole month. Orcas and leopard seals showed the biggest differences: Leopard seals

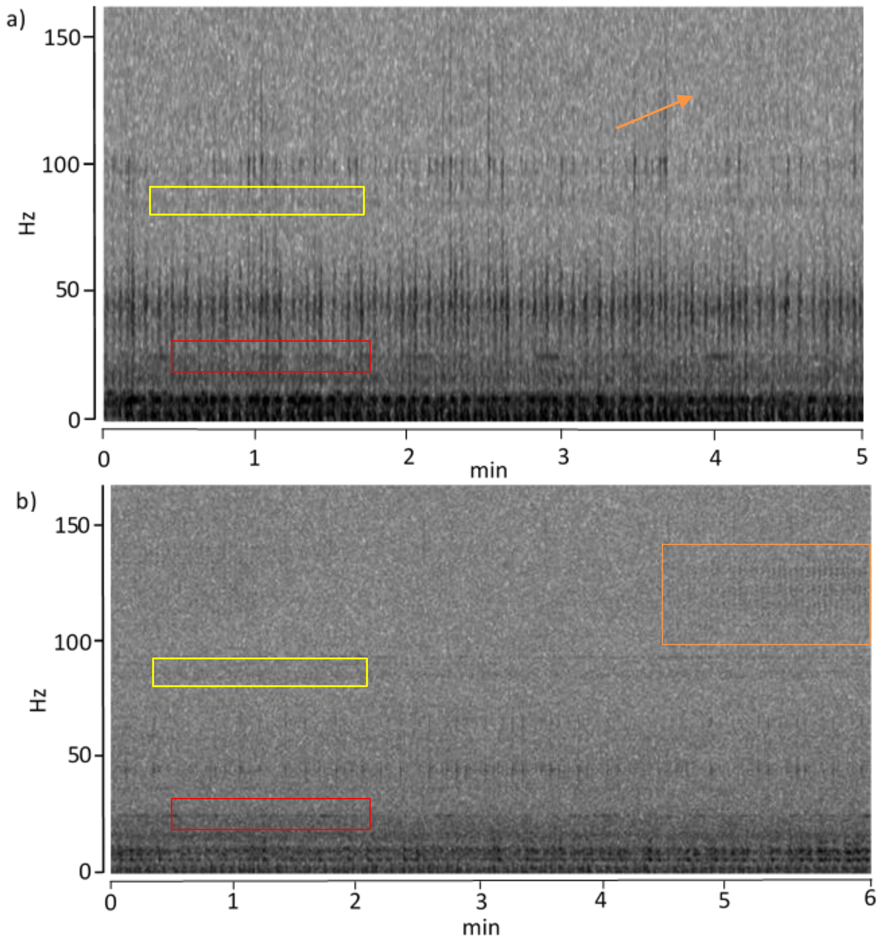

Fig. 5: Comparison of spectrograms of Aural and Sono.Vault. The spectrograms shown are both of the same time on the same date (05.09.2013, 8 pm). In Aural (**a**) and in Sono.Vault (**b**) blue (red) and fin whales (yellow) can easily be detected. The biggest difference is seen in the detection of the minke whale (orange). In Sono.Vault the minke whale sound pattern is very visible, in Aural though it is hard to see. Furthermore, the background noise is aurally recognized in both recordings, but is seen as aliasing more strongly in Aural than in Sono.Vault. Another example is shown in the Appendix (App. 1).

could be detected 8% more often in Sono.Vault than in Aural, orcas even 11% more often. One explanation could be that both species do not appear over a long period of time like blue, fin or humpback whales. In the recordings both species appear at times for several minutes and then disappear again. This can be retraced in the continuous Sono.Vault recordings. When the species were absent in the five minutes the Aural device was recording, they count as absent for the whole hour. Further, high frequency sounds do not get conducted as far in water as low frequency sounds (Bradley & Stern 2008), therefore high sounds of orcas cannot be detected over a long distance, like for blue or fin whales. Another fact relevant to leopard seals is that they are semiaquatic marine mammals, which explains short temporal appearances underwater.

Another factor that might have influenced the analysis were different resolutions of Aural and Sono.Vault in the same frequency range: When comparing both recording devices, it was Aural that showed a more diffused spectrogram than Sono.Vault (Fig. 5). This is because Aural recorded over 16 kHz, so zooming in to 2.5 kHz or less leaded to a poorer resolution. At times when detection was not possible aurally, visual analysis helped to detect the species by its sound pattern anyway. This was more reliable in Sono.Vault than in Aural. Therefore it is possible that some species were not aurally detectable in both recording methods, nonetheless visually detectable in Sono.Vault but not in Aural.

5. Conclusion

The compared data between Aural 16 kHz and Aural 2.5 kHz did not show significant differences. Aural 16 kHz showed slightly higher detection rates for orcas than Aural 2.5 kHz, which can be led back to the orcas high frequency vocalization. Between Sono.Vault 2.5 kHz and Aural 2.5 kHz the differences were more obvious, but also unsurprising. The continuous recording of Sono.Vault enabled a detection of more species in one hour than Aural 2.5 kHz in the subsampled five minutes recording per hour. It is reliable to say that a frequency range of 2.5 kHz is enough to detect all ten species so far stated to occur off Elephant Island. Further, the lower sampling rate frequency range leads to a less diffused spectrogram, which allows a better analysis of species appearance also visually. Thomisch *et al*. (2018) had a closer look at the effects of subsampling of passive acoustic recording and suggest to collect short samples in short duty cycles to get a good overview over appearing species and reliable results. A subsampling scheme of five minutes recording every 20 or 30 minutes would be an example for that and also shortens the amount of data that the recording device has to be able to store. The continuous recording uses up a high amount of data storage, but also gives a sufficient way of detecting all species present. Nevertheless, analyzing continuous recordings takes up a high amount of working hours and is therefore not cost and time efficient. Recording with a range of 2.5 kHz in Sono.Vault and a sufficient subsampling is suggested. For species that only transit the observed area sporadically, like orcas or leopard seals, Thomisch *et al*. (2018) state that subsampling is not quite suitable. In their opinion, for these species it is inevitable to collect continuous records, to get the most reliable information.

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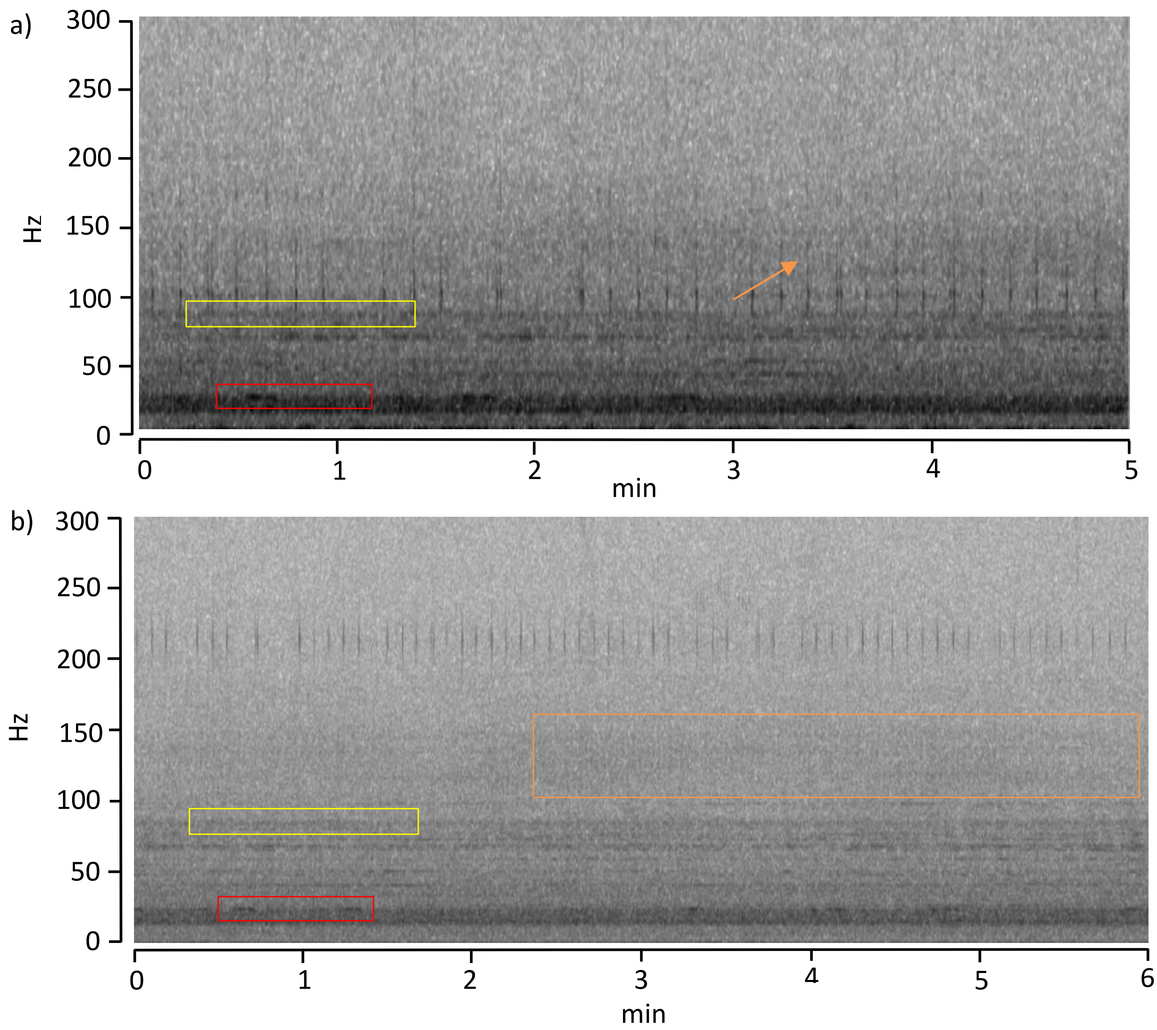
APPENDIX



App. 1: Comparison of spectrograms of Aural and Sono.Vault. Both spectrograms shown are from the 03.09.2013, 5 pm. As also shown in Fig. 5 the detection of blue (yellow) and fin whales (red) is in both cases, Aural (**a**) and Sono.Vault (**b**), possible. Detecting the minke whale (orange) is easy in Sono.Vault but a bigger challenge in Aural. Further, also the background noises are stronger in the Aural spectrogram than in the Sono.Vault spectrogram.