# Temporal patterns in the acoustic presence of marine mammals off Elephant Island, Antarctica

Bachelor thesis

by

**Marlene Meister**

Reviewers:

Prof. Dr. Claudio Richter
Biosciences, Bentho-Pelagic Processes, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven

Prof. Dr. Wilhelm Hagen
BreMarE – Bremen Marine Ecology, Marine Zoology, University of Bremen

External Supervisor:

Dr. Karolin Thomisch
Ocean Acoustics Lab, Physical Oceanography of the Polar Seas, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven

Dr. Ilse van Opzeeland
Ocean Acoustics Lab, Physical Oceanography of the Polar Seas, Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven

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**Summary**

To develop reliable and effective management and conservation strategies for marine mammals, a profound knowledge about their distribution, as well as on the location of key habitats are essential. The waters off Elephant Island (Antarctica) are thought to serve as a feeding ground for baleen whales; however, detailed long-term information on patterns in the distribution of marine mammals in this area is still lacking for many species. This study aimed to investigate i) the acoustic biodiversity, as well as ii) inter-annual patterns, and iii) intra-annual patterns in the acoustic presence of marine mammals off Elephant Island. For this purpose, passive acoustic data collected here from January 2013 to February 2016 were analyzed both visually (in the form of spectrograms) and aurally for the presence of marine mammal vocalizations. Daily acoustic presence of marine mammals was assessed based on species-specific vocal signatures. During the overall recording period, eight marine mammal species were identified: Antarctic blue whales (*Balaenoptera musculus intermedia)*, fin whales (*B. physalus)*, Antarctic minke (*B. bonaerensis)* whales, humpback whales (*Megaptera novaeanglia)*, Killer whales (*Orcinus orca*), sperm whales *(Physeter macrocephalus),* Leopard seals (*Hydrurga leptonyx*) and crabeater seals (*Lobodon carcinophaga*). For some species, a temporal pattern in the acoustic presence was detected, whereas other species did not exhibit a temporal pattern in their acoustic presence, but were acoustically present either year-round or rather occasionally. Antarctic minke whales were acoustically present from June to September and absent during austral summer, indicating that their acoustic presence was linked to the formation of sea-ice. Furthermore, the annual number of days with Antarctic minke whale calls declined from 2013 to 2015, which might possibly be linked to an inter-annual decrease in the sea-ice extent off Elephant Island. The amount of days with killer whale vocalizations peaked during austral winter when the amount of days with Antarctic minke whale vocalizations reached its maximum, indicating a possible link between killer whale acoustic presence and the availability of their prey (Antarctic minke whales, amongst others). Vocalizations of both seal species occurred primarily during austral winter and spring, i.e. from September to December for leopard seals and during September and October for crabeater seals, which is in accordance with their breeding period and suggests that both species were breeding off Elephant Island. Besides, vocalizations of all four baleen whale species were detected during austral winter, possibly indicating that part of the populations remained in the Southern Ocean year-round. Hence, this study adds further evidence for the hypothesis of a complex migratory behavior of baleen whales. Overall, this study suggests that the Elephant Island region serves as an important feeding and breeding habitat for several marine mammal species either year-round or seasonally. The identification of such ecologically important areas with high (acoustic) biodiversity can considerably benefit future conservation applications, such as the designation of marine protected areas.

Zusammenfassung

Um verlässliche und effektive Management- und Schutzstrategien für marine Säugetiere zu entwickeln, ist ein profundes Wissen über ihre Verbreitung sowie die Identifizierung wichtiger Lebensräume essentiell. Das Gebiet vor Elephant Island (Antarktis) stellt möglicherweise einen Nahrungsgrund für Bartenwale dar; jedoch fehlen detaillierte Langzeit-Informationen über Verbreitungsmuster mariner Säugetiere in dieser Gegend. Ziele dieser Studie sind darum i) die akustische Biodiversität mariner Säugetiere vor Elephant Island festzustellen, ii) Muster im Jahresvergleich (inter-jährlich) und iii) saisonale (intra-jährliche) Muster in der akustischen Präsenz mariner Säugetiere zu erforschen. Zu diesem Zweck wurden passiv-akustische Daten von Januar 2013 bis Februar 2016 sowohl visuell (in Form von Spektogrammen) als auch auditiv analysiert. Die tägliche akustische Präsenz wurde anhand artspezifischer Rufsignaturen erfasst. Innerhalb der gesamten Aufnahmeperiode konnten acht Arten von marinen Säugetieren identifiziert werden: Antarktische Blauwale (*Balaenoptera musculus intermedia)*, Finnwale (*B. physalus)*, Antarktische Zwergwale (*B. bonaerensis)*, Buckelwale (*Megaptera novaeanglia)*, Schwertwale (*Orcinus orca*), Pottwale *(Physeter macrocephalus),* Seeleoparden (*Hydrurga leptonyx*) und Krabbenfresser (*Lobodon carcinophaga*). Für manche Arten konnte ein zeitliches Muster in der akustischen Präsenz gefunden werden; andere wiesen kein solches Muster auf, waren aber ganzjährig oder gelegentlich akustisch präsent. Antarktische Zwergwale waren zwischen Juni und September akustisch präsent, im südlichen Sommer akustisch abwesend. Dies deutet darauf hin, dass ihre akustische Präsenz mit der Bildung von Packeis in Verbindung stand. Weiterhin nahm die Anzahl an Tagen mit Rufen von Antarktischen Zwergwalen von 2013 bis 2015 ab, was mit einer jährlichen Abnahme der Packeis-Ausdehnung vor Elephant Island zusammengehangen haben könnte. Die meisten Tage mit Rufen von Schwertwalen wurden während des südlichen Winters festgestellt, im gleichen Zeitraum zeigten Antarktische Zwergwale maximale akustische Präsenz. Dies deutet daraufhin, dass ein Zusammenhang zwischen der akustischen Präsenz von Schwertwalen und der Verfügbarkeit ihrer Beute (u.a. Antarktische Zwergwale) bestand. Rufe der beiden Robbenarten wurden hauptsächlich während des südlichen Winters und Frühlings gefunden, was in zeitlicher Übereinstimmung mit der Aufzuchtsphase der Jungen steht. Dies deutet darauf hin, dass beide Arten vor Elephant Island ihre Jungen aufzogen. Weiterhin wurden Rufe von allen vier Bartenwal-Arten während des südlichen Winters gefunden, was eventuell zeigt, dass Teile der Populationen ganzjährig

im Südlichen Ozean blieben. Daher liefert diese Studie weitere Hinweise für die Hypothese eines komplexen Migrationsverhaltens von Bartenwalen. Insgesamt deuten die Ergebnisse dieser Studie daraufhin, dass Elephant Island ein wichtiger Nahrungsgrund und Aufzuchtsort für marine Säugetiere ist; entweder ganzjährig oder saisonal. Die Identifizierung solcher ökologisch wichtiger Gebiete mit hoher (akustischer) Biodiversität kann von erheblichem Nutzen für die Entwicklung neuer Schutzstrategien sein, zum Beispiel für die Ausweisung von Meeresschutzgebieten.

## List of Tables and Figures

## 1 Introduction

Marine mammals (whales, dolphins and seals) take a key role in marine ecosystems worldwide (Bowen 1997, Ainley et al. 2010, Van Opzeeland 2010, Ratnarajah et al. 2015). They form a substantial component of the food chain and influence their environment via both top-down (i.e. consumer effects on resources) and bottom-up (i.e. resource effects on consumers effects (Bowen 1997, Ainley et al. 2010, Van Opzeeland 2010). Marine mammals are top predators and hence one important top-down effect having strong impacts on surrounding community structure is the consumption of prey, such as krill (*Euphausia spec.)* engulfed in large amounts by baleen whales (Kanwisher & Ridgway 1983, Laws 1985, Bowen 1997). Regarding bottom-up effects, sinking carcasses or defecations of marine mammals near the surface contribute to the recycling and input of nutrients and hence provide resources for various marine organisms (Smith & Baco 2003, Lavery et al. 2010). Besides, bottom-feeding species, such as walruses (*Odobenus rosmarus*) and grey whales (*Eschrichtius robustus*), modify their habitat, thereby offering opportunities to invertebrates to settle or feed (Bowen 1997).

Notwithstanding the ecological importance of marine mammals, past and current human activities have led to a drastic decline in several marine mammal species (Clapham et al. 1999, Thomas et al. 2016). During the commercial whaling era in the 20$^{th}$ century (roughly from 1925 to 1980), various whale species, but also seals, were massively hunted and consecutively over-exploited for commercial purposes (Clark & Lamberson 1982, Branch & Williams 2006, Trathan & Reid 2009). The Southern Ocean (i.e. waters south of 60°S) was the prime commercial whaling ground due to the high abundance of whales in this area during austral summer (Laws 1977, Clark & Lamberson 1982). Overall, about 1.6 million of great whales (all baleen whale species occurring in the Southern ocean and sperm whales) were killed in the Southern Ocean alone (Branch & Williams 2006). Baleen whales were the principal target of the commercial whaling industry and hence, several populations were reduced to a fraction of their original size (Clark & Lamberson 1982, Branch et al. 2004, Leaper et al. 2008, Pershing et al. 2010). Following the exploitation of most baleen whale populations, whalers increasingly focused on sperm whales (Whitehead 2002, Rocha et al. 2014, Clapham 2016). Besides, some species of seals, such as the Antarctic fur seal (*Arctocephalus gazella*), were depleted close to the point of extinction (Branch & Williams

2006, Trathan & Reid 2009). As a consequence of the exploitation during the commercial whaling era, multiple marine mammal species are nowadays still listed as "endangered" or "near threatened" by the IUCN[1], e.g. blue whales, fin whales, or narwhales (*Monodon monoceros*).

The recovery status of most marine mammal species is still unknown to date and there is a lack of information about their abundance and distribution patterns in many areas, as well as on the ecology and habitat use for many species[2]. Furthermore, several recent anthropogenic stressors, such as climate change, ocean acidification, commercial shipping, bycatch, pollution, and habitat destruction, have been identified to have cumulative impact on the world's oceans (Clapham et al. 1999, Halpern et al. 2015, Thomas et al. 2016). The resulting consequences for the marine environment cannot be anticipated with certainty at present but are likely to pose a hazard to marine mammals (Clapham et al. 1999, Thomas et al. 2016). To develop effective management and conservation strategies, a detailed understanding of large-scale spatio-temporal patterns in the distribution of marine mammals is required (Becker et al. 2012, Hammond et al. 2013). Particularly the establishment of marine protected areas (MPAs) is based on a profound knowledge of the location of key habitats and migration routes of different marine mammal species (Kelleher & Kenchington 1991, Hooker et al. 1999, Cañadas et al. 2002).

The South Shetland Island "Elephant Island" has been suggested to serve as such a key "hot-spot" for both whales and seals. It is located within the International Whaling Commission's area II (i.e. waters south of 40°S ranging from 0°E to 60°W) (Donovan 1991) at the boundary of the Antarctic Circumpolar Current (Fig. 1). Several studies reported high abundances of krill off the island and in the surrounding area (Laws 1977, Siegel 1988, Loeb et al. 1997, Reiss et al. 2008). Since baleen whales mainly prey on krill, Elephant Island has been hypothesized to be an important feeding ground for several baleen whale (Friedlaender et al. 2006, Santora et al. 2010). Three species of baleen whales were reported to occur directly (i.e. at small spatial scales of few kilometers) off Elephant Island based on visual surveys: Fin whales, humpback whales and Antarctic minke whales (*Balaenoptera bonaerensis*) (Santora et al. 2010, Scheidat et al. 2011, Burkhardt & Lanfredi 2012, Joiris & Dochy 2013). Exceptionally high aggregations of fin whales were observed off Elephant Island during

[1] For further information, see http://www.iucnredlist.org/ (last accessed on 23 June 2017).
[2] See ibid.

dedicated visual surveys in autumn 2012, indicating that Elephant Island might serve as a feeding ground for fin whales before migrating towards lower latitudes during austral winter months (Burkhardt & Lanfredi 2012, Joiris & Dochy 2013). Additionally, vocalizations of Antarctic blue whales were recorded off Elephant Island year-round (Meister et al. 2017). However, since blue whale calls in the Southern Ocean can range over large distances of more than hundred kilometers (Širović et al. 2007, Miller et al. 2015) the acoustic presence does not necessarily imply the occurrence of this species directly off Elephant Island. Regarding toothed whales, two species were visually observed off Elephant Island: Gray's beaked whale (*Mesoplodon grayi*) and Southern bottlenose whale (*Hyperoodon planifrons*) (Scheidat et al. 2011). On a greater spatial scale, other marine mammal species reported to occur in the waters west of the Antarctic Peninsula are: Sei whales, sperm whales, killer whales (*Orcinus orca*), hourglass dolphins (*Lagenorhynchus cruciger*), Antarctic fur seals, Southern elephant seals (*Mirounga leonina*), crabeater seals (*Lobodon carcinophaga*), Weddell seals (*Leptonychotes weddellii*), ross seal (*Ommatophoca rossii*), and leopard seals (*Hydrurga leptonyx*) (Thomas et al. 1980, Bengtson et al. 1990, Casaux et al. 1997, Daneri et al. 2000, Secchi et al. 2001, Thiele et al. 2004). In addition, Southern right whales (*Eubalaena australis*) were reported to occur north of the Antarctic Peninsula in the Scotia sea (Sirovic et al. 2006).

However, information on temporal patterns in the presence of the above mentioned species off Elephant Island over multiple years, i.e. whether these species inhabit the waters off Elephant Island year-round, seasonally or rather occasionally, is still lacking. Seasonal patterns in the number of baleen whale catches in the Southern Ocean, as reported in historic whaling data, has often been considered indicative of migratory movements of these species (e.g. Mackintosh 1966). The traditional migration 'paradigm' describes the majority of baleen whales to feed in summer in cold and nutrient-rich waters in high latitudes and migrate to temperate or tropical waters in lower latitudes during winter to breed (Mackintosh 1966). However, there is accumulating evidence that the migratory behavior of baleen whales is more complex than previously assumed (Brown et al. 1995, Geijer et al. 2016, Thomisch 2017), with part of the populations staying in high-latitude areas year-round (Širović et al. 2004, Simon et al. 2010, Van Opzeeland et al. 2013, Dominello & Širović 2016, Thomisch et al. 2016).

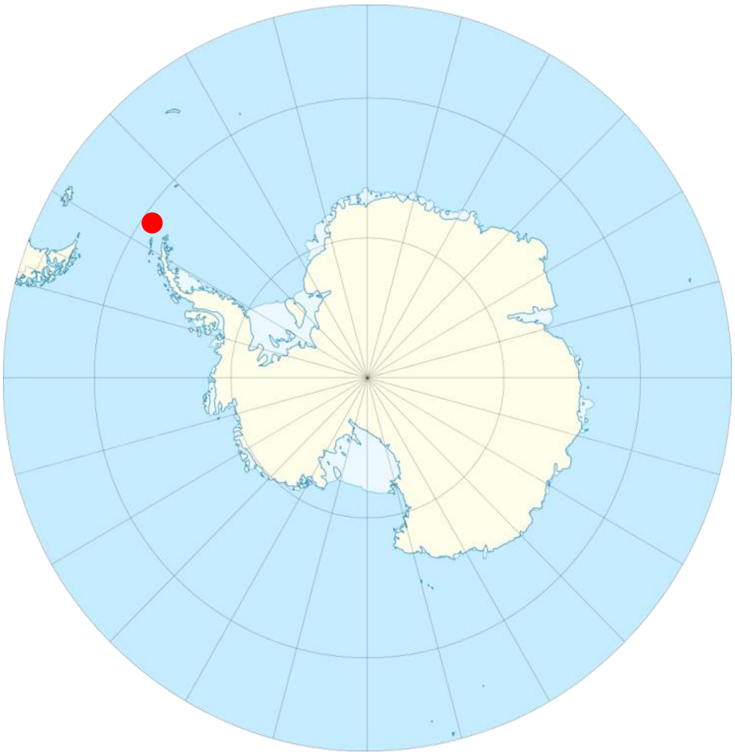

Fig. 1. Overview of the Southern Ocean (N: 50.0° S, S: 90.0°, W: -180.0° E, E: 180.0° E). Red dot indicates position of Elephant Island[3].

Regarding the South Shetland Island region, most studies on the distribution of marine mammals were conducted during austral summer or autumn (Secchi et al. 2001, Thiele et al. 2004, Friedlaender et al. 2006, Santora et al. 2010, Scheidat et al. 2011, Burkhardt & Lanfredi 2012, Joiris & Dochy 2013). Therefore, these studies often covered a comparatively short period of time, i.e. of several weeks or months, hampering the detection of long-term temporal patterns in the presence and distribution of marine mammals in the area. Besides, most studies in the Elephant Island region were based on visual surveys (Secchi et al. 2001, Thiele et al. 2004, Friedlaender et al. 2006, Santora et al. 2010, Scheidat et al. 2011, Burkhardt & Lanfredi 2012, Joiris & Dochy 2013). This technique has considerable disadvantages for studying marine mammals, since the pelagic nature and low abundance of most species often cause low encounter rates of the focal species (Costa & Crocker 1996). Especially in remote and seasonally inaccessible areas such as the Southern Ocean, the seasonal ice-coverage impedes the accessibility of the study sites and generates high financial and logistic costs, raising the need to conduct surveys applying other than visual methods (Gordon 1981).

[3] Adapted from: https://fr.wikipedia.org/wiki/Fichier:Antarctic_Ocean_location_map.svg, (last accessed 1 July 2017).

Marine mammals produce species-specific calls, which make them well-suitable for being identified and distinguished based on their acoustic behavior (Thomas et al. 1986, Mellinger et al. 2007, Thomas & Marques 2012). Their vocalizations vary, for example in terms of frequency range, duration, spectrographic shape and audible character, and hence can be used to distinguish different species or even populations (Winn & Winn 1978, Širović et al. 2004, McDonald et al. 2006, Mellinger et al. 2007). Besides, some call-types are produced in specific behavioral contexts providing information on the habitat-use of marine mammals (e.g. Watkins 1981, Jaquet et al. 2001, Croll et al. 2002, Johnson et al. 2006).

Over the past decades, passive acoustic monitoring (PAM) has become an invaluable tool to study marine mammals in remote areas and over large temporal and spatial scales (Mellinger et al. 2007). Using autonomous passive acoustic recorders, PAM has the potential to provide continuous and seasonally unbiased data over multiple years and is less dependent on weather and light conditions compared to visual surveys (Thomas et al. 1986, Clark & Ellison 1988, Sirovic et al. 2006, Wiggins & Hildebrand 2007). In addition, PAM is an invaluable tool to conduct perennial studies on the distribution of marine mammals (Širović et al. 2004, Wiggins & Hildebrand 2007, Thomisch et al. 2016). Previous studies based on passive acoustic data collected in the Southern Ocean provided unprecedented insight into small- and large-scale distribution patterns, migration behavior, and to some extent on habitat-use of marine mammals (e.g. Stirling & Siniff 1979, Širović et al. 2004, McDonald et al. 2005, Van Opzeeland et al. 2010, Van Opzeeland et al. 2013, Dominello & Širović 2016, Thomisch et al. 2016).

This study aimed to investigate i) the biodiversity, ii) inter-annual patterns, and iii) intra-annual patterns in the acoustic presence of marine mammal off Elephant Island. For this purpose, passive acoustic data recorded off Elephant Island over a period of approximately three years from 2013 to 2016 were analyzed for vocalizations of marine mammals. Such acoustic long-term data can provide important information about the distribution of both whales and seals in the Elephant Island area and help to investigate the ecological importance of this area for marine mammals.

## 2 Materials and Methods

### 2.1 Acoustic data collection

Between January 2013 and February 2016, passive acoustic data were collected off Elephant Island, which is located in the Southern Ocean northwest of the Antarctic Peninsula. A recording device of the type AURAL[4] (manufactured by Multi-Électronique Inc., Quebec, Canada) was attached to a deep-sea mooring of the Hybrid Antarctic Float Observation System (HAFOS) at 61° 0.88’ S, 55° 58.53’ W (Fig. 2). HAFOS is an oceanographic observing basis collecting information on the ocean interior of the Atlantic sector of the Southern Ocean and additionally provides the infrastructure for the deployment of passive acoustic recorders (Rettig et al. 2013). The acoustic device was moored at 210 m depths (Boebel 2013) (Fig. 4). Deployment and recovery of the recorder took place on 16 January 2013 and 10 February 2016 during Antarctic expeditions PS81 (formerly ANT-XXIX/2) and PS96 with RV Polarstern, respectively (Boebel 2013) (Fig. 3).

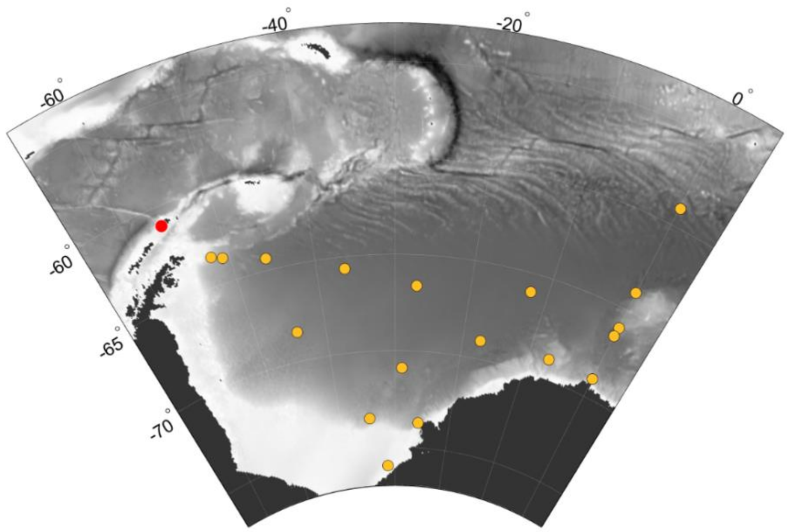


Fig. 2. Locations of autonomous passive acoustic recording devices within the HAFOS array in the Atlantic sector of the Southern Ocean. Red dot indicates the position of the passive acoustic recorder analyzed during this study, yellow dots show locations of other recorders of the HAFOS network[5].

[4] For further technical details on the passive acoustic recorder, see also http://www.multi-electronique.com/aural.html (last accessed on 27 May 2017).

[5] Source: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven

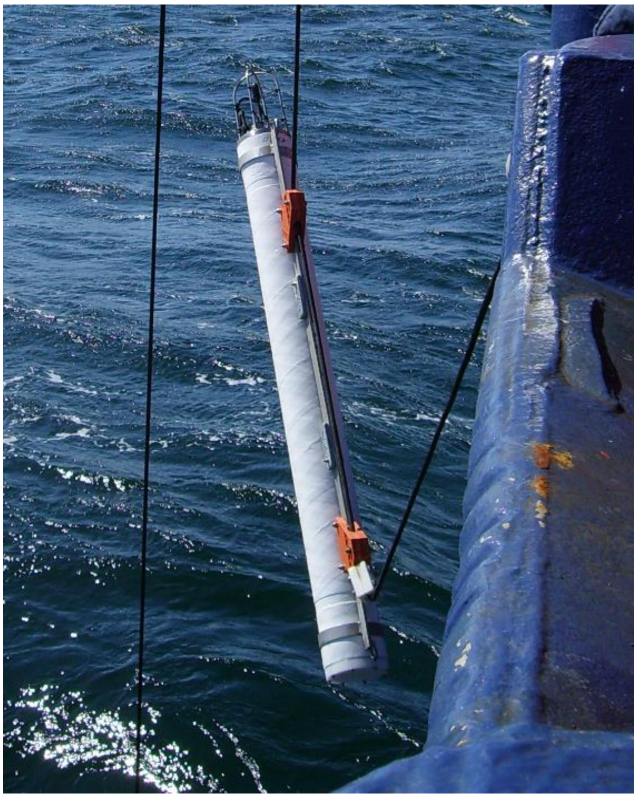

Fig. 3. Deployment of the AURAL recording device on 16 January 2013 during Antarctic expedition PS96 with RV Polarstern[6].

The AURAL was scheduled to record at 32 kHz and 16 bit sampling (Boebel 2013, Rettig et al. 2013). Due to constraints in battery life and storage capacity, the recorder was set to a duty cycle of 1/12, recording 5 min every hour in order to obtain a year-round and multi-year data coverage. This sampling scheme resulted in a total recording time of two hours per day (Boebel 2013, Rettig et al. 2013). Overall, passive acoustic data were collected for 1120 days (A 1, 2, 3, 4).

A second recording device of the type SonoVault[7] (manufactured by Develogic GmbH, Hamburg, Germany) was attached to the same mooring in 212 m depths, recording continuously between January and November 2013 (Fig. 4). However, acoustic data collected by this device were not analyzed in the present study (but see Meister et al. 2017).

[6] Source: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven

[7] For further technical details on the passive acoustic recorder, see also http://www.develogic.de/wp-content/uploads/2014/05/SonoVault-Acoustic-Recorder-Signal-Analyzer-05-2014.pdf. (last accessed on 2 April 2017).

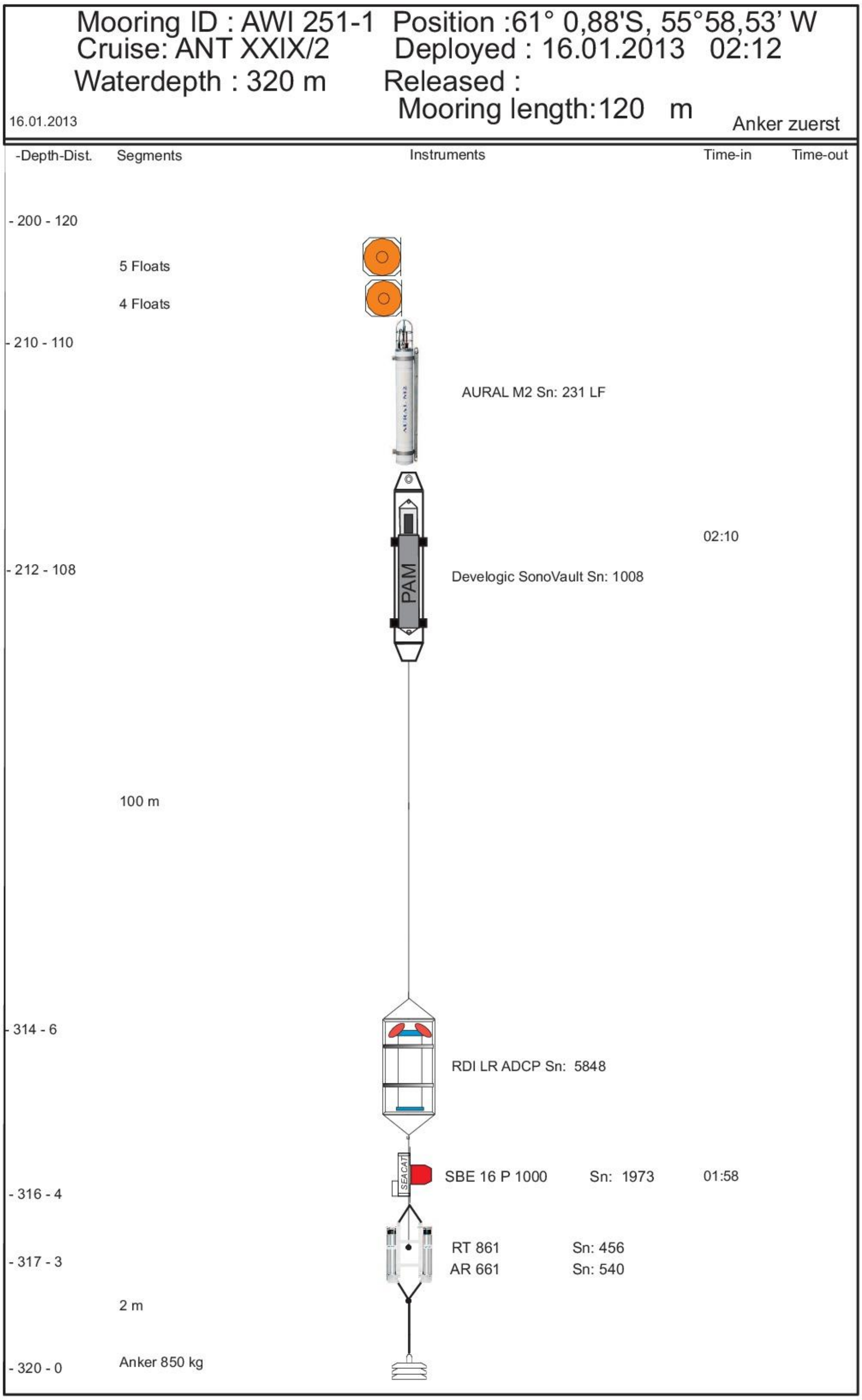


Fig. 4. Mooring scheme of mooring AWI 251-1, deployed from 16 January 2013 to 10 February 2016. Two recording devices of the type AURAL and SonoVault were attached at 210 and 212 m depths, respectively[8].

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[8] Source: Alfred-Wegener-Institut Helmholtz-Zentrum für Polar- und Meeresforschung, Bremerhaven

## 2.2 Acoustic data analysis

Spectrograms of the passive acoustic data were analyzed both visually and aurally using the bioacoustic software Raven Pro 1.5, developed by Cornell Lab of Ornithology, Ithaca, NY (Bioacustics Research Program 2014). Spectrograms were scanned for vocalizations of marine mammals and anthropogenic noise (originating from seismic investigations and vessels). Spectogram settings (Hanning window, overlap: 50 %, FFT: 16,000 points, resulting in a time resolution of 2 s and a frequency resolution of 0.5 Hz) were kept constant throughout the analysis procedure. Only when analyzing frequencies below 250 Hz, the FFT setting was changed (to 20,000 points) to increase the resolution of low-frequency signals.

The acoustic presence of marine mammals was assessed on a daily basis, i.e. one detected call per day was sufficient to represent acoustic presence of a focal species. Every second day of the recordings was analyzed. Each 5-min file was analyzed three times, each time focusing on different frequency ranges (i.e. 0 -16000 Hz, 0 – 3000 Hz, and 0 – 250 Hz) in order to reliably assess the presence of signals at low(er) frequencies.

Calls were identified on the basis of call descriptions and spectrograms published in literature (e.g. Payne & McVay 1971, Condy et al. 1978, Clark 1982, Møhl et al. 2000, Širović et al. 2004, Dominello & Širović 2016) and sound-examples provided by websites associated to marine mammal vocalizations[9]. Signals were logged using a built-in function of the Raven Pro software, which allows drawing boxes around a sound of interest and assigning labels or detailed descriptions to each of these events. Both known and unknown signals were categorized by giving different “tags” in order to assign the detected signals to species-level where possible (Tab. 1). During the process of ‘logging’ the signals of interest, the program automatically generated a table containing information about each logged event, such as start and end time, frequency range, and duration. These tables were stored as .txt-files and afterwards used to create one common table summarizing the acoustic presence of all signals during the overall recording period.

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[9] For further information, see also https://www.nefsc.noaa.gov/psb/acoustics/sounds.html, http://macaulaylibrary.org/search?open_advanced=1, http://cetus.ucsd.edu/voicesinthesea_org/index.html, http://www.dosits.org/galleries/audio/, https://whalewatch.com/research-education/whale-sounds/, http://ocr.org/ (all websites last accessed 24 June 2017).

Only sounds that were clearly recognizable as individual signal or parts of one signal were logged. Vocalizations produced by distant individuals of Antarctic blue whales ('Z-calls') and fin whales ('20 Hz pulses') can form a continuous 'chorus' in the frequency range between 15 and 30 Hz (Širović et al. 2009, Baumann-pickering et al. 2015, Thomisch et al. 2016). Partially, the passive acoustic data collected off Elephant Island contained vague blurred bands in this frequency range. These bands were however not considered as a proxy of acoustic presence of Antarctic blue and fin whales during the analysis procedure in the present study, since the actual calls may have been produced far away from the recorder.

Based on the results of the manual data analysis, the monthly percentage of days with acoustic presence was calculated for each marine mammal species (or sound type) detected.

Tab. 1. Tags used for the categorization of different signals.

| **Tag** | **Source** |
|---|---|
| B | Antarctic blue whale |
| F | Fin whale |
| M | Antarctic minke whale |
| H | Humpback whale (high-frequency sounds) |
| O | Killer whale |
| S | Sperm whale |
| L | Leopard seal |
| W | Weddell seal |
| C | Crabeater seal |
| R | Ross seal |
| Fm | Frequency-modulated call (details on frequency range) |
| A | Seismic signals ('airguns') |
| V | Sounds of vessels |
| D2 | Humpback whales (low-frequency sounds) |
| D3 | Unknown sound: 'ripple' |
| D4 | Unknown sound: 'low-frequency (< 50 Hz) pulses and upsweeps' |
| D5 | Unknown sound: 'bark' |
| ? + 'Zahnwal' in comments | unidentified toothed whale |
| ? | Unknown sounds occurring only once or twice |

# 3 Results

## 3.1 Acoustic biodiversity of marine mammals off Elephant Island

In this study, eight marine mammal species were identified based on their species-specific acoustic signatures in the passive acoustic data from off Elephant Island. Four baleen whale species were acoustically present during the recording period: Antarctic blue whales, fin whales, Antarctic minke whales and humpback whales. In terms of toothed whales, sperm whales and killer whales were found in the present study. Occasionally, clicks and whistles were detected on several days. These signals were presumably produced by toothed whales but could not be assigned to a particular species with certainty. Furthermore, two species of seals, i.e. leopard seals and crabeater seals, were acoustically present off Elephant Island.

### 3.1.1 Baleen whales

*Antarctic blue whales*

Antarctic blue whales were recognized by their characteristic “Z-call”, consisting of three units generating a Z-shaped mark in a spectrographic view (Ljungblad et al. 1998, Širović et al. 2004, McDonald et al. 2006) (Fig. 5). As described by previous studies (Ljungblad et al. 1998, Širović et al. 2004), the Z-call started with a tonal sound in the frequency range from 26 -29 Hz lasting about 9 s (unit A), followed by a short (about 1.5 s) down-sweep to approximately 19 Hz (unit B) and a slightly frequency-modulated tone at 18 -19 Hz of 8-12 s duration (unit C). Z-calls occurred either in regular, repetitive sequences (i.e. as song) or temporally unstructured at irregular intervals.

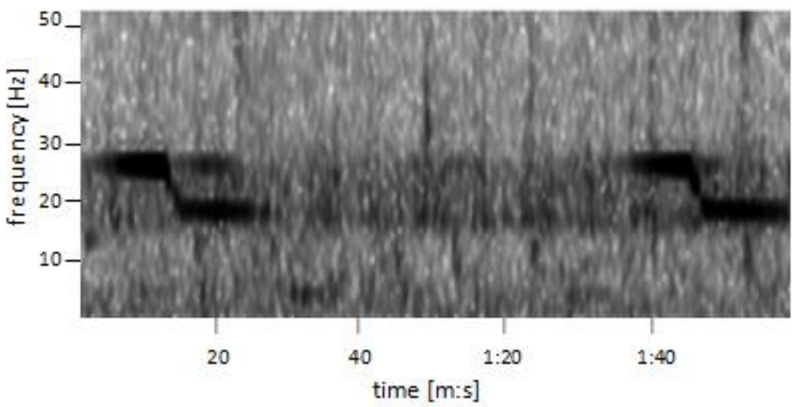



Fig. 5. Spectrogram of Antarctic blue whale Z-calls (20,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 17 February 2013. Faint fin whale 20-Hz pulses are also visible.

*Fin whales*

Off Elephant Island, the "20-Hz pulse" produced by fin whales was frequently recorded (Fig. 6). This call is a short (0.7 to 1 s) down-sweep centered around 20 Hz (Watkins 1981, Watkins et al. 1987, Thompson et al. 1992, Širović et al. 2004). In the present study, the 20-Hz pulse mostly occurred in regular, repetitive sequences, also referred to as fin whale song (Watkins 1981, Watkins et al. 1987, Thompson et al. 1992, McDonald & Fox 1999). Besides, single calls or short irregular series of 20-Hz pulses were also often found, which is in accordance with results of previous studies (Watkins 1981, Watkins et al. 1987, McDonald et al. 1995). Similar to fin whale calls recorded off the Western Antarctic Peninsula (Širović et al. 2004), an additional pulse centered around 89 Hz was often present in the acoustic data collected off Elephant Island. The frequency range of this additional pulse varies between regions, possibly indicating differences in the call characteristics of separate populations (Širović et al. 2009).

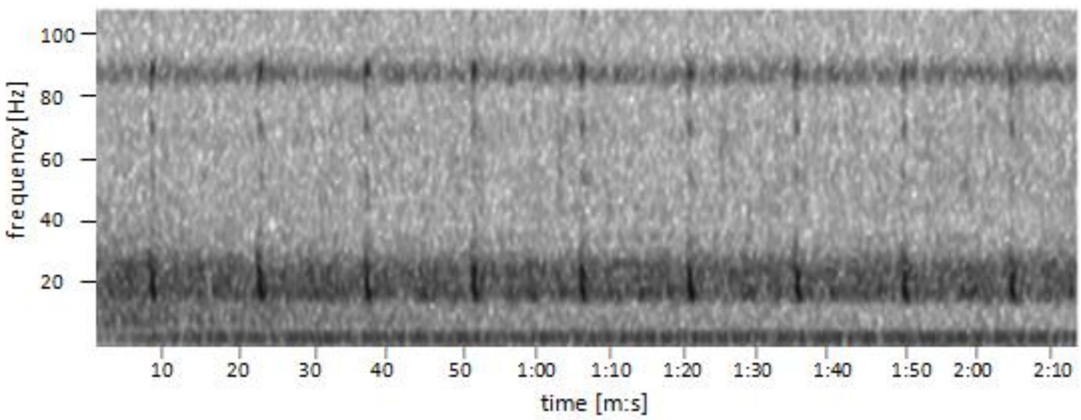



Fig. 6. Spectrogram of fin whale 20-Hz pulses (20,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 20 May 2014 + info über "zusätzlichen" Puls bei 89 Hz.

*Antarctic minke whales*

In this study, Antarctic minke whales were recognized by their 'bio-duck call', a signal that was named after its audible character which resembles a duck (Van Opzeeland 2010, Risch et al. 2014, Dominello & Širović 2016) (Fig. 7). This call is extremely rhythmic, consisting of bouts of short (0.1 s) pulses, which are repeated at regular intervals (see also Mellinger et al. 2000, Matthews et al. 2004, Risch et al. 2014) (Fig. 8). In accordance with findings from Dominello and Širović (2016), bouts of Antarctic minke whales calls recorded off Elephant Island usually contained four pulses with a peak frequency at ca. 150 Hz.

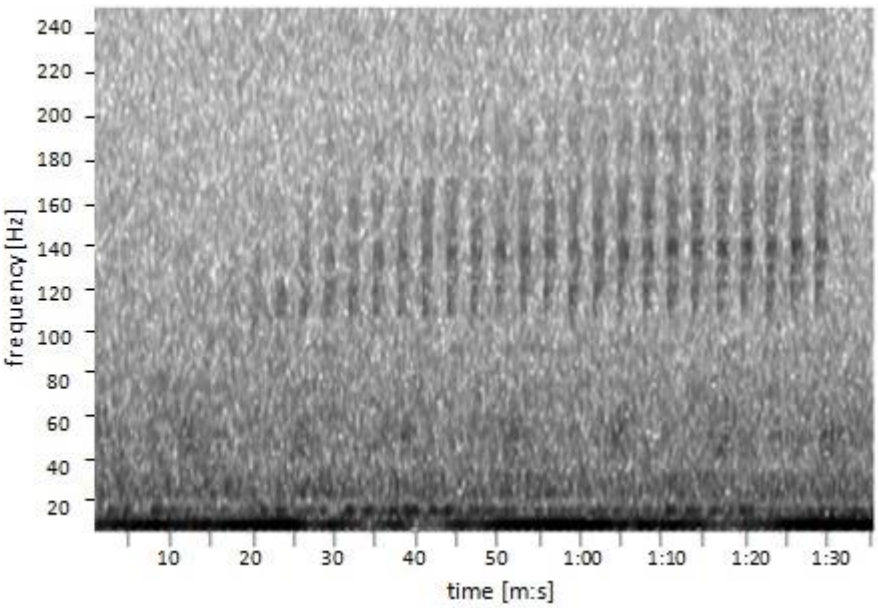



Fig. 7. Spectrogram of Antarctic minke whale (‘bioduck’) call sequence (1,600-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 12 September 2013

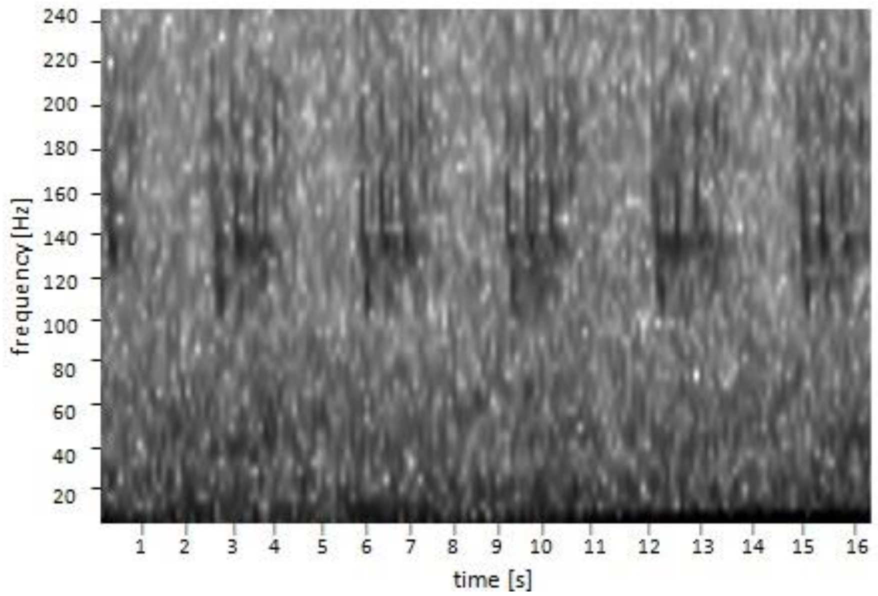



Fig. 8. Detailed spectrogram of the Antarctic minke whale (‘bioduck’) call sequence showing bouts of four pulses (6,500-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 12 September 2013.

*Humpback whales*

Humpback whale vocalizations recorded off Elephant Island were highly variable in their spectrographic shape (Fig. 9, 10). The whales produced several types of sounds (such as up-calls, down-sweeps, tonal sounds, combination of up- and down-sweeps) with main frequencies below 4 kHz (e.g. Payne & McVay 1971, Winn & Winn 1978, Winn et al. 1981). The different elements occurred either as single signals, in short sequences without notable structure or in regular patterns forming continuous sequences (also referred to as humpback whale song) (Payne & McVay 1971). Besides, social sounds, such as moans or grunts (Thompson et al. 1986, Dunlop et al. 2007, Van Opzeeland et al. 2013), were recorded off Elephant Island.

In the present study, two different types of humpback whale vocalizations were distinguished based on their frequency range: high-frequency calls (hereinafter defined as calls with fundamental frequencies > 200 Hz) and low-frequency calls (defined as calls with fundamental frequencies < 200 Hz) sounds (Fig. 9, 10; A 5, 6, 7, 8). While the high-frequency calls could be easily assigned to humpback whales based on literature data (Payne & McVay 1971, Winn & Winn 1978, Dunlop et al. 2008), the low-frequency signatures seemed to be rather untypical for humpback whales, given the rather long duration (around 8 s) of single elements, which also slightly changed the audible character compared to sound samples provided by websites associated to marine mammal vocalizations[10]. Besides, the production of long sequences consisting only of low-frequency sounds it is not mentioned in previous studies on humpback whale acoustic behavior (Payne & McVay 1971, Winn & Winn 1978, Thompson et al. 1986, Dunlop et al. 2008). However, based on the variability of the vocalizations in terms of their spectrographic shape, their occurrence in regular, repetitive sequences, and the presence of passages with both short- and long-duration elements, these signals were assigned to humpback whales in the present study. Nevertheless, it cannot be ruled out that part of the low-frequency sounds were produced by other species.

[10] For further information, see also https://www.nefsc.noaa.gov/psb/acoustics/sounds.html, http://macaulaylibrary.org/search?open_advanced=1, http://cetus.ucsd.edu/voicesinthesea_org/index.html (last accessed 24 June 2017)

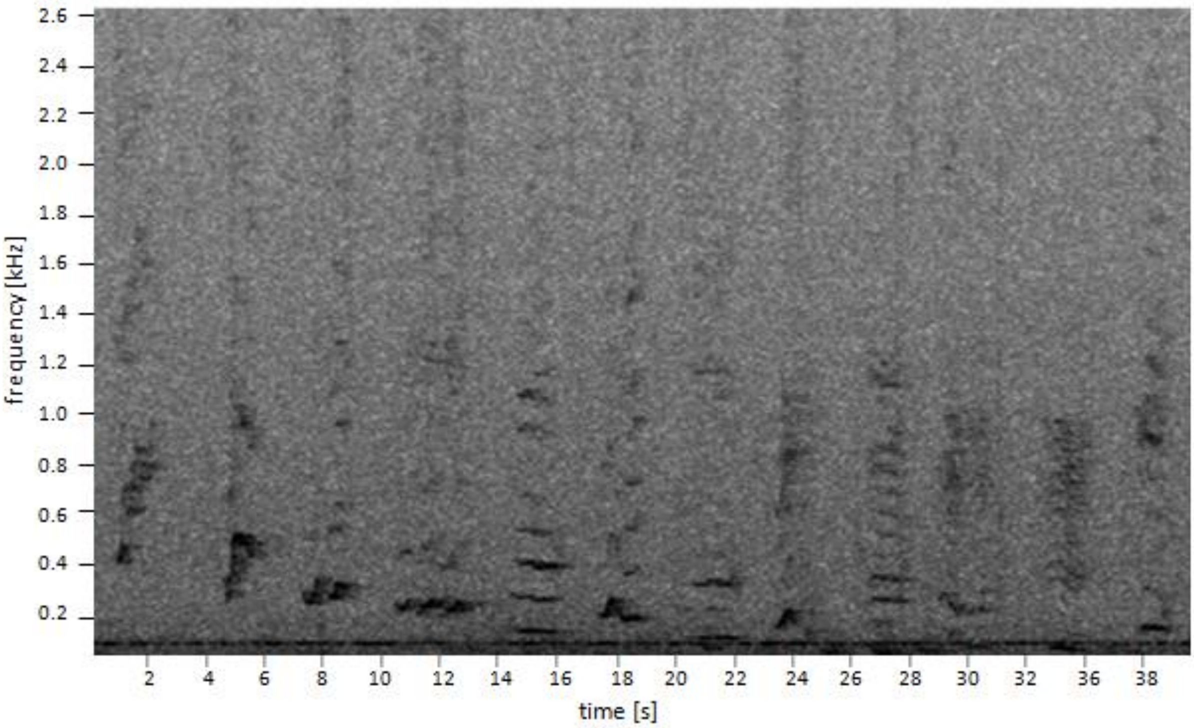



Fig. 9. Spectrogram of high-frequency humpback whale vocalizations (11,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 28 May 2015.

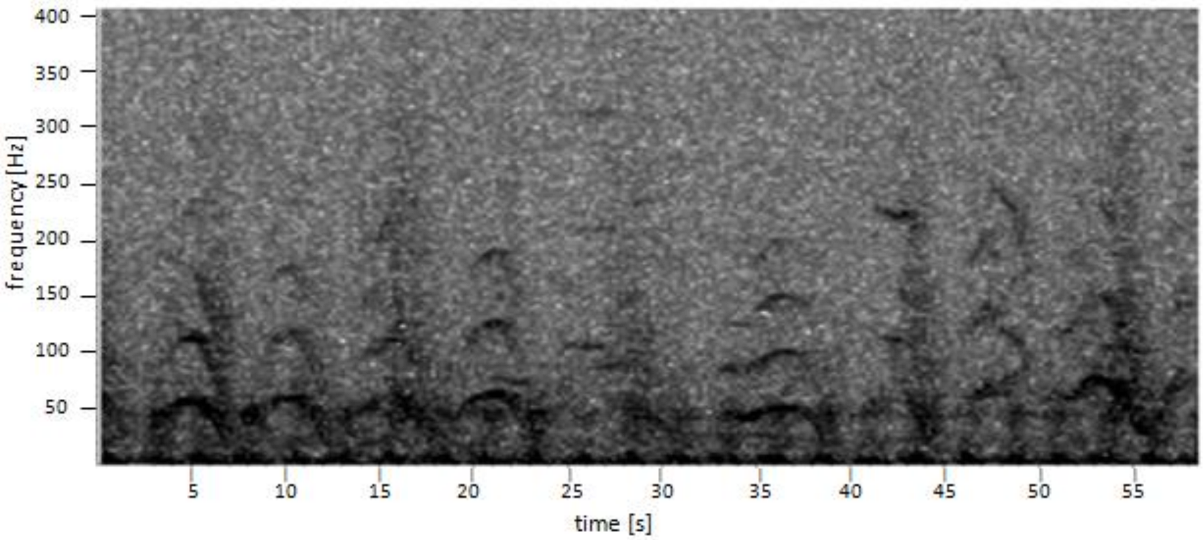



Fig. 10. Spectrogram of low-frequency humpback whale vocalizations (11,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 8 March 2015.

*Frequency-modulated calls (Fm-calls)*

Frequency-modulated down-sweep calls below 200 Hz (further referred to as Fm-calls) were frequently recorded off Elephant Island (Fig. 11). These calls are produced by several baleen whale species, such as Antarctic blue whales (Rankin et al. 2005), fin whales (Watkins 1981), Antarctic minke whales (Dominello & Širović 2016) and sei whales (Calderan et al. 2014). In the present study a reliable assignment to species-level was not possible due to the similarity of spectral characteristics.

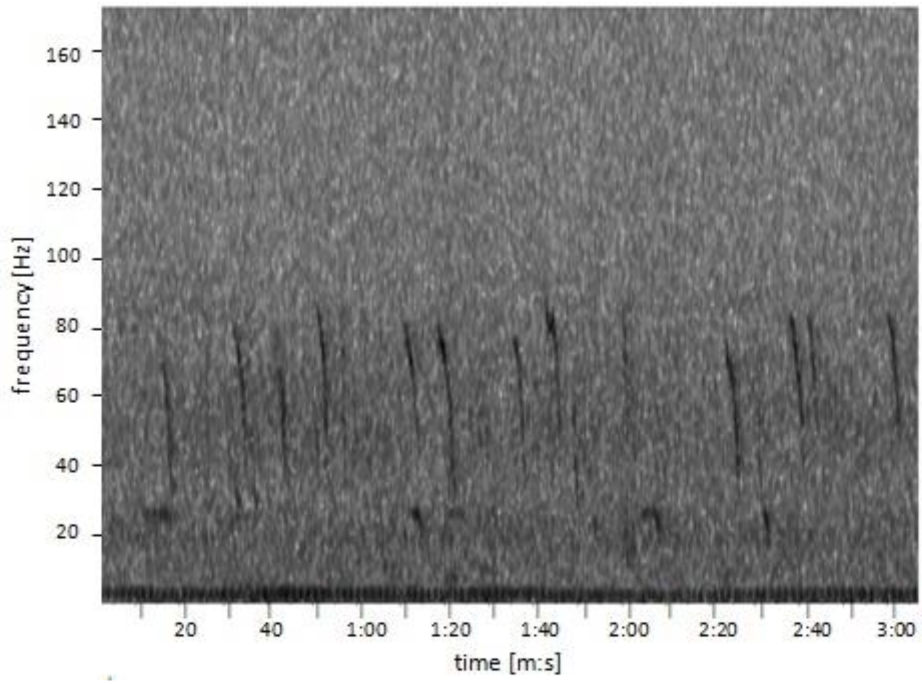



Fig.11. Spectrogram of Fm-calls (1000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 1 November 2014. Vocalizations of blue and fin whales are slightly visible between 15 and 25 Hz.

### 3.1.2 Toothed whales

*Killer whales*

Three types of killer whale vocalizations were recorded off Elephant Island: whistles, burst pulses, and clicks (Fig. 12). Whistles occurred as narrow-band tones, at frequencies mainly above 4000 Hz, exhibiting no harmonics. Burst pulses were rich in harmonics and recognized acoustically by their high repetition rate of ca. 60 to 4000 pulses/s (Steiner et al. 1979, Ford 1989). The recorded clicks were highly variable regarding their start frequency and repetition rates (see also Diercks et al. 1973, Steiner et al. 1979, Awbrey et al. 1982, Ford 1989). The frequency range of killer whale clicks usually seemed to exceed 16 kHz and hence only the lower parts of the clicks were visible in the spectrograms of the passive acoustic data.

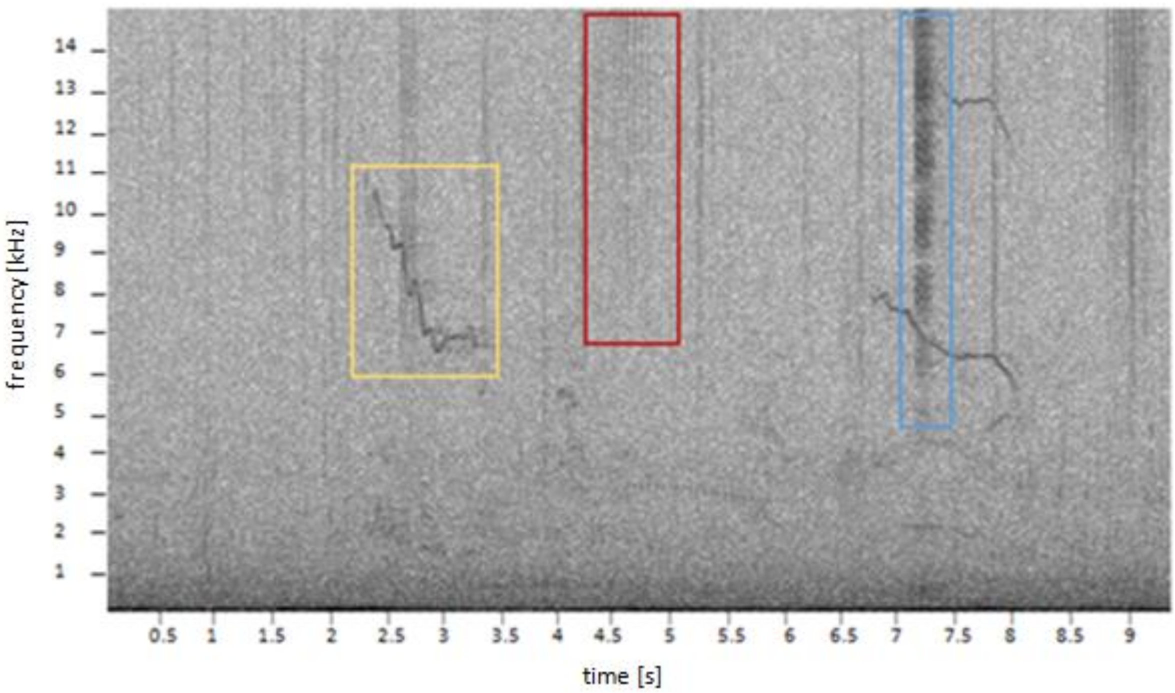



Fig. 12. Spectrogram of killer whale vocalizations (1,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 16 September 2013. Three different call types are visible, indicated by boxes of different colors: whistles (yellow box), clicks (red box), and burst pulses (blue box).

*Sperm whales*

Click trains of sperm whales were detected in the data from off Elephant Island (Fig. 13). In contrast to clicks produced by killer whales, sperm whale clicks exhibited slower repetition rates and constant inter-call intervals (ICIs). Sperm whales are known to produce usual clicks (ICI about 0.5 to 1.25 s) and slow clicks (ICI about 5 to 7 s) (Backus & Schevill 1966, Weilgart & Whitehead 1988). Both click types were detected in the present study. Other types of sperm whale vocalizations, such as creaks (series of very rapid clicks) and codas (patterned series of clicks exhibiting irregular repetition rates) (Watkins & Schevill 1977, Jaquet et al. 2001), were not detected in the passive acoustic data from off Elephant Island.

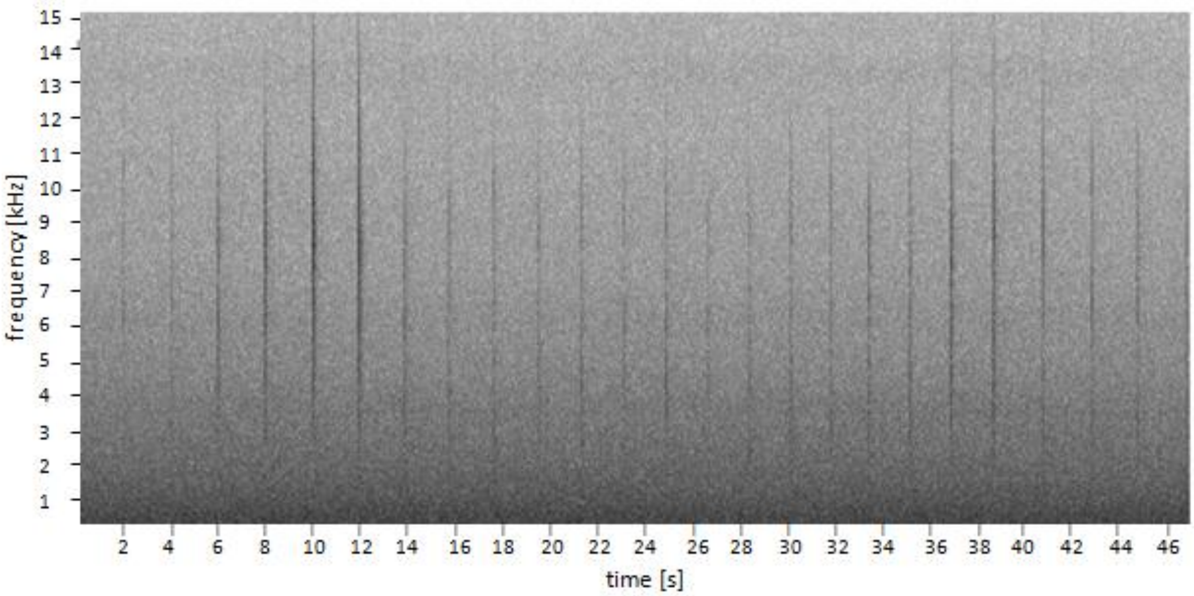



Fig. 13. Spectrogram of clicks produced by sperm whales (1,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 30 April 2014.

*Unspecified toothed whale vocalizations*

Occasionally, clicks, whistles and unspecified narrow-band sounds, which could not be assigned to species-level in the present study, were found (Fig. 14). These vocalizations were highly variable in terms of frequency range, duration, ICIs, and spectrographic shape and may have been produced by different toothed whale species. The vocalizations had various audible characters (e.g. metallic clicks, sharp whistles, sounds resembling laughter) depending on the particular call.

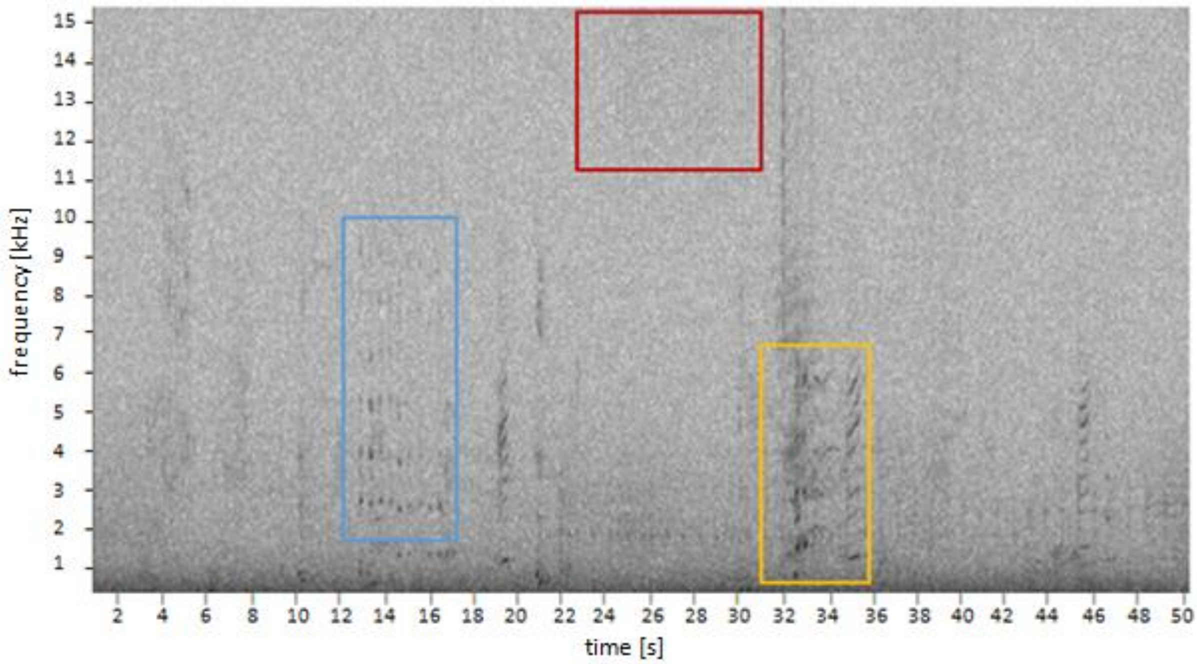



Fig. 14. Spectrogram of unspecified toothed whale vocalizations (1,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 18 July 2013. Boxes indicate sound resembling a laughter (blue), clicks (red), unspecified narrowband sounds (yellow).

### 3.1.3 Seals

*Leopard seals*

Leopard seal trills, composed of rapid series of pulses (Stirling & Siniff 1979, Rogers et al. 1995), were recorded off Elephant Island (Fig. 15). In accordance with previous call descriptions (Stirling & Siniff 1979, Rogers et al. 1995), these trills could be assigned to three main categories based on their frequency range: low trills (at around 300 Hz), medium trills (between 1300 and 2500 Hz), and high trills (between 2500 and 4800 Hz). In addition, the detected trills occurred either as single trills or as double trill (refer to Fig. 13) (see also Stirling & Siniff 1979, Rogers et al. 1995). On 26 June 2013 less stereotyped versions of the low trill produced by juveniles (Rogers 2007) were recognized.

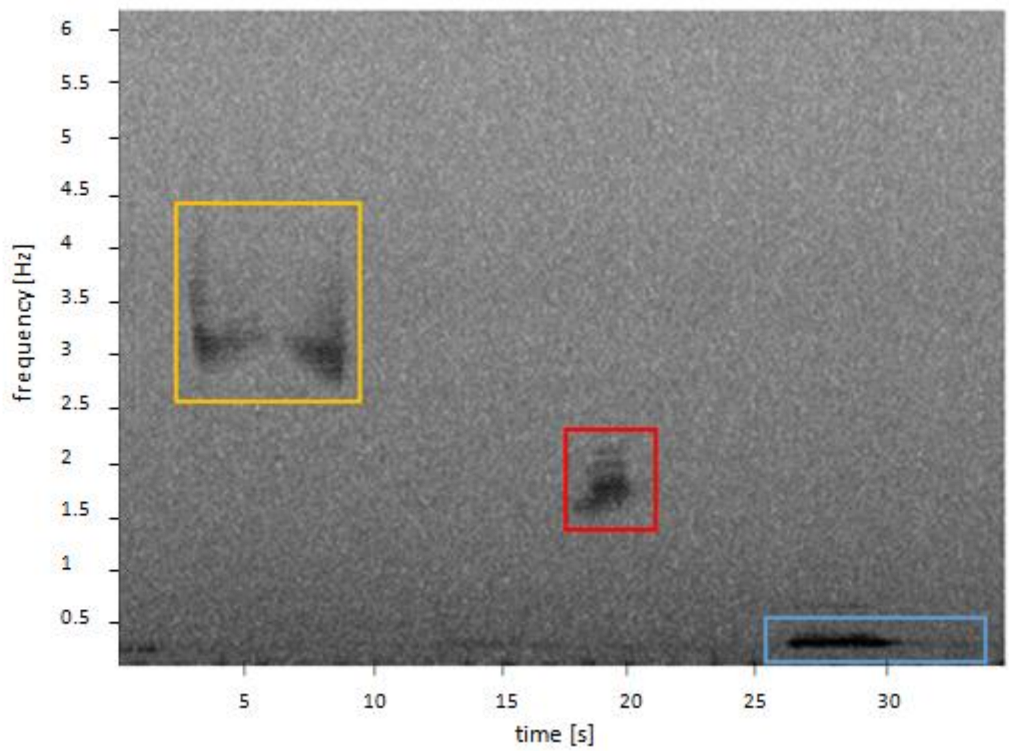



Fig. 15. Spectrogram of trills produced by leopard seals (16,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 2 January 2014. Box colors indicate different types of trills: high double trill (yellow), medium single trill (red), and low single trill (blue).

*Crabeater seal*

The most frequently detected call produced by crabeater seals was the “low moan call” (Stirling & Siniff 1979) (Fig. 16). This call is composed of a series of rapidly (about 75 Hz) repeated pulses forming a sideband structure, and exhibits main energy below 2500 Hz and a duration of about 2.5 s (Klinck et al. 2010). In addition, a second vocalization type of crabeater seals, the “high moan call” (Klinck et al. 2010) was recorded off Elephant Island. The high moan call is also composed of a series of rapidly repeated pulses, but ranges at higher frequencies (mean frequency between 1000 to 4900 Hz) than the low moan calls (Klinck et al. 2010).

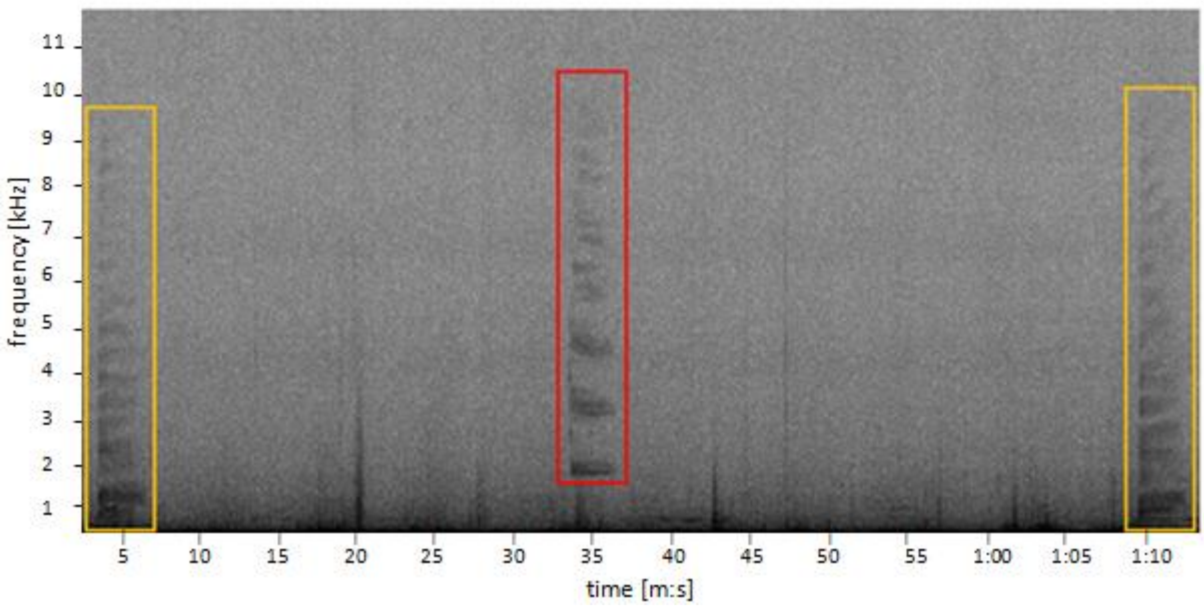



Fig. 16. Spectrogram of low moan call (yellow boxes) and high moan call (red box) produced by crabeater seals (16,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 18 October 2015.

### 3.1.4 Unknown signals

In the passive acoustic data from off Elephant Island, several unknown signals were found. Most of these signals occurred only once or twice and hence will not be discussed further in this study. However, three signals were found to occur in each year from 2013 to 2015.

The audible character of the first unknown signal resembled a bark and the sound seemed to be of biological origin. It consisted of a group of around 15 pulses at around 600 Hz with overtones ranging up to 2100 Hz (Fig. 17).

The second signal resembled a ripple. Its spectrographic view was characterized by several broadband lines with the main frequency below 4 kHz (Fig. 18).

Pulses and upsweeps (lasting about 5s) below 50 Hz classified to belong to one category due to similar ICIs of about 12s. These calls occurred either in sequences or as single signals (Fig. 19, 20).

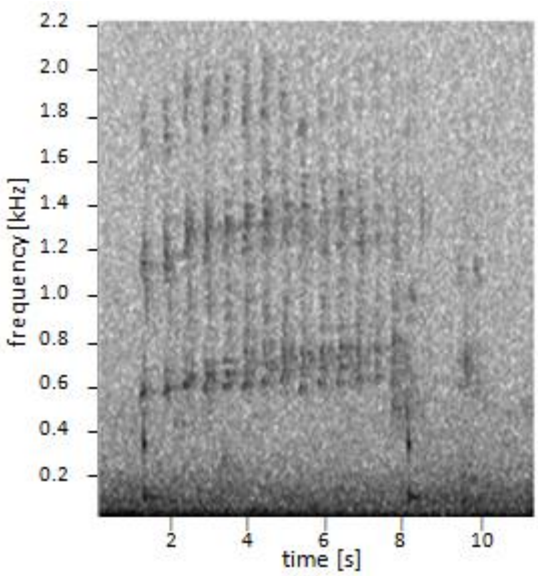



Fig. 17. Spectrogram of unknown signal ('bark') (16,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 2 September 2013.

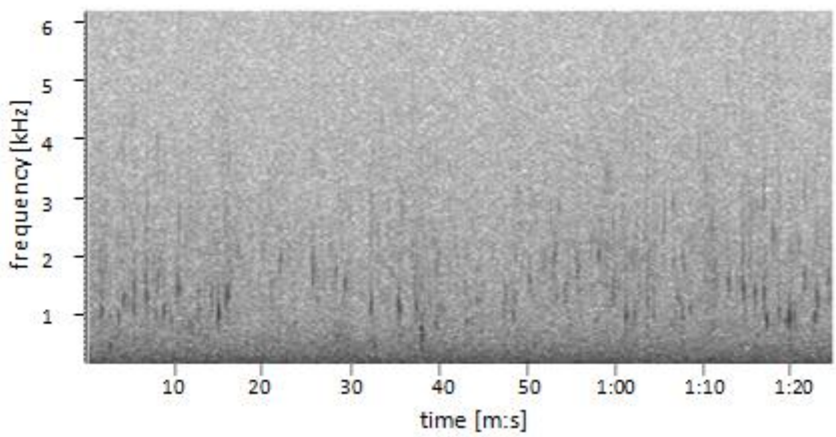



Fig. 18. Spectrogram of unknown signal ('ripple') (16,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 4 August 2013.

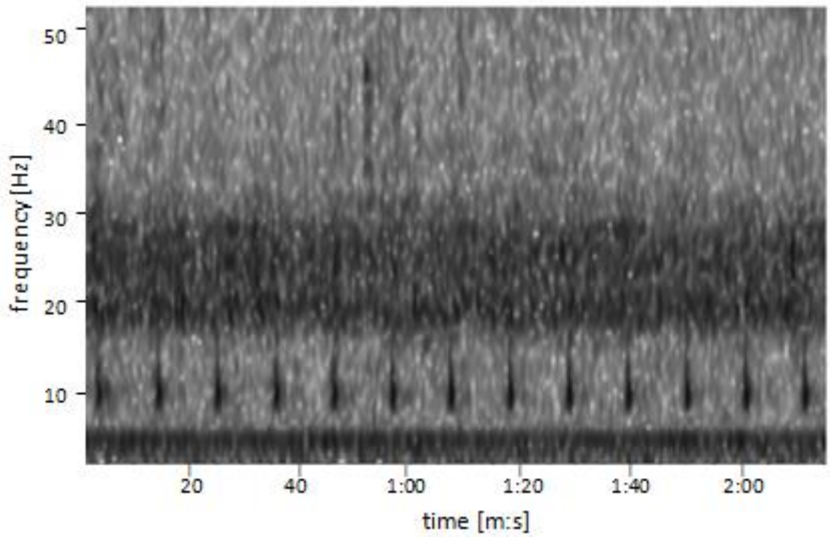



Fig. 19. Spectrogram of unknown signal (low-frequency pulses) (25,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 18 June 2013.

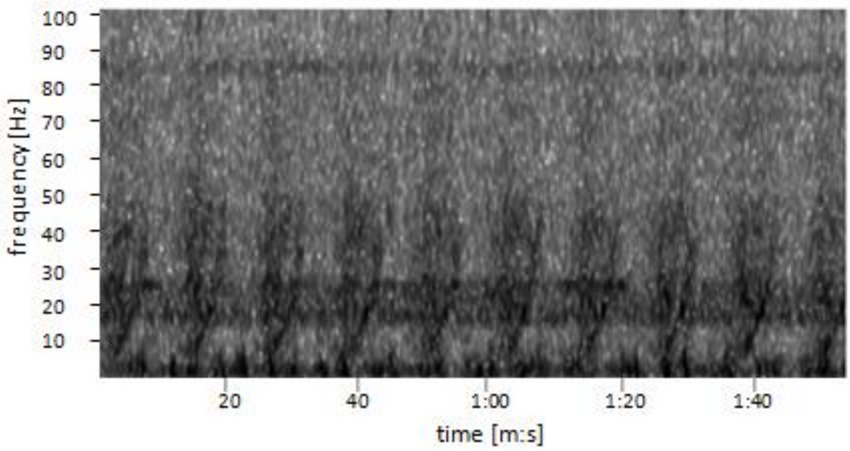



Fig. 20. Spectrogram of unknown signal (low-frequency upsweeps) (25,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 2 September 2013.

### 3.1.5 Anthropogenic noise

Two types of anthropogenic noise were detected in the passive acoustic data: seismic signals and vessel noise (Fig. 21, 22). Seismic signals were characterized as regularly repeated pulses at frequencies of up to 1800 Hz. Vessels produced narrow-band lines at low frequencies (i.e. <1000 Hz).

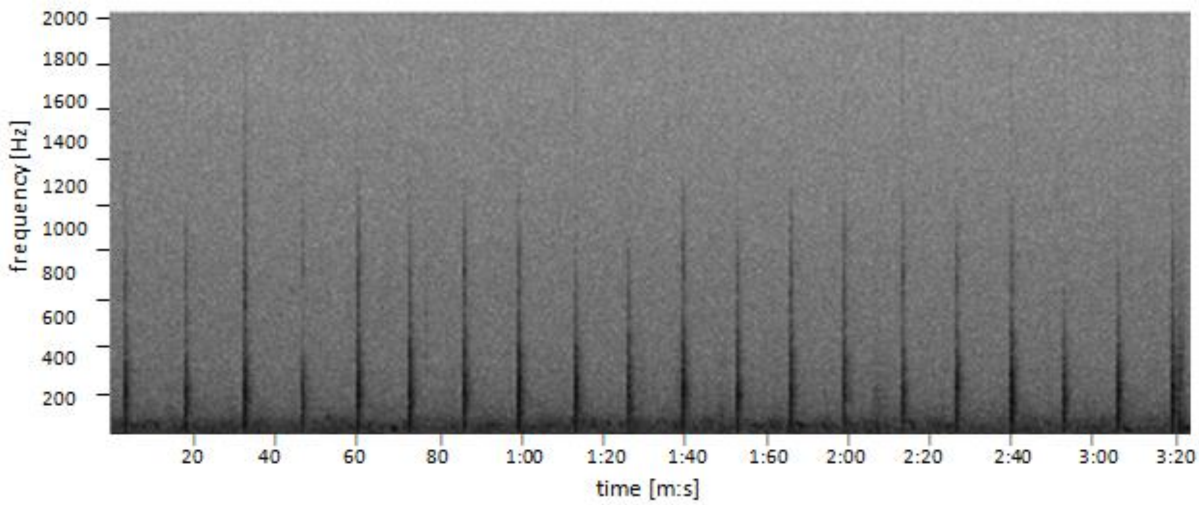



Fig. 21. Spectrogram of seismic signals (20,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 2 February 2013.

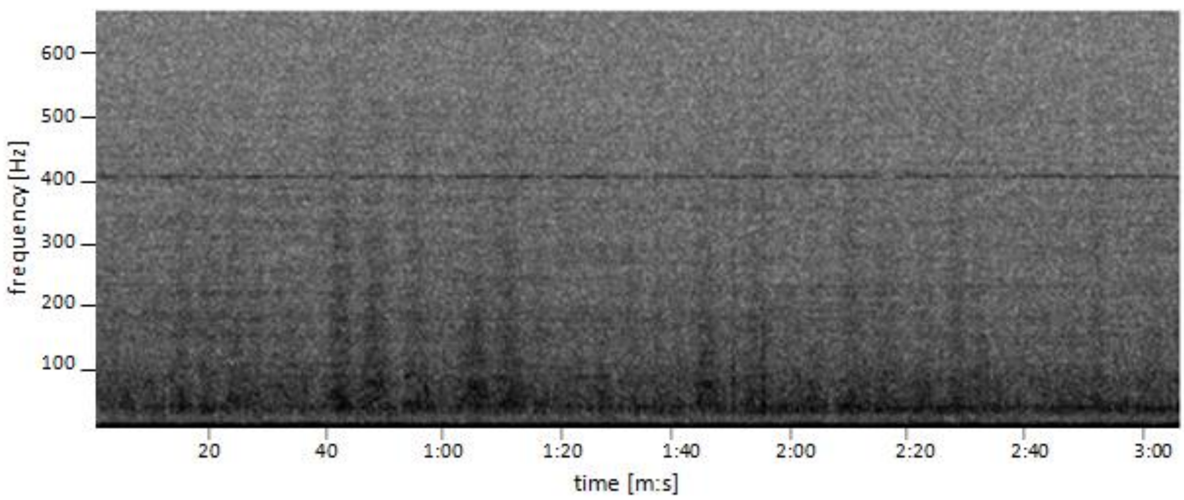
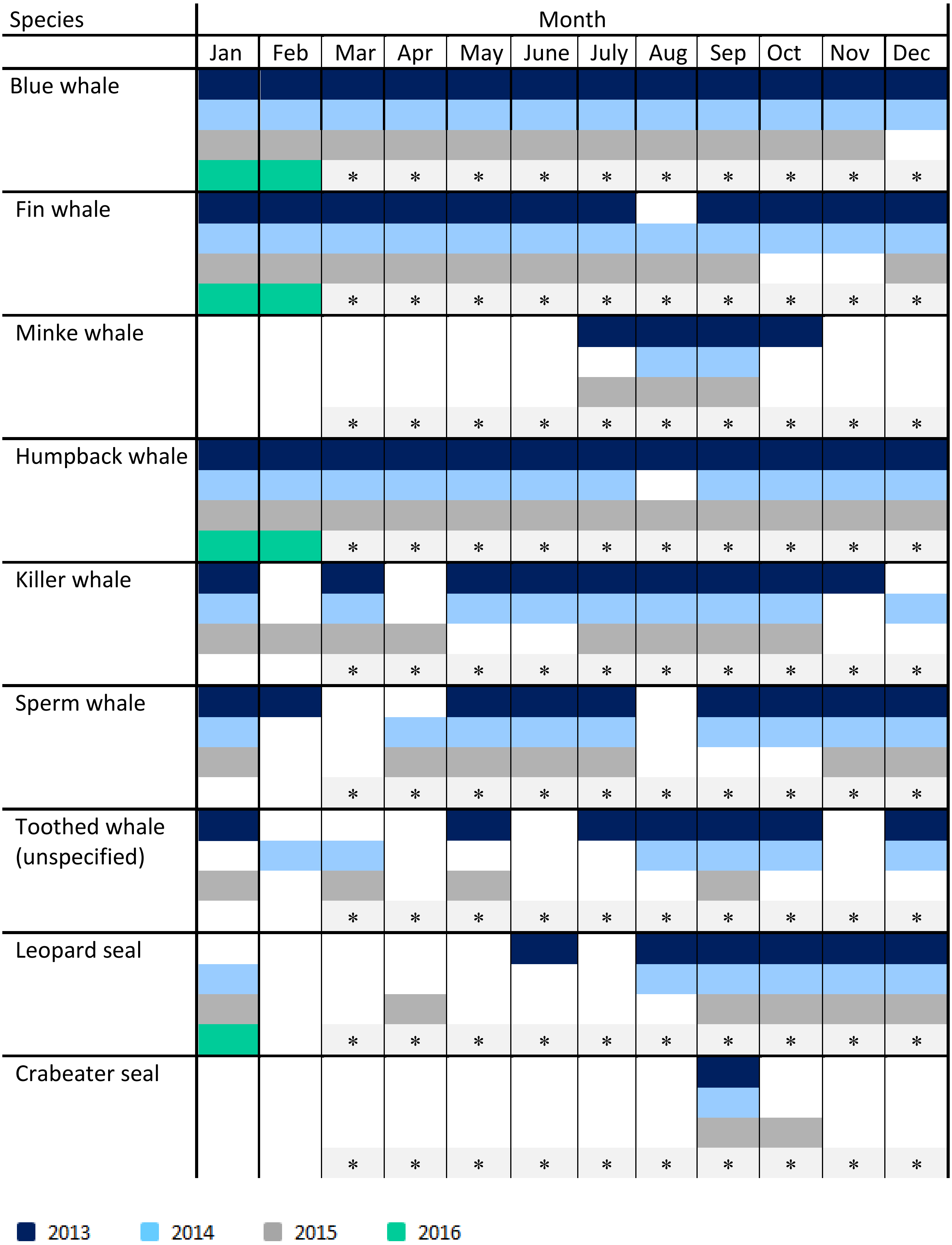



Fig. 22. Spectrogram of vessel noise (20,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 16 January 2013.

## 3.2 Temporal patterns

Temporal, i.e. both intra- and inter annual, patterns in the acoustic presence varied between species and recording years. All detected marine mammal species were acoustically present off Elephant Island within each recording year from 2013 to 2015. In 2016, four marine mammal species (i.e. Antarctic blue whales, fin whales, humpback whales, and leopard seals) were detected (Tab. 2). However, only a small amount of data was available for this year, since the recorder was recovered in early February 2016. Furthermore, given that (due to the analysis procedure) only four recording days from February 2016 were analyzed, the acoustic biodiversity found in February 2016 may not be representative for the whole month.

Tab. 2. Monthly acoustic presence of marine mammals recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent acoustic presence within different recording years (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). White color represents acoustic absence. Star indicates a lack of data.



### 3.2.1 Baleen whales

*Antarctic blue whales*

Antarctic blue whales were acoustically present during all recording months, except for December 2015, with detected calls on 82 % of all analyzed days on average (Tab. 2, Fig. 23). The annual acoustic presence was high from 2013 to 2015 (84 % of days with calls in 2013, 93 % in 2014, and 78 % in 2015). In contrast, in 2016, only 5 % of the days contained calls. No regular inter-annual pattern in the amount of days with calls was found.

During 17 months of the overall recording period, Antarctic blue whale calls were acoustically present during each (analyzed) day. Four months (January, February, July, and October) contained continuous acoustic presence in 2013, nine months (February, May to December) in 2014, and four months (March, May to July) in 2015.

A regular seasonal pattern in the acoustic presence of Antarctic blue whales was not evident over the three-year recording period (Fig. 22). In 2013, the acoustic presence was high from January to March (more than 90 % of days with calls) and decreased in April and May. From June to October 2013, the acoustic presence increased again (more than 86 % of days with calls) and decreased again in November and December. In 2014, nearly all month contained calls on every day, with the exception of January, March, and April. During these three months, Antarctic blue whales were acoustically present on at least 67 % of days. Between January and October 2015, all months contained at least 73 % of days with calls. In November 2015, the acoustic presence was considerably decreased (7% of days contained calls) and no vocalizations were detected in December 2015. In January and February 2016, the acoustic presence was low compared to previous recording years, with 33 and 25 % of days containing calls, respectively.

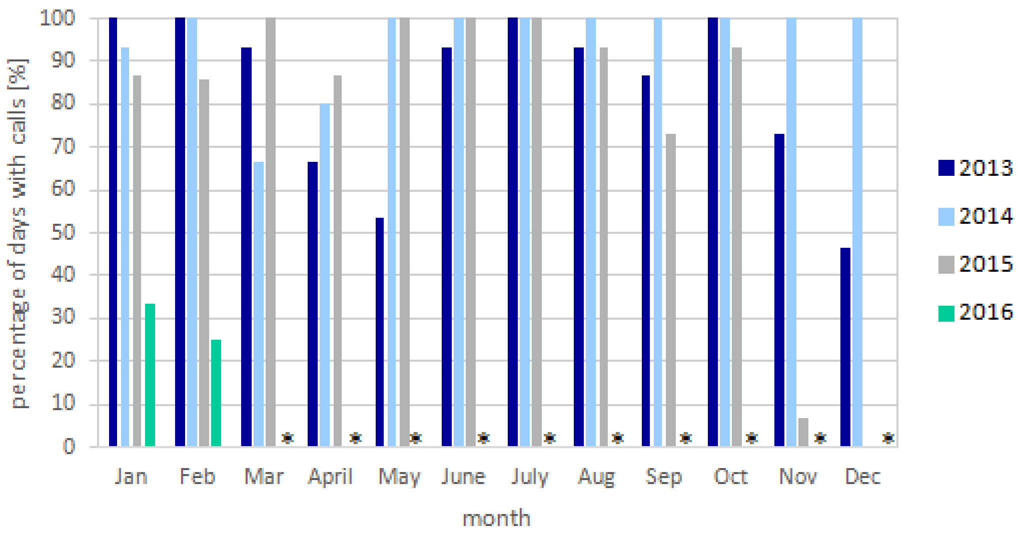



Fig. 23. Monthly percentage of days with blue whale vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*Fin whales*

During the overall recording period, fin whales were acoustically present on 75 % of all analyzed days on average (Fig. 24). The highest acoustic presence was detected in 2014 (95 % of days with calls per year) and in 2016 (80 % of days with calls per year). In 2013 and 2015, 65 % and 62 % of the days contained calls, respectively.

During 17 months of the overall recording period, fin whales were acoustically present during each (analyzed) day, with 3 months of continuous acoustic presence in 2013 (February, May, and June) 8 months in 2014 (February to September) 5 months in 2015 (March to July), and 1 month (February) in 2016. No general inter-annual pattern in the amount of days with detected calls was found.

Within all years, the acoustic presence of fin whales was especially high from February to July, i.e. from late austral summer to early austral winter. During this period, fin whale calls were present at more than 90 % of the days for all months in all years. However, regarding the rest of the year the acoustic presence of fin whales varied between the recording years. In 2013, fin whales were acoustically absent in August. Besides, the acoustic presence was comparatively low in September, December, and January (between 13 % and 38 %). In contrast, fin whales were acoustically present the whole year in 2014. In August and September 2014, every day contained at least one fin whale call. In January 2014 and from

October to December 2014, the acoustic presence was slightly decreased, but still at least 80 % of the days of each month contained calls. In 2015, fin whale acoustic presence started to decrease in August. During October and November 2015, no calls were detected. From December 2015 to February 2016, the acoustic presence increased again.

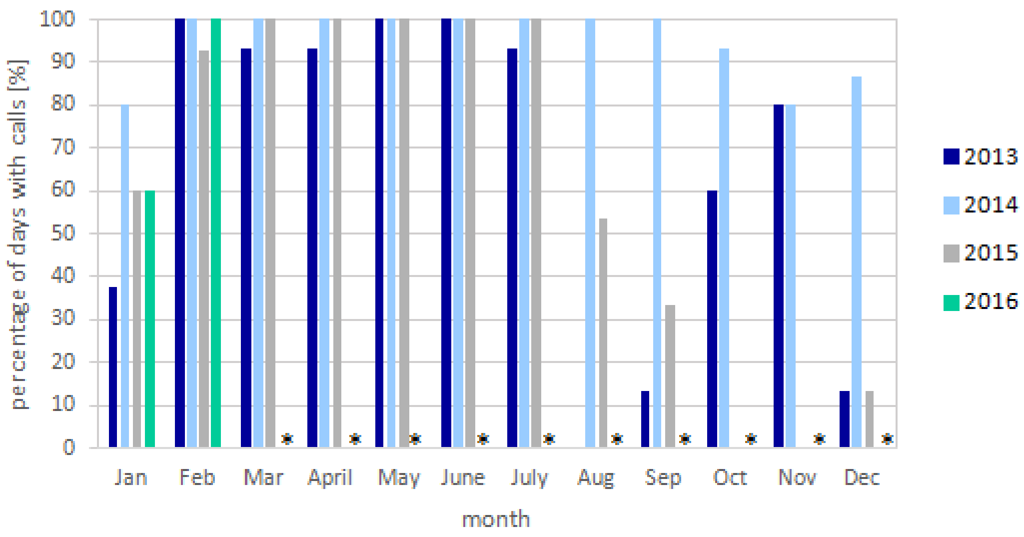



Fig. 24. Monthly percentage of days with fin whale vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*Antarctic minke whales*

Overall, Antarctic minke whales were acoustically present at 10 % of all analyzed days on average (Fig. 25). The annual acoustic presence reached its maximum in 2013 with 14 % of days with calls per year. In 2014 and 2015, 10 % and 7 % of the days contained calls, respectively. No calls were detected in 2016. Inter-annually, the acoustic presence of minke whales declined from 2013 to 2015.

The acoustic presence of Antarctic minke whales showed a clear intra-annual pattern. The animals were acoustically absent from late austral spring to early austral winter (November to June). A small percentage (7 %) of days with calls was detected in July (2013 and 2015) and October (2013), whereas the acoustic presence showed a distinct peak (up to 80 %) in August and September in all years.

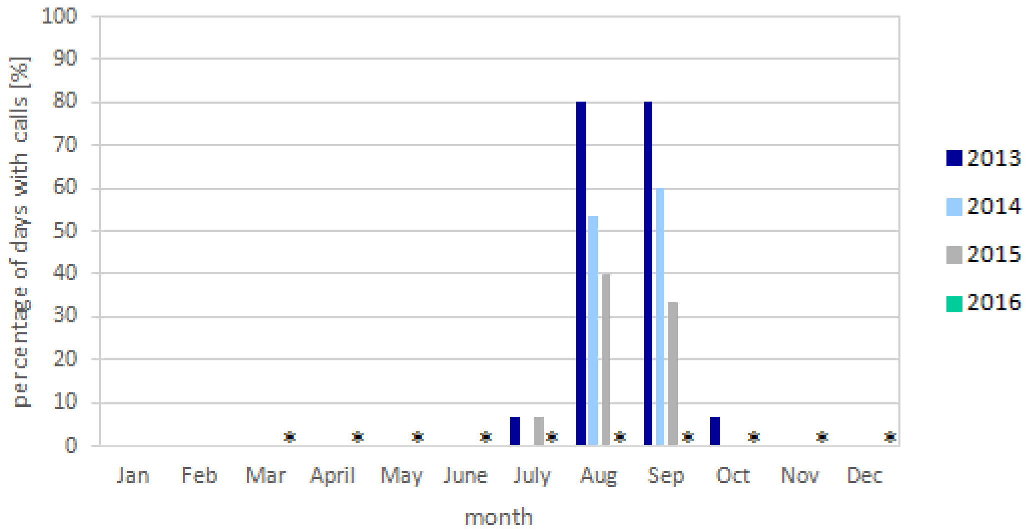



Fig. 25. Monthly percentage of days with Antarctic minke whale vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*Humpback whales*

Humpback whale vocalizations were detected within all month of the recording period, except in August 2014 (Fig. 26). Overall, the species was acoustically present at 60 % of the analyzed days on average. Altogether, the annual acoustic presence was highest in 2016 (100 %) and 2015 (70 %). In contrast, around 57 % and 37 % of the days in 2013 and 2014 contained calls, respectively.  No regular inter-annual pattern in the amount of days with detected calls was found.

A rough seasonal pattern in the acoustic presence was recognizable. For all years, the acoustic presence peaked between October and March, i.e. during austral spring and summer. The exact time (=month) of the peak acoustic presence however varied between the years. Humpback whale acoustic presence peaked in October and November in 2013, in November in 2014, in January and March in 2015, and in January and February in 2016.

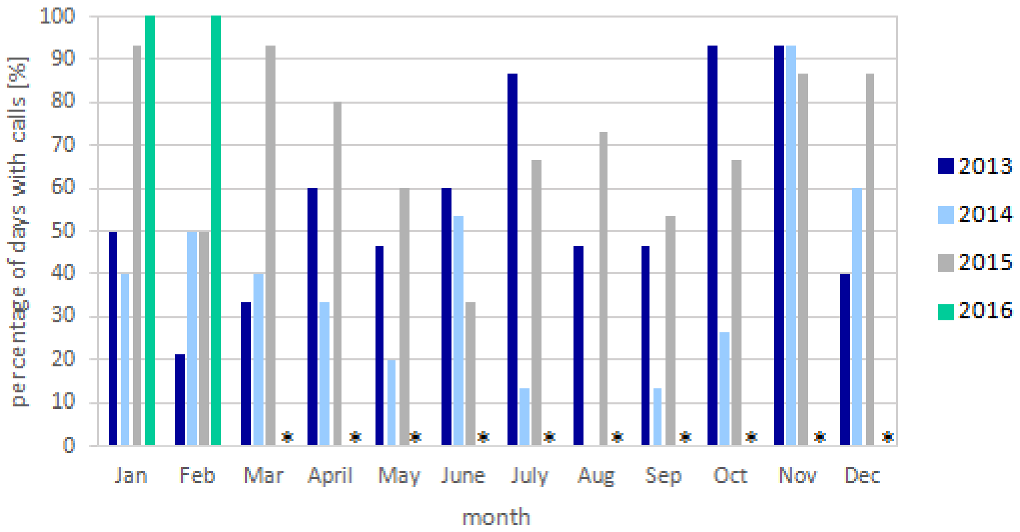



Fig. 26. Monthly percentage of days with humpback whale vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

As explained previously, two different categories of humpback whale vocalizations were differentiated (Fig. 27, 28). Over the entire recording period, low-frequency calls occurred more frequently (being present on 20 % of all analyzed days) than high-frequency calls (occurring at 11 % of all days) were detected. The high-frequency vocalizations were present on 9 % of the analyzed days in 2013, 7 % in 2014, 16 % in 2015, and 13 % in 2016. In contrast, the low-frequency sound was detected on 52 % of the analyzed days in 2013, 33 % in 2014, 61 % in 2015 and 100 % in 2016. For both call-types, no regular inter-annual pattern was found.

The high-frequency vocalizations were detected mainly from January to July. In contrast, the acoustic presence of the low-frequency sounds peaked between October and March in all years.

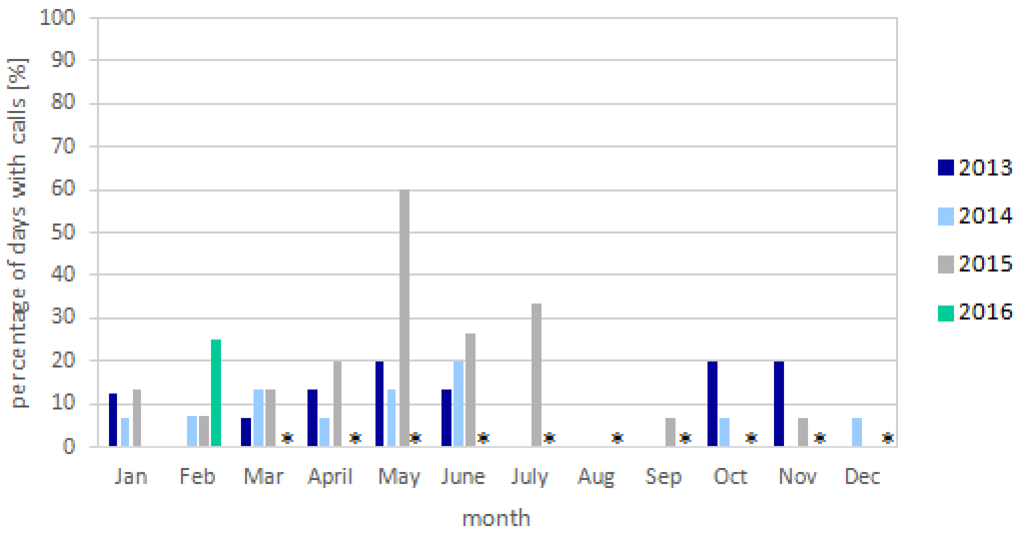



Fig. 27. Monthly percentage of days with high-frequency (fundamental frequency > 200 Hz) humpback whale vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

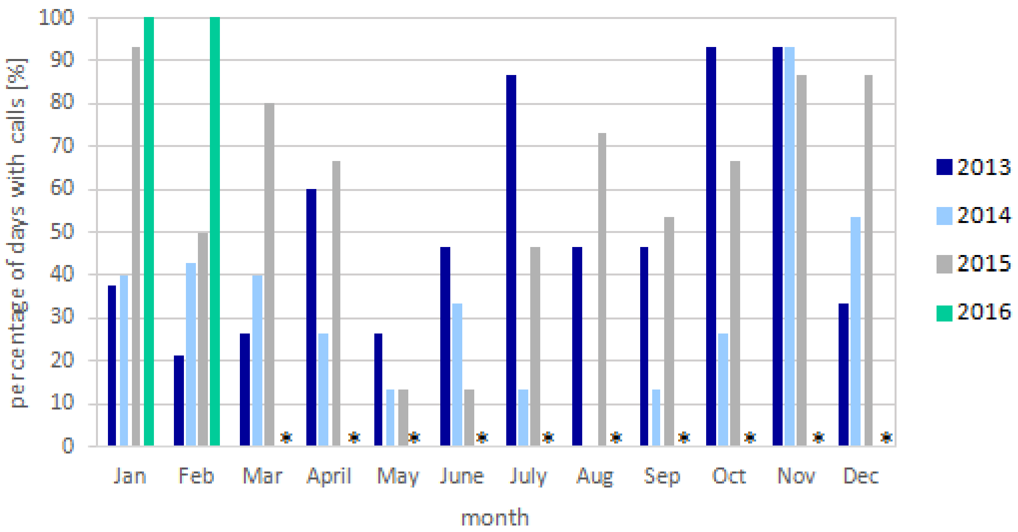



Fig. 28. Monthly percentage of days with low-frequency (fundamental frequency < 200 Hz) humpback whale vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*Fm-calls*

Fm-calls were detected on all months of the recording, with detected calls on 82 % of all analyzed days on average (Fig. 29). Fm calls were present 89 % of the analyzed days in 2013, 94 % in 2014, 63 % in 2015, and 75 % in 2016.

During 15 months of the overall recording period, Fm-calls were detected on each (analyzed) day. Five months (February to May, December) contained Fm-calls on each day in 2013, five months (January, March, May, September, November) in 2014, four months (January to April) in 2015, and one month (January) in 2016.

With the exception of February 2016 the amount of days containing Fm-calls was high (more than 88 %) from January to June. For all years, the amount of days with detected Fm-calls decreased in austral winter (July to August). The amount of days with Fm-calls increased again in October 2013 and September 2014 to more than 93 % of days with calls. In contrast relatively few days (up to 40 %) contained Fm-calls from September to December 2015.

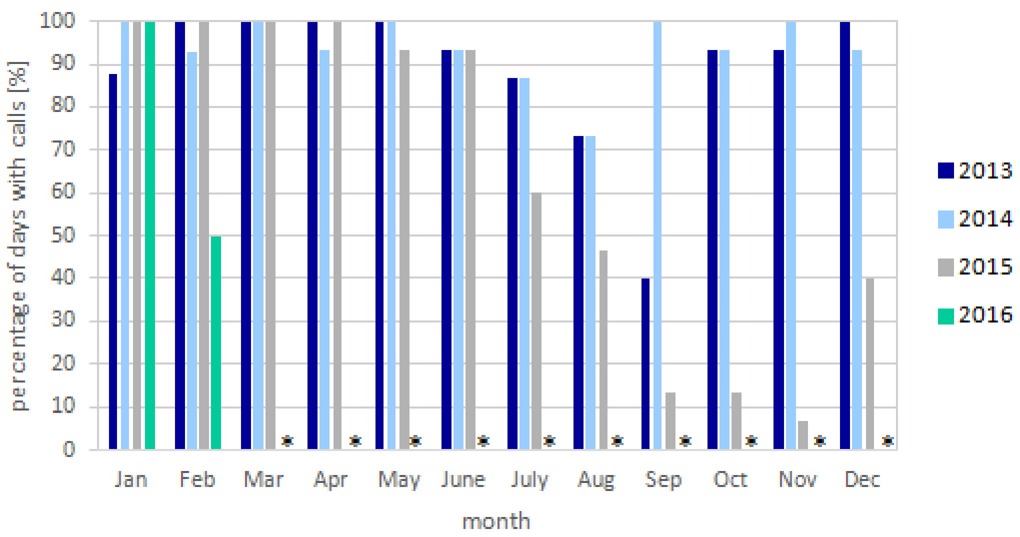



Fig. 29. Monthly percentage of days with Fm-calls recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

### 3.2.2 Toothed whales

*Killer whales*

Over the entire recording period, killer whales were acoustically present at 19 % of all analyzed days on average (Fig. 30). The percentage of days with vocalizations per year was similar for all three recording years (21 % in 2013, 16 % in 2014, and 23 % in 2015). No killer whale vocalizations were detected in 2016.

A seasonal pattern in the acoustic presence of killer whales was evident in this study. In general, the acoustic presence of killer whales was low from November to July, with up to 20 % of days per month containing vocalizations. The percentage peaked in August and September (up to 73 % in 2013, 80 % in 2014 and 87 % in 2015) and was still increased in October in 2013 (33 %) and in 2015 (47 %).

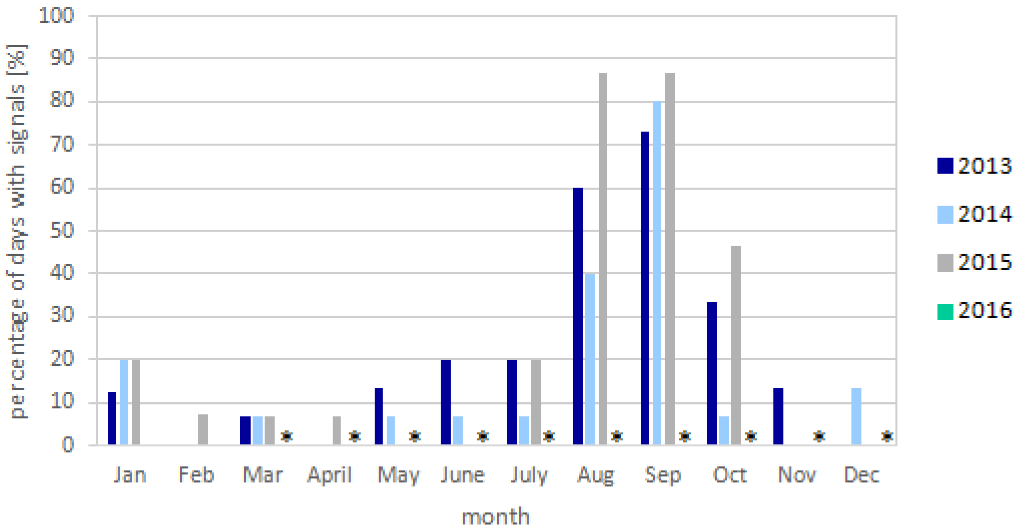



Fig. 30. Monthly percentage of days with killer whale vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*Sperm whales*

Overall, vocalizations of sperm whales were detected on 21 % of all analyzed days on average (Fig. 31). Altogether, the acoustic presence was highest in 2013 and 2014 with 29 % and 25 % of days containing clicks, respectively. The relative amount of days with vocalizations per year was decreased in 2015 (12 % of days with calls). In 2016, sperm whales were acoustically absent. Variations in the acoustic presence between the same months of different years were found, however, a regular inter-annual pattern in the acoustic presence was not evident.

Sperm whales were acoustically present from April to July and September to February in most years. Besides, they were acoustically absent in March and August for all years. The amount of days with detected signals varied over the year. Most days with vocalizations were detected from April to June and from October to December in all years. During these months, the percentage of days with signals per month was usually between 13 and 80 %. However, in April 2013 and October 2015, no signals were detected. For the rest of the year, the acoustic presence was decreased (0 to 20 % of calls per month) compared to the peak period of sperm whale acoustic presence.

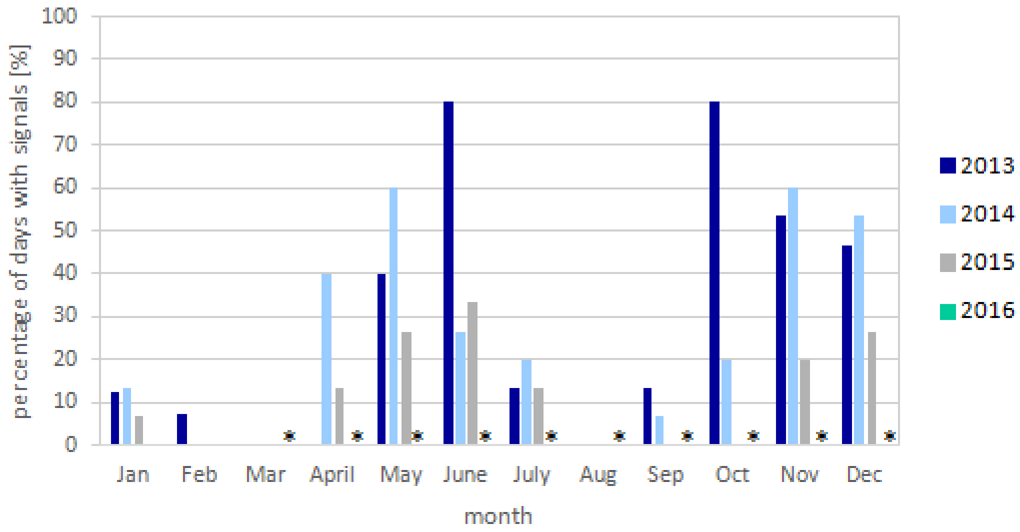



Fig. 31. Monthly percentage of days with sperm whale vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*Unspecified toothed whale vocalizations*

Unspecified vocalizations, possibly produced by toothed whale species other than killer or sperm whales, were detected on 4 % of all analyzed days on average (Fig. 32). In 2013 and 2014, 5 %, and in 2015, 2 % of the analyzed days contained such unspecified toothed whale vocalizations. In 2016, such vocalizations were however not detected.

No distinct inter- and intra-annual pattern was found. For all months, the acoustic presence varied between 0 and 13 % of days with calls present. In this context, it is important to keep in mind that most vocalizations produced by small toothed whales may not be represented in the passive acoustic data recorded off Elephant Island. The recorder was set to record at a sample rate of 32 kHz and in turn, did not record vocalizations at frequencies higher than 16 kHz as usually produced by toothed whales (Zimmer et al. 2005, Johnson et al. 2006, Kyhn et al. 2009, Kyhn et al. 2010, Reyes Reyes et al. 2015).

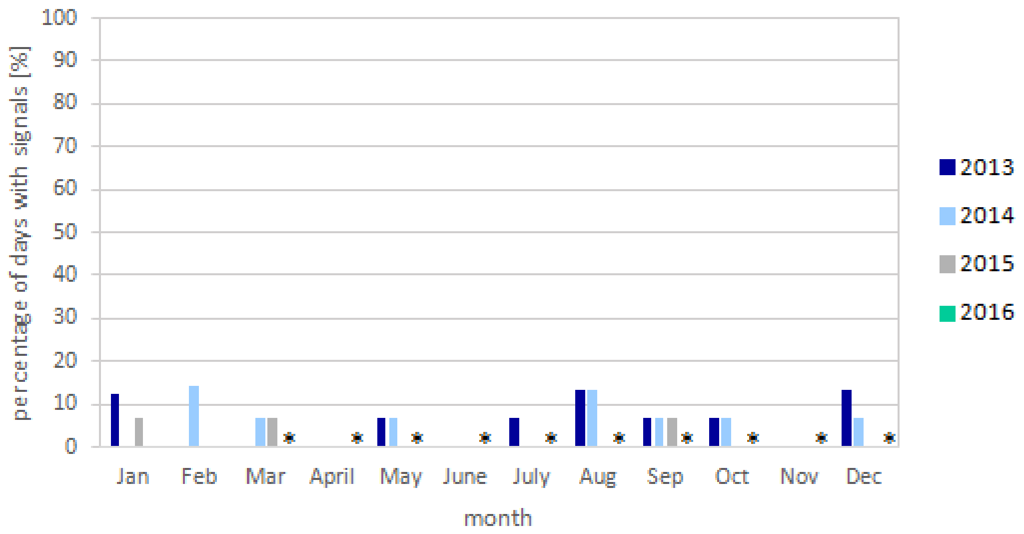



Fig. 32. Monthly percentage of days with unspecified toothed whale vocalizations (excluding signals assigned to sperm and killer whales) recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

### 3.2.3 Seals

*Leopard seals*

During this study, leopard seals were acoustically present on 27 % of all analyzed days on average (Fig. 33). The percentage of days with calls per year was similar for all years, with 26 % of days containing leopard seal calls in 2013, 28 % in 2014, 27 % in 2015, and 20 % in 2016. Little variations in the amount of days with calls were found between the years, however, a distinct inter-annual pattern in the acoustic presence was not evident.

Leopard seal vocalizations showed a clear seasonal pattern. With the exception of April 2015 and June 2013, the species was acoustically absent from February to July in all years. In August, some days (up to 33 %) contained calls in 2013 and 2014, and the acoustic presence increased in the following months until it reached its maximum in December in all recording years. During this month, the percentage of days with calls was 100 %, i.e. at least one call was detected at each day, for all three years. In January, the number of days containing leopard seal calls decreased, with up to 40 % of days with calls.

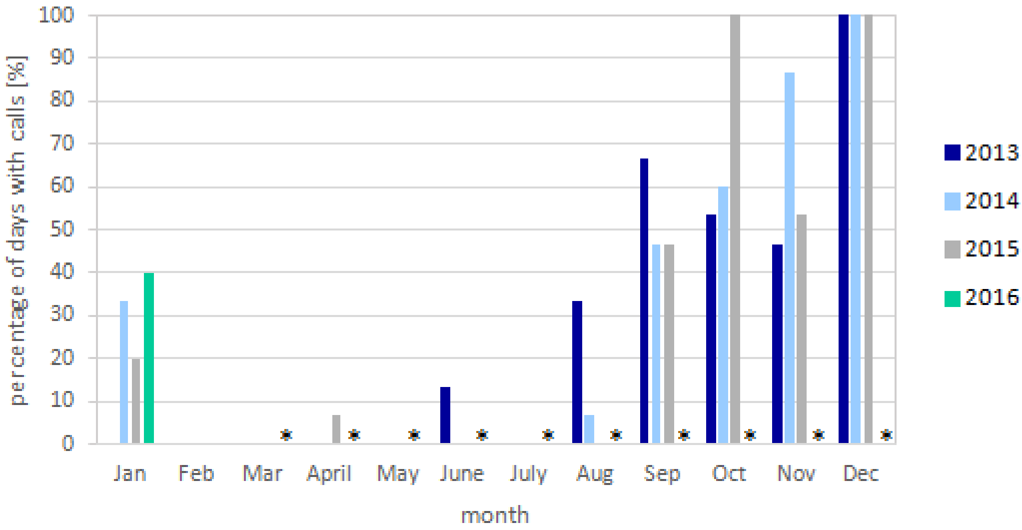



Fig. 33. Monthly percentage of days with leopard seal vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*Crabeater seals*

Overall, vocalizations produced by crabeater seals were detected in 3 % of all analyzed days on average (Fig. 34). Most days with calls were detected in 2015 (6 %). In 2013 and 2014, 3 % and 1 % of days contained calls, respectively. No crabeater seal vocalizations were detected in 2016. A regular inter-annual pattern in the acoustic presence was not evident.

Similar to leopard seals, the acoustic presence in crabeater seals followed a distinct intra-annual pattern. Calls were only detected during austral spring, i.e. mainly in September (2013, 2014, 2015) and October (2015). In 2013 and 2015, the acoustic presence of crabeater seals peaked in September (with 40 % of days containing calls) and October (with 47 % of days with calls), respectively. In contrast, the peak acoustic presence was considerably lower in 2014, with 7 % of days with calls in September.

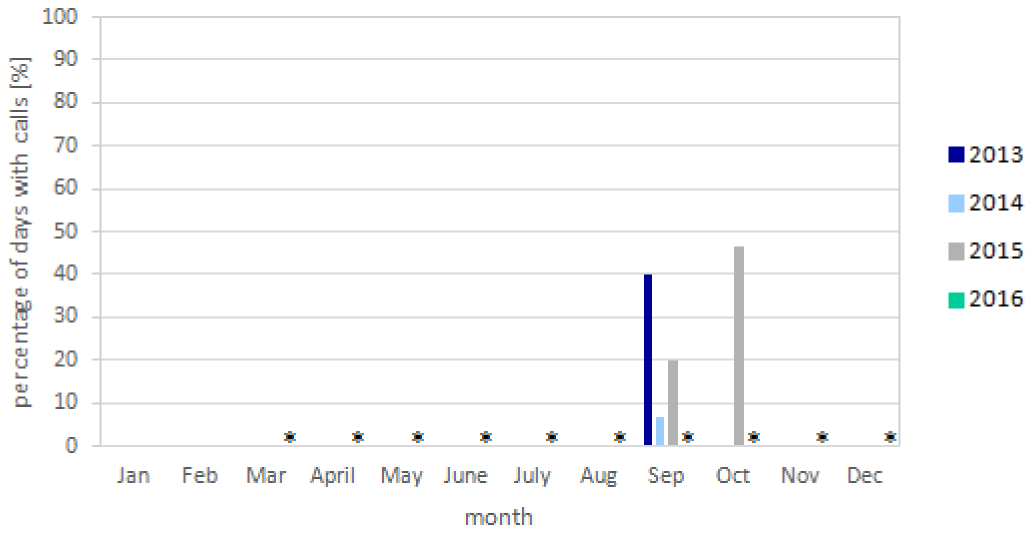



Fig. 34. Monthly percentage of days with crabeater seal vocalizations recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

### 3.2.4 Unknown signals

*'Bark'*

A sound resembling a bark occurred at 1 % of all analyzed days over the entire recording period (Fig. 35). Its acoustic presence was relatively low in all years (1 % of days with calls in 2013, 2 % in 2014, 1 % in 2015, and 0 % in 2016).

It occurred sporadically during austral winter, i.e. in August 2015, in September 2014 and 2015, and in October 2015.

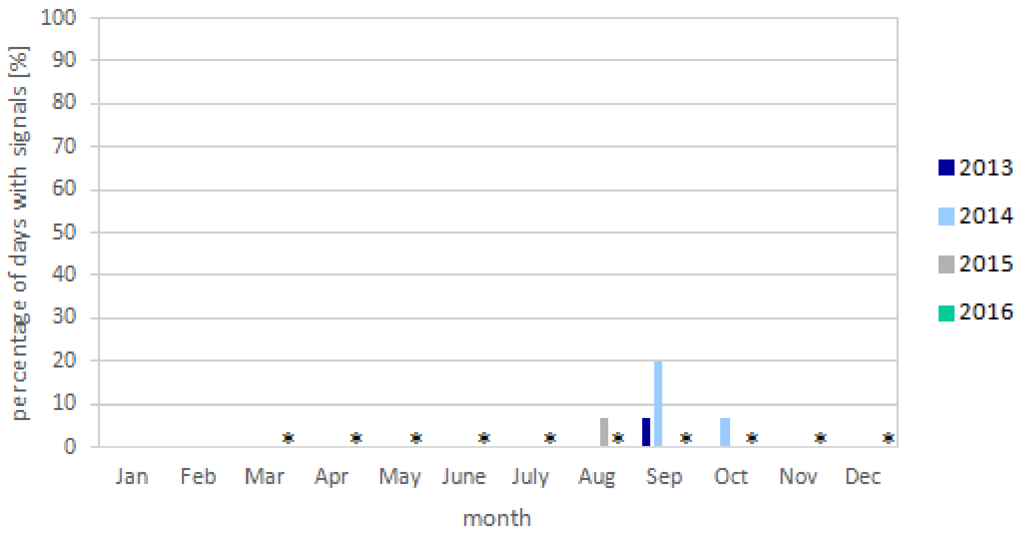



Fig. 35. Monthly percentage of days with unidentified sound (bark) recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*'Ripple'*

The unknown signal resembling a ripple occurred at 3 % of all analyzed days on average (Fig. 36). Its acoustic presence was relatively similar in terms of detected days with calls from 2013 to 2015 (3 % of days with calls in 2013, 4 % in 2014, 4 % in 2015). The signal was not detected in 2016.

The signal occurred occasionally, but mainly during austral winter and spring (i.e. from June to October), with up to 17 % of days with calls per month.

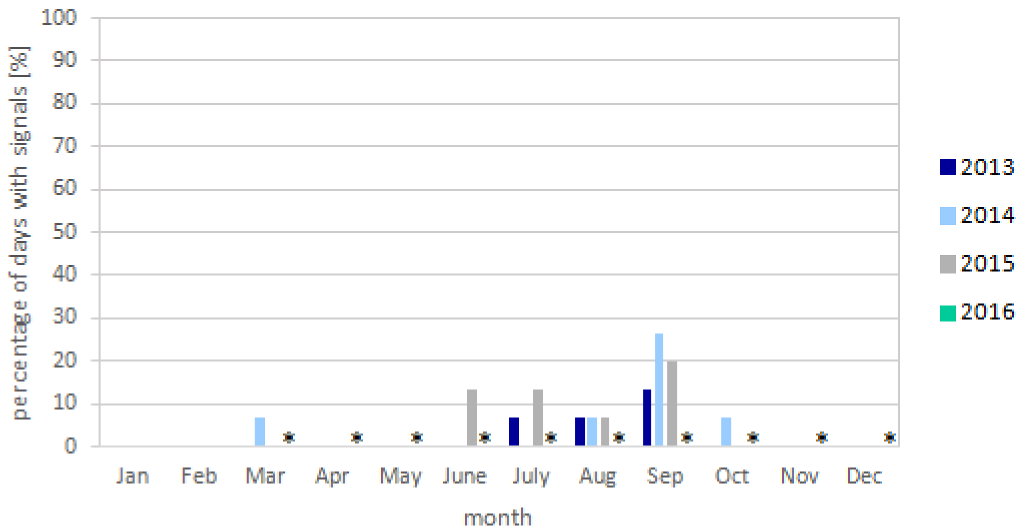



Fig. 36. Monthly percentage of days with unidentified sound ('ripple') recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*'Pulses and upsweeps below 30 Hz'*

Pulses and upsweeps below 30 Hz were detected at 16 % of all analyzed days on average (Fig. 37). The annual mean acoustic presence declined from year to year, with 27 % of days with calls in 2013, 19 % in 2014, 5 % in 2015, and 0 % in 2016.

The signal was detected during 23 months of the overall recording period. The amount of days with calls was increased from November to January 2013 (up to 50% of days with calls) and January, February and October 2014 (up to 80 % of days with calls).

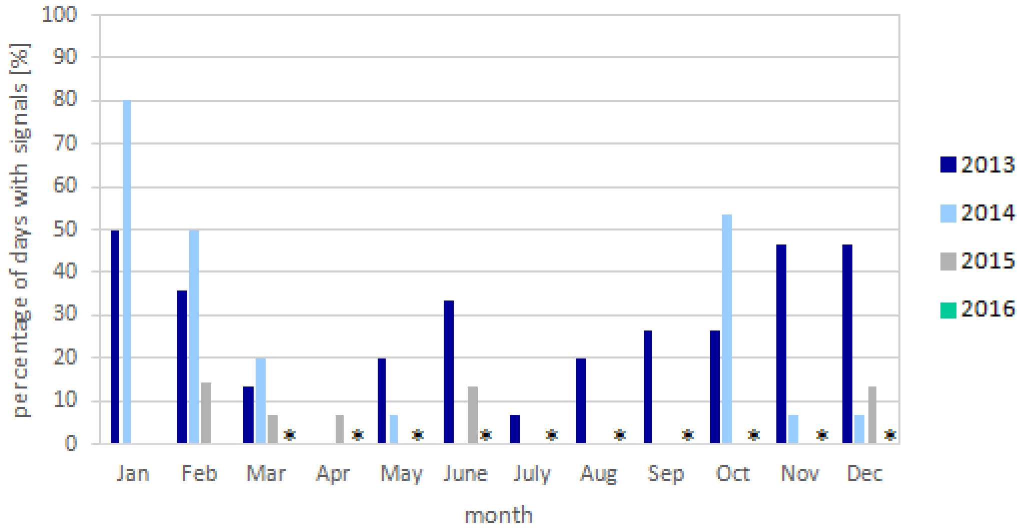



Fig. 37. Monthly percentage of days with unidentified sounds (low-frequency pulses) recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

### 3.2.5 Anthropogenic noise

*Seismic signals*

Seismic signals occurred at 3 % of the analyzed days, showing a decline from 2013 to 2016 (6 % of days with signals in 2013, 3 % in 2014, 1 % in 2015, and 0 % in 2016) (Fig. 38).

The signals occurred sporadically between January and June, at up to 43 % of days per month.

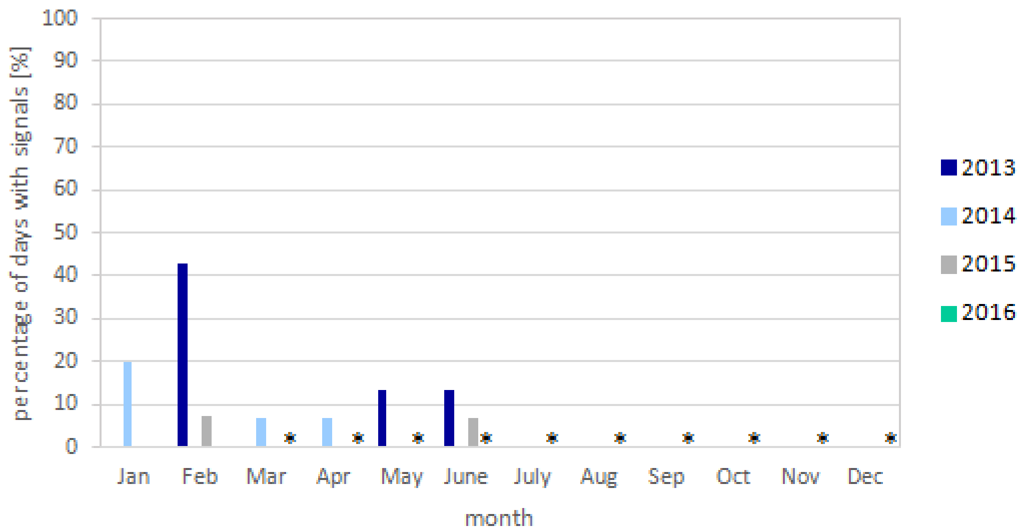



Fig. 38. Monthly percentage of days with seismic signals recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

*Sounds of vessels*

Sounds of vessels were found during 11 % of all analyzed days on average (Fig. 39). The relative amount of days with signals was relatively similar for all years (11 % of days with signals in 2013, 12 % in 2014, 12 % in 2014, and 10 % in 2016).

The signals occurred mainly in austral summer and fall (January to May), with up to 63 % of days with signals per month. During the rest of the year, vessel noise was sporadically detected, with up to 7 % of days with signals per month.

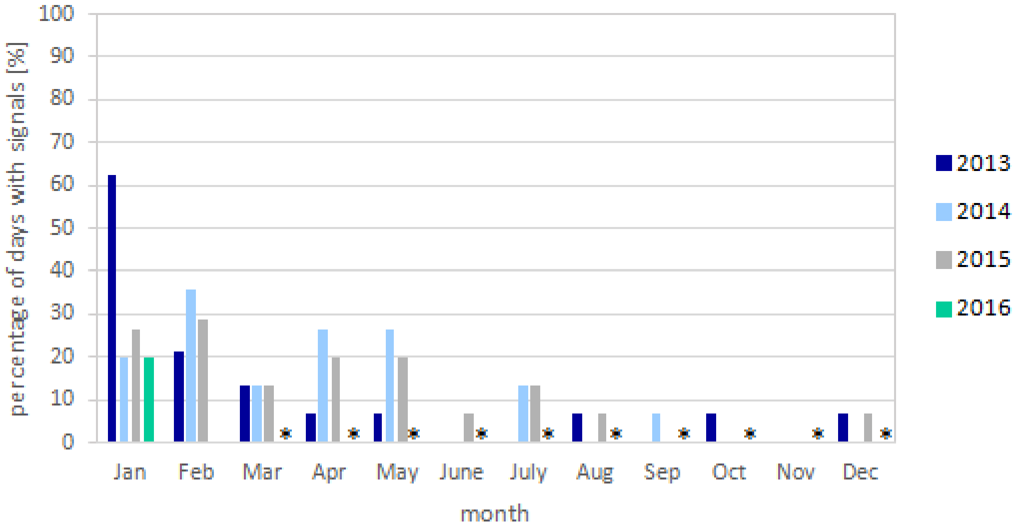



Fig. 39. Monthly percentage of days with sounds of vessels recorded off Elephant Island from 16 January 2013 to 8 February 2016. The different colors represent different years of recording (dark blue = 2013, light blue = 2014, gray = 2015, green = 2016). Star indicates a lack of data.

# 4 Discussion

## 4.1 Acoustic biodiversity of marine mammals off Elephant Island

### 4.1.1 Baleen whales

Off Elephant Island, four baleen whale species (Antarctic blue, fin, Antarctic minke, and humpback whales) were identified based on their characteristic, species-specific calls in the passive acoustic data (Tab. 2). These results are in line with previous studies applying both visual and acoustic methods, reporting the (acoustic) presence of the these species west of the Antarctic Peninsula (Secchi et al. 2001, Širović et al. 2004, Thiele et al. 2004, Friedlaender et al. 2006, Sirovic et al. 2006, Scheidat et al. 2007, Širović et al. 2007, Širović et al. 2009, Santora et al. 2010, Scheidat et al. 2011, Burkhardt & Lanfredi 2012, Joiris & Dochy 2013).

Apart from the four baleen whale species detected in the present study, sei and southern right whales are also known to occur in the Scotia Sea and the South Shetland Island region as reported by both visual and acoustic surveys (Secchi et al. 2001, Thiele et al. 2004, Sirovic et al. 2006, Scheidat et al. 2007). These species were however not detected during this study. Both southern right and sei whales prey on Antarctic krill (Pauly et al. 1998), and hence might be attracted by the waters off Elephant Island, which are known for an elevated amount of krill (Laws 1977, Siegel 1988, Loeb et al. 1997, Reiss et al. 2008). However, no vocalizations that could be assigned to either of these species with certainty were detected during this study.

Southern right whales produce a variety of different calls with most energy concentrated between 50 and 500 Hz (Cummings et al. 1972, Clark 1982). The different signals are produced one after another forming sequences with certain types more common than others (Clark 1982). The most commonly described call type of Southern right whales is the up-call, an up-sweeping sound from 50 – 200 Hz lasting between 0.5 and 1.5 s (Clark 1982, Sirovic et al. 2006).

Sound production of sei whales is poorly documented and most studies were conducted in the Northern Hemisphere (Knowlton et al. 1991, Rankin & Barlow 2007, Baumgartner et al. 2008). However, sei whales recorded off the Western Antarctic Peninsula (WAP) were reported to produce tonal and frequency-modulated calls below 600 Hz, which often consist of multiple parts and resemble moans (McDonald et al. 2005).

There are three possibilities potentially explaining the acoustic absence of sei and southern right whales in the present study, i.e. i) the whales were absent during the study period, ii) the whales were silent during the recording time, or iii) vocalizations present in the passive acoustic data were either not detected or mistakenly assigned to another species. Whether southern right and sei whales were physically absent or silent in the study area cannot be differentiated based on passive acoustic data alone. However, southern right whales were reported to be distributed primarily between 40° and 50°S in summer and they have rarely been reported south of the Antarctic convergence (Omura et al. 1969). Sei whales in general are very rare[11]and to my knowledge, only two acoustic studies conducted in the Southern Ocean reported the presence of this species off the WAP and north of the Ross Sea, respectively (McDonald et al. 2005, Calderan et al. 2014). Hence, it is possible that both species do not or only sporadically occur off Elephant Island and hence, were not recorded in the present study. Alternatively, vocalizations of southern right whales or sei whales, which were potentially present in the passive acoustic data, might mistakenly have been assigned another species. Southern right whale vocalizations are similar to humpback whale vocalizations, since both species produce sequences consisting of repeated elements (Payne & McVay 1971, Clark 1982). Humpback whale vocalizations in general are more variable and, when occurring as song, hierarchically structured (Payne & McVay 1971). However, it is possible that part of the low-frequency sounds, which were assigned to humpback whales in the present study, was produced by southern right whales instead. Up-calls that might have been produced by southern right whales occurred within several parts of the records (Fig. 40). However, also humpback whales are known to produce up-sweeping sounds (Stimpert et al. 2011), hampering a reliable assignment of such up-calls to species-level. However, since the low-frequency passages were highly variable and exhibited a great complexity, they were considered to be produced by humpback whales. Nevertheless, as mentioned before, the acoustic repertoire of sei whales in the Southern Ocean is still poorly documented (McDonald et al. 2005, Calderan et al. 2014) and hence, it cannot be excluded that some of the unidentified sounds recorded in the present study were produced by this species.

[11] For further information, see also http://www.iucnredlist.org/details/2475/0 (last accessed 07.07.2017).

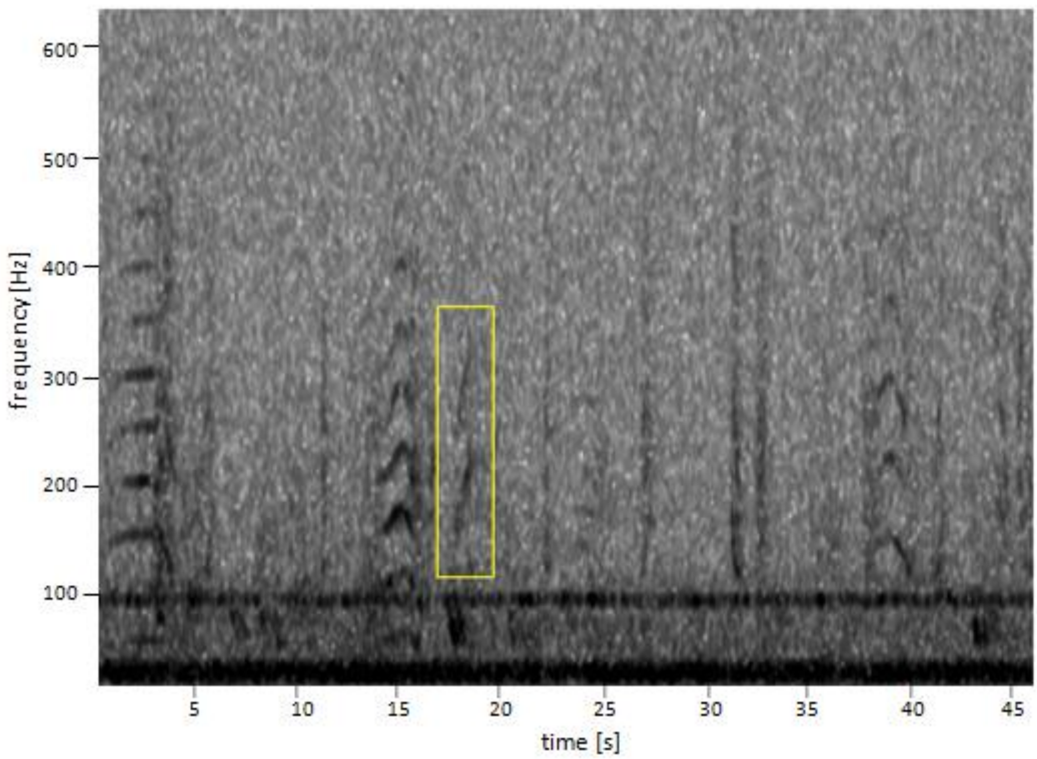



Fig. 40. Spectrogram potential right whale vocalizations (1000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 28 March 2015. Yellow box frames characteristic up-call.

### 4.1.2 Toothed whales

Two toothed whale species (sperm and killer whales) were identified in the acoustic data in this study (Tab. 2). Besides, vocalizations of toothed whales that could not be identified more closely were detected. These vocalizations may have been produced by one or different species but could not be assigned to sperm or killer whales with certainty. Prior studies reported the presence of killer and sperm whales, as well as of some smaller whales, such as southern bottlenose whale, Grays beaked whale, and strapped-toothed whale off Elephant Island and in the South Shetland Island region (Thiele et al. 2004, Scheidat et al. 2007, Scheidat et al. 2011, Joiris & Dochy 2013).

Usually small toothed whales, such as beaked whales or dolphins produce clicks and other vocalizations at high frequencies (>16 kHz) (Zimmer et al. 2005, Johnson et al. 2006, Kyhn et al. 2009, Kyhn et al. 2010, Reyes Reyes et al. 2015). However, due to the recorder's sampling rate of 32 kHz, sounds above 16 kHz were not recorded and hence, the majority of the acoustic presence of small toothed whales may not be represented in the acoustic data analyzed in this study. In addition, the information on the acoustic repertoire of several small whales is sparse and needs further investigation (Zimmer et al. 2005). There is evidence for some species, such as Cuvier's beaked whales to produce vocalizations below 16 kHz (Frantzis et al. 2002), and hence, some of the recorded unspecified vocalizations may have been produced by small cetaceans.

Alternatively, some of the unknown sounds might have been produced by Antarctic killer whales. Three different ecotypes of Antarctic killer whales (ecotype A, B, and C) were reported to occur in the Antarctic (Pitman & Ensor 2003). These ecotypes differ in terms of phenotype, prey-preferences and probably also in their acoustic repertoire (Pitman & Ensor 2003, Schall & Van Opzeeland 2017). The acoustic behavior of ecotype C was described by Schall et al. (2017), based on acoustic recordings of killer whale obtained off the PerenniAL Acoustic Observatory in the Antarctic Ocean (PALAOA, located on the Ekström ice shelf in the eastern Weddell Sea (Boebel et al. 2006). However, due to the relatively short recording period of two days, the recorded calls may not cover the whole vocal repertoire of ecotype C and the vocal repertoire of Southern killer whales in general is poorly investigated (Schall & Van Opzeeland 2017). Hence, it cannot be excluded that some Antarctic killer whale calls were not correctly identified in this study. When unidentified vocalizations consisted of clicks only (i.e. neither whistles nor burst pulses occurred within the same 5-minute audio-file), they may possibly have been produced by sperm whales. However, due to seemingly different audible characters, they could not be assigned to sperm whales with certainty.

### 4.1.3 Seals

Two species of seals (crabeater and leopard seals) were acoustically present within the records (Tab. 2). These results are in accordance with previous findings, reporting both species to occur in the South Shetland Island region (Boveng et al. 1998, Hiruki et al. 1999, Joiris & Dochy 2013).

Apart from crabeater seals and leopard seals, the presence of elephant seals and Antarctic fur seals off the South Shetland Islands was reported by visual surveys (Bengtson et al. 1990, Boveng et al. 1998, Daneri et al. 2000, Hucke-Gaete et al. 2004, Osman et al. 2004, Joiris & Dochy 2013). However, these species were not detected in the acoustic data of this study, which can possibly be explained on the basis of their breeding behavior. While crabeater and leopard seals breed on ice and mate in water, both Antarctic fur and Elephant seals breed and mate on land (Siniff 1991). Land-breeding pinnipeds vocalize in-air for the purpose of mother–pup recognition and male–male competition (Insley et al. 2003, Tripovich et al.

2008). Since the passive acoustic device was moored underwater at 200 m depth, these calls were likely not recorded during this study.

In addition, two other seal species were reported to occur in the Southern Ocean: Weddell and ross seals (Costa & Crocker 1996). Both species breed on ice and vocalize under-water (Siniff 1991, Van Opzeeland et al. 2008, Van Opzeeland et al. 2010) but were not detected in the acoustic data analyzed during this study. Ross seals produce calls described to resemble police sirens at 1 to 4 kHz (Watkins & Ray 1985). Weddell seals recorded at the Antarctic Peninsula produced a variety of call types, such as trills, chirps, whistles and whistles at 200 to 4600 Hz (Thomas & Kuechle 1982). To my knowledge, no acoustic or visual study reported their presence off Elephant Island yet. Weddell seals occur primarily on near-shore fast-ice and pack-ice close to the continent (Siniff et al. 1977) and might have not been present off Elephant Island. Ross seals are the rarest of the Antarctic seals but and were reported to spend several months foraging in the open ocean (Blix & Nordøy 2007). During the breeding season (austral summer) they have a seasonal circumpolar distribution in the pack-ice surrounding the Antarctic (Siniff 1991, Blix & Nordøy 2007) and hence might occur sporadic off Elephant Island. However, some seal species seem to use different habitats, probably to reduce inter-specific competition (Costa & Crocker 1996). Hence, the acoustic absence of ross seals might be linked to the presence of leopard and crabeater seals off Elephant Island.

#### 4.1.4 Unknown signals

Three different unknown signals (‘bark’, ‘ripple’, and ‘low-frequency upsweeps and pulses’) occurred within each year from 2013 to 2015.

The bark occurred sporadically during austral winter and spring from August to October. Its audible character gave evidence that the signal was produced by seals. Besides, the vocal behavior of seals is linked to their breeding behavior (Van Opzeeland et al. 2008), which could explain the seasonality in the acoustic presence of this signal. However, to my knowledge, for none of the seal species occurring in the Southern Ocean a similar vocalizations was described.

The signal resembling a ripple occurred mainly during austral winter and spring. Besides, it was recorded in March 2014. The audible character of this signal gave no evidence whether it was produced by marine mammals (e.g. toothed whales), fish or probably invertebrates. It also cannot be excluded that the signal was not of animal origin.

The pulses and upsweeps below 50 Hz occurred within all months, especially from October to February. Similar signals of unknown origin were described before in a coastal Antarctic environment in the eastern Weddell Sea (Van Opzeeland 2010). The pulses and upsweeps may have been produced by a baleen whale species, such as blue or fin whales which in general produce low-frequency sounds (< 200 Hz) (Watkins 1981, Širović et al. 2004) and were acoustically present in most months of the recording. However, no confirmation of this origin and no assignment to species-level was possible. Furthermore, it cannot be excluded that the signals were of another origin, such as movements of the mooring or ice.

## 4.2 Ecological importance of Elephant Island as a marine mammal habitat

### 4.2.1 Baleen whales

The acoustic presence of four different baleen whale species provides evidence that the Elephant Island region serves as an important baleen whale habitat. Several studies conducted in the Southern Ocean clearly showed that the relative abundance of baleen whales is ultimately linked to the distribution on their primary prey (Antarctic krill) (Reid et al. 2000, Thiele et al. 2004, Friedlaender et al. 2006, Friedlaender et al. 2008, Friedlaender et al. 2009, Santora et al. 2010). Baleen whales are thought to be capable of tracking their prey, either directly or on the basis of physical features of the ocean that may lead them towards enriched prey abundances (Murase et al. 2002, Friedlaender et al. 2006, Friedlaender et al. 2009, Santora et al. 2014). The waters off Elephant Island are known for an elevated amount of krill (Laws 1977, Siegel 1988, Loeb et al. 1997, Reiss et al. 2008) and were suspected to serve as an important feeding ground for baleen whales (Friedlaender et al. 2006, Santora et al. 2010, Burkhardt & Lanfredi 2012, Joiris & Dochy 2013). Vocalizations of baleen whales are thought to be produced in different behavioral contexts (Watkins 1981, Croll et al. 2002, Dunlop et al. 2007), and hence, acoustic data can provide information on the habitat-use of a focal species in a study area. In the present study, Fm-calls were found, which are produced by several baleen whale species, such as Antarctic blue whales (Rankin et al. 2005), fin whales (Watkins 1981), Antarctic minke whales (Dominello & Širovic 2016), and sei whales (Calderan et al. 2014). Baleen whales are suspected to produce Fm-calls in a feeding context, maybe to maintain spacing between individuals and hence to reduce competition (Watkins 1981, Edds-Walton 1997, Edds-Walton 2000). The occurrence of Fm-calls in the present study provides evidence that the whales were feeding during the recording period. Furthermore, the passive acoustic data collected off Elephant Island contained song or song sequences of several baleen whale species (Antarctic blue whales, fin whales, and humpback whales). Singing (i.e. the production of song) is defined as "[…] the behaviour during which a limited number of stereotypic sound types are produced in regular succession and form a recognisable pattern in time" (McDonald et al. 2006). Song is thought to be produced by males in a reproductive context (Darling & Bérubé 2001, Croll et al. 2002, McDonald et al. 2006). For fin whales, there is evidence that only males produce song to attract females to high aggregations of prey (Croll et al. 2002). Considering the elevated amount of Antarctic krill in the Elephant Island region it seems plausible that baleen whale song was produced for the advertisement of resources in the present study. Besides, the production of song might provide evidence that the whales were mating during the recording period. This is line with previous studies reporting baleen whales to sing on high-latitude feeding grounds outside the presumed breeding period, and hence suggesting that breeding in baleen whales is not confined to lower-latitude regions or to austral winter (Clark & Clapham 2004, Širović et al. 2004, Thomisch 2017).

Temporal patterns in the acoustic presence might provide information about the inter- and intra-annual occurrence of marine mammal species off Elephant Island. In line with findings from Dominello and Širović (2016) the acoustic presence of minke whale peaked in August and September. This could possibly indicate that the number of minke whales off Elephant Island increased during austral winter. Besides, a decline in the number of days with Antarctic minke whale vocalizations from year to year was detected, eventually giving evidence that the number of individuals decreased between 2013 and 2015. Alternatively, it is possible that temporal patterns in the acoustic presence were caused by temporal changes in the calling behavior (Mellinger et al. 2007).

For Antarctic blue, fin and humpback whales, neither an intra- nor an inter-annual pattern in their acoustic presence was found, giving no evidence for a seasonal or annual change in the amount of individuals or, alternatively, the acoustic activity of these species off Elephant Island. In contrast, prior studies covering approximately two years reported a seasonality in

the acoustic presence of all three species in the Southern Ocean, with the acoustic presence peaking during austral fall (Širović et al. 2004, Van Opzeeland et al. 2013). Off the WAP, Antarctic blue whale vocalizations were recorded year-round peaking March to April (Širović et al. 2004). Fin whale vocalizations likewise recorded off the WAP were detected from February to June with a peak in March (Širović et al. 2004). Regarding humpback whales, acoustic data from the Weddell Sea collected at PALAOA demonstrated a clear seasonality in the detection of vocalizations, with a peak from February to April (Van Opzeeland et al. 2013). The authors suspected the seasonal acoustic presence to be influenced by prey availability, sea-ice formation, and migratory behavior (Širović et al. 2004, Van Opzeeland et al. 2013). The absence of a clear temporal pattern in the present study might be linked to the assessment of calls on a daily basis. Studies reporting a clear seasonality in the acoustic presence assessed total numbers of calls of the focal species based on automated detection (Širović et al. 2004, Van Opzeeland et al. 2013). By assessing acoustic presence on a daily scale, a potential seasonal pattern in the acoustic presence of marine mammals might have been modified or obscured in the present study.
Regarding fin whales, acoustic data collected off Elephant Island with another recording device (of the type SonoVault) demonstrated the acoustic presence of fin whales in August 2013 and their acoustic absence in September 2013 (Meister et al. 2017). Thus, data from the AURAL analyzed in the present study and from the SonoVault analyzed previously (Meister et al. 2017) show contradicting results. This is a rather unexpected finding, since both recorders were attached to the same mooring at similar depths. However, while the SonoVault recorded continuously, data collection of the AURAL was limited to two hours per day in total and only every second day was analyzed. According to the SonoVault data, relatively few hours contained calls in August 2013 (less than 3 % of hours with presence of fin whale 20-Hz pulses per day) (Meister et al. 2017). Due to recording scheme of 5 min per hour, these calls may not be captured by the AURAL data or they may have occurred on days that were not analyzed in the present study. However, acoustic data from both recorders should be compared in more detail to reveal the reason for the contradicting results.

When distinguishing low- and high-frequency sounds of humpback whales the seasonal acoustic presence slightly varied between both call types. Low-frequency sounds were produced year-round but occurred more often from October to February, whereas high-frequency sounds occurred preferably from January to June. Possibly, low- and high-frequency sounds were produced in different behavioral contexts. For instance, the low-frequency sound could be produced preferably during feeding, which might occur more frequently during austral summer, when Antarctic krill abundance is highest (Siegel 1988). Besides, social sounds of humpback whales were described to contain low-frequency elements (Dunlop et al. 2007, Dunlop et al. 2008). The authors suspected these elements to be used to regulate intra-specific group social interactions, to elect social roles within male groups, to seek other groups, to advertise their availability or as parent/offspring contact calls (Dunlop et al. 2008). In contrast high-frequency sounds occurred partly as humpback whale song, which might be used as a breeding display (Darling & Bérubé 2001).

Overall, temporal variations in the acoustic presence of baleen whales might be an implication for the amount of individuals off Elephant Island and can provide evidence for the habitat-use of the animals. The acoustic presence of three baleen whale species (Antarctic blue whales, fin whales, humpback whales) during austral summer and autumn months, i.e. during the main baleen whale feeding period (Mackintosh 1966), as well as the detection of Fm-calls provide further evidence that Elephant Island serves as a feeding ground. However, it is important to keep in mind that baleen whale vocalizations in the Southern Ocean were reported to range more than hundred kilometers (Širović et al. 2007, Miller et al. 2015) and hence, the acoustic presence does not automatically imply the actual occurrence of the detected species directly off Elephant Island. Besides, abiotic and biotic parameters might have influenced the calling behavior, as well (D'Vincent et al. 1985, Jefferson et al. 1991, Van Parijs et al. 2004, Van Opzeeland 2010). Two important factors (prey-availability and sea-ice extent) are discussed below.

Temporal changes in the krill stock size off Elephant Island might influence the acoustic presence of baleen whales. Antarctic krill off the WAP was reported to underlie distinct inter-annual fluctuations in stock size (Loeb et al. 1997, Siegel et al. 1998). Between 1977 and 1997, an approximate 21- to 23-fold change in biomass and density between the highest and lowest estimate of krill stock size in the Elephant Island region was reported (Siegel et al. 1998). Besides, from 1900 to 2003, a general downward trend in the abundance of krill in the Atlantic Sector of the Southern Ocean has been observed, potentially due to changes in sea-ice extent and chlorophyll concentrations (Atkinson et al. 2004). In addition, krill stock size west of the Antarctic Peninsula underlies distinct seasonal variations (Siegel 1988, Lascara et al. 1999). Studies conducted between 1991 and 1993 reported a high mean biomass (150 g/m³) with aggregations of krill in the upper layer (<50m depths) of the water column in austral summer (Lascara et al. 1999). In contrast the authors reported a low mean biomass (10 g/m³) and aggregations of krill occurring deeper (>100 m depths) during austral winter (Lascara et al. 1999). To my knowledge, no study about the seasonal krill stock size off Elephant Island between 2013 and 2016 was published, yet. However, the seasonal abundance of krill might have been similar to previous years, with high mean biomass in summer and low mean biomass in winter (Lascara et al. 1999). The acoustic presence of humpback whales peaked between October and March (austral spring to austral fall), which might associated to the higher abundance of krill within these months. However, regarding Antarctic blue and fin whales, no regular differences in the amount of days with calls between summer and winter months were evident, giving no evidence for a correlation between krill stock size and the acoustic presence. In terms of minke whales, the acoustic presence peaked in austral winter, when krill abundance was reported to be the lowest (Lascara et al. 1999). However, other parameters, such as the extent of sea-ice, might have affected the acoustic presence of minke whales. For all years, the amount of days with detected Fm-calls decreased in austral winter (A6), which might be linked to the lower amount of Antarctic krill in this season and adds further evidence for the hypothesis that Elephant Island serves as a feeding ground for baleen whales.

In addition to krill abundance, sea-ice conditions off Elephant Island might have affected the acoustic presence of baleen whales. Elephant Island is located at the outer edge of the Antarctic where sea-ice occurs usually mainly during austral winter reaching its maximum in August, November or October (Gloersen et al. 1992). Antarctic minke whales were reported to occur year-round in the Southern Ocean but in greater numbers associated to pack-ice during winter and autumn (Thiele et al. 2004), probably as a strategy to reduce inter-specific competition (Friedlaender et al. 2006, Santora et al. 2010). In the present study, sea-ice around Elephant Island formed in August 2013, September 2015, and September 2016 (Fig. 40), coinciding with the peak in the acoustic presence of Antarctic minke whales. This suggests that the peak in the acoustic presence of Antarctic minke whales during austral winter off Elephant Island is linked to the formation of sea-ice. Besides prior studies reported Antarctic minke whales to be directly influenced by year-to-year changes in the spatial extent of sea ice (Murase et al. 2002, Thiele et al. 2004). The spatial extent of sea ice off Elephant Island and in the South Shetland Island region was relatively wide in August 2013 compared to the following years (Fig. 41). This might explain the high acoustic presence of Antarctic minke whales in 2013 and the decline in the years after. Antarctic blue and humpback whales seem to occur in both ice-free and ice-covered areas (Van Opzeeland et al. 2013, Thomisch et al. 2016), whereas fin whales seem to avoid sea ice (Mackintosh et al. 1929, Širović et al. 2004). The acoustic absence of fin whales in early winter in 2013 might be linked to the relatively wide extent of sea-ice in August 2013 (Fig. 41). Antarctic blue and humpback whales may have been less affected by the ice conditions, since their acoustic presence showed no considerably variations between the years. However, it needs to be stressed again that baleen whale vocalizations can have a wide propagation ranges (Širović et al. 2007, Miller et al. 2015) and whether the animals were calling from ice-covered or ice-free areas in austral winter cannot be concluded from the results of this study.

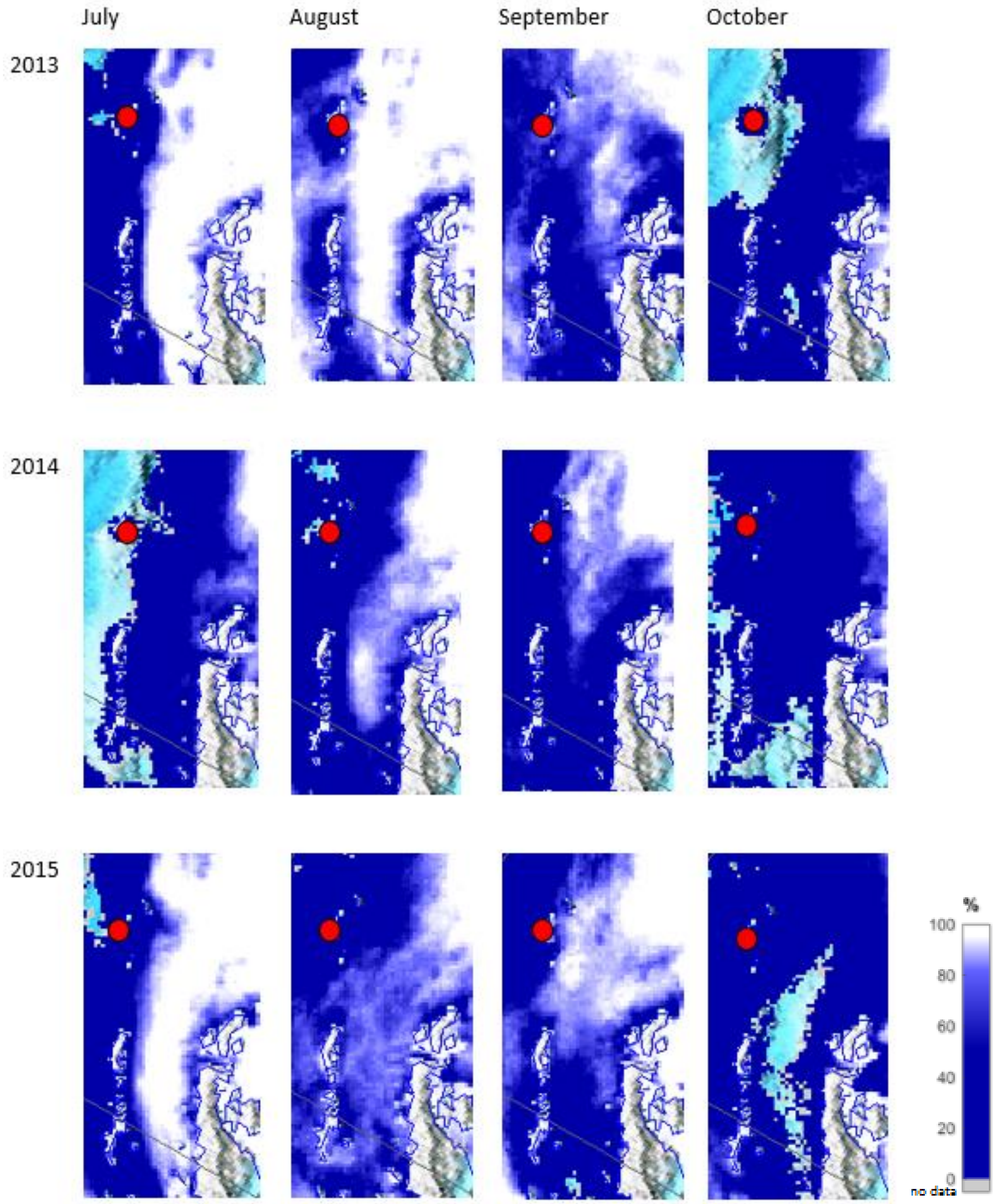



Fig. 41. Monthly average of sea ice concentration west of the Antarctic Peninsula from July to October 2013, 2014, and 2015. Red dot indicates the position of Elephant Island[12].

[12]Adapted from http://www.meereisportal.de/ (last accessed on 30 June 2017), Spreen G, Kaleschke L, Heygster G (2008) Sea ice remote sensing using AMSR-E 89-GHz channels. Journal of Geophysical Research: Oceans 113.

### 4.2.2 Toothed whales

The results of this study provide evidence that the Elephant Island region serves as a feeding ground for toothed whales. In contrast to baleen whales, toothed whales do usually not prey on krill but on fish, cephalopods, and warm-blooded animals (Pauly et al. 1998). In the present study, usual clicks' produced by sperm whales were recognized, which were reported to be used for echolocation purposes during foraging dives (Jaquet et al. 2001). In addition, clicks produced by killer whales were recorded off Elephant Island, which are assumed to be used for locating and catching prey (Ford 1989, Barrett-Lennard et al. 1996, Au et al. 2004). The occurrence of these vocalizations in the acoustic data suggests that both species were feeding during the recording period. The waters off Elephant Island might host several species of fish and cephalopods, since they are close to the Antarctic circumpolar current, which is high in primary production (Tynan 1998). Besides, toothed whale vocalizations have a relatively short propagation range (about 3-37 km) (Barrett-Lennard et al. 1996, Madsen et al. 2002, Møhl et al. 2003, Barlow & Taylor 2005), suggesting that the animals were calling in relative proximity to Elephant Island.

The acoustic presence of killer whales was probably influenced by the availability of prey off Elephant Island. In the present study, killer whale vocalizations peaked from August to October and were occasionally detected during the rest of the year. These results are in line with findings from Condy et al. (1978), who reported a strong seasonality in the presence of this species off Marino Island (Prince Edward Islands, sub-Antarctica) based on visual sightings. The whales occurred preferably from October to December, with their presence linked to the abundance of prey, such as Southern elephant seals and Macaroni penguins (Condy et al. 1978). This suggests that the acoustic presence of killer whales off Elephant Island was influenced by prey availability. In this study, killer whale and minke whale acoustic presence peaked simultaneously in August and September. In contrast, killer whale vocalizations decreased from October to December, when leopard seal acoustic presence increased. This could potentially indicate that part of the killer whales off Elephant Island belong to the ecotype A, which preys on minke whales rather than on seals (Pitman & Ensor 2003). Besides, this ecotype was described to occur in open water and preferably at the outer edge of Southern Ocean (north of 70° S) where sea ice is less abundant (Pitman & Ensor 2003). Since Elephant Island is located at around 62° S, this ecotype could occur around the Island. However, according to previous visual studies, ecotype B occurs more frequently off the WAP (Pitman & Ensor 2003). This ecotype mainly preys on seals (Pitman & Ensor 2003), which were detected in the acoustic data from off Elephant Island. This could suggest that killer whales of ecotype B were acoustically present during the recording period as well. However, the differences in the acoustic repertoire of Antarctic killer whale ecotypes are still poorly understood (Schall & Van Opzeeland 2017). Hence, based on the acoustic data no reliable determination of the particular ecotype is possible in the present study. Alternatively or in addition, the peak in the acoustic presence of Antarctic killer whales could also be linked to movement patterns on larger scale, since killer whales are known to range over thousands of kilometers (Dahlheim et al. 2008, Matthews et al. 2011). However, there is little evidence for seasonal or regular long-distance migrations (Dahlheim et al. 2008, Matthews et al. 2011). Durban and Pitman (2012) studied Antarctic killer via satellite tagging and reported the whales to make rapid, round-trip movements to subtropical waters, probably to regenerate their skin in warmer waters. However, this migration seemed to occur irregular and not on a regular seasonal basis (Durban & Pitman 2012).

Similarly to killer whales variations in the availability of prey might have affected the acoustic presence of sperm whales. The amount of days with sperm whale vocalizations seemed to fluctuate seasonally peaking from April to June and from October to December. There is evidence for a sex-segregated migration of sperm whales with only males migrating from lower-latitude breeding areas to colder regions (Slijper et al. 1964, Nishiwaki 1966, Clarke 1972, Christensen et al. 1992). Female and young sperm whale are normally not found in higher latitudes (> 40° S/N) and only large male occur in the Antarctic (Slijper et al. 1964). However, whether migration of male individuals occurs annually or if the animals stay in high-latitude areas for several years is not known (Christensen et al. 1992). Instead of seasonal migration, the fluctuations in the acoustic presence of sperm whales might have rather been originated from variations in small scale variations in prey availability. Sperm whales mainly prey on squid, which in turn preys partly on krill (Nemoto et al. 1988). Therefore seasonal variations in krill density might affect the distribution of sperm whales (Nemoto et al. 1988).

The results of this study indicate that killer and sperm whales occur off Elephant Island either year-round or occasionally. Besides the detection of ‘clicks‘ suggests that the animals were feeding during the recording period. The peak in the acoustic presence of killer whales probably indicates that the main feeding period of killer whales was during austral winter. Regarding sperm whales the availability of prey off Elephant Island might possibly reached its maximum from April to June and from October to December.

### 4.2.3 Seals

Both leopard and crabeater seals might probably feed off Elephant Island and hence their occurrence might have been affected by the availability of prey. Crabeater seals prey almost exclusively on Antarctic krill and are often found near the outer edge of the pack ice region, where krill is being more abundant (Gilbert & Erickson 1977). The Elephant Island region might fulfill both needs of crabeater seals, the diet coupled with the habitat specialization (pack ice), because it provides both a great krill stock size and seasonal sea-ice coverage (Gloersen et al. 1992, Siegel et al. 1998). In contrast, the prey-preferences of leopard seals are more variable, since these seals prey on Antarctic krill, as well as fish, cephalopods, and warm-blooded animals (Siniff & Stone 1985, Siniff 1991). However, krill becomes the most important prey during austral winter (Siniff & Stone 1985, Lowry et al. 1988). Furthermore, leopard seals prey on newly weaned crabeater seals during December and January (Siniff & Stone 1985). The presence of both crabeater seals and Antarctic krill off Elephant Island might attract leopard seals. Additionally, these seals seem to occur in higher densities in the pack ice (Laws 1984). Correspondingly, a significant overlap in habitat-use between crabeater and leopard seals was reported before (Costa & Crocker 1996).

The Elephant Island region probably serves as a breeding ground for leopard seals during early austral summer. In the present study a strong seasonality in the acoustic presence of leopard seals was detected showing an increase from austral spring and early summer, i.e. from September to December. The temporal pattern found in the present study is in accordance with previous studies reporting a distinct seasonality in the acoustic presence of leopard seals in a coastal Antarctic environment (Van Opzeeland et al. 2010). Off PALAOA calls of leopard seals were detected between October and January, with peak calling activity between December and January (Van Opzeeland et al. 2010). The seasonality in the acoustic presence of leopard seals was probably linked to an increased calling activity during the breeding season (mainly in December) (Siniff & Stone 1985, Rogers et al. 1995, Rogers et al. 1996, Van Opzeeland et al. 2010). Leopard seals were reported to migrate during austral summer to and beyond the marginal sea-ice zone and return in winter to breed on the inner pack-ice (Siniff & Stone 1985). During the breeding season, both sexes produce calls (Rogers et al. 1995, Rogers et al. 1996). Male vocalizations functions to attract females especially over long distances, while females signal their sexual receptivity by calling (Rogers et al. 1995, Rogers et al. 1996). The strong seasonality in the acoustic presence of Leopard seals suggests that the Elephant Island region serves as a breeding ground for this species. Note that whether the calls were produced by males, females or juveniles was not differentiated in the present study. However, in June 2013 the acoustic presence of juveniles was recognized. This finding provides further evidence that the animals were breeding in the Elephant Island region. In line with findings from Siniff & Stone (1985), the animals seemed to return to the South Shetland Islands region between August and September, when vocalizations occurred more frequently. Besides, single calls were detected in April and June. This indicates that several leopard seals are present off Elephant Island in austral fall and winter, either year-round or occasionally, probably to feed on krill (Siniff & Stone 1985, Lowry et al. 1988) .

Inter-specific interactions might have affected the presence of leopard seals off Elephant Island, as well, potentially explaining the observed temporal patterns in their acoustic presence. For instance, leopard seal acoustic presence was especially high during all years in December, the time when most crabeater seals pups are weaned (Siniff et al. 1979). Assuming that a high acoustic presents reflects a high amount of individuals, this could suggest that leopard seals were attracted by the waters off Elephant Island in December to feed on crabeater seal pups. In addition, the increase in leopard seal vocalizations in September to December might have been linked to the decrease of killer whale calls during that time period. Assuming that the decrease in the acoustic presence represents a decrease in the actual presence of individuals, the predation pressure from killer whales on leopard seals decreased from September to December. In turn, either the number of leopard seals or their calling activity increased. However, at this point it is important to keep in mind that the acoustic presence may be an indication for the amount of individuals, but it might be influenced by several abiotic and biotic parameters, as well (D'Vincent et al. 1985, Jefferson et al. 1991, Van Parijs et al. 2004, Van Opzeeland 2010). Hence a high acoustic presence does not automatically imply a high amount of individuals and vice versa, but could also reflect changes in the vocal behavior of a focal species (Mellinger et al. 2007).

The area around Elephant Island probably serves as a breeding ground for crabeater seals during austral spring. In this study crabeater seals were relatively rarely detected and were acoustically present only during September and October. Similarly, acoustic data collected by PALAOA showed the acoustic presence of crabeater seals from August to December with a peak in October and November (Van Opzeeland et al. 2010). As described for leopard seals, moans produced by crabeater seals play a role in the act of breeding and mating, as well (Shaughnessy & Kerry 1989, Rogers 2003). The seasonality in the vocalizations suggests that the main breeding season of crabeater seals off Elephant Island was in austral spring. These results are in accordance with findings from Siniff et al. (1979) who reported crabeater seals to pup and breed from September to October in the pack-ice encircling the Antarctic. While leopard seal calls are thought to range over long distances, calls produced by crabeater seals function in short-range underwater male-male competition (Rogers 2003). The limited propagation range of crabeater seal vocalizations might explain the relatively low number of days with detected calls off Elephant Island. Besides, it indicates that the animals were calling in proximity to the recorder.

Overall, the strong seasonality in the acoustic presence of leopard and crabeater seals suggests that both species were breeding between austral spring and summer off Elephant Island. Besides the leopard seal were detected from late austral fall to early winter probably indicating that this species feeds off Elephant Island.

### 4.3 Implications on baleen whale migration

Most baleen whales are thought to be highly migratory (Corkeron & Connor 1999). The traditional view describes them to undergo seasonal migrations from low-latitude summer feeding grounds to high-latitude winter breeding grounds (e.g. Mackintosh 1966). However, nowadays there is accumulating evidence that this description is too simplified. Contradicting the traditional view on baleen whale migration behavior, previous studies reported parts of population to stay either in high-latitude, mid- or low-latitude areas year-round, indicating a rather complex migratory behavior of baleen whales (Brown et al. 1995, Širović et al. 2004, Simon et al. 2010, Van Opzeeland et al. 2013, Dominello & Širović 2016, Geijer et al. 2016, Thomisch et al. 2016, Thomisch 2017).

In the present study all four detected baleen whale species were acoustically present during austral winter suggesting that part of the population overwinters off Elephant Island. This is in line with prior studies reporting the year-round acoustic presence of Antarctic blue whales, Antarctic minke whales and humpback whales in the Southern Ocean. Off the WAP, Antarctic blue whale vocalizations were recorded year-round between 2001 and 2004 (Širović et al. 2004, Širović et al. 2009). In addition, Antarctic blue whales were acoustically present in the Weddell Sea year-round, at more than 80 % of all recording days between 2008 and 2013 (Thomisch et al. 2016). Studies on minke whales near the WAP demonstrated their year-round vocal activity with a distinct peak between June and October (Dominello & Širović 2016). Acoustic data collected at PALAOA demonstrated the acoustic presence of humpback whales for most months in 2008 and 2009 (Van Opzeeland et al. 2013). Several authors suggested a partial migration of baleen whales, with part of the populations skipping the energy-costly migration towards lower latitude and overwintering in the Southern Ocean (Brown et al. 1995, Van Opzeeland et al. 2013, Dominello & Širović 2016, Thomisch et al. 2016, Thomisch 2017). Analyses of the sex-ratio of humpback whales at a breeding area near the east-Australian coast revealed a sex-bias towards males, indicating a sex-segregated migration with some females overwintering at their feeding grounds (Brown et al. 1995). Especially young females without dependent calves are suspected to stay in high-latitude areas during austral winter to reduce energy expenditure and benefit from a prolonged exploitation of food sources (Brown et al. 1995). In turn, the presence of females was suggested to attract males to overwinter and opportunistically mate in the Southern Ocean (Thomisch et al. 2016). In the present study high-frequency sounds occurred partly as humpback whale song, which is mainly produced by males (Darling & Bérubé 2001). The absence of high-frequency sounds from July to September in 2013 and 2014, as well as in August 2015 might add further evidence for a sex-segregated migration in baleen whales (Brown et al. 1995).

To my knowledge, no studies reported the year-round presence of fin whales in the Southern Ocean and hence this species is suspected to leave the Antarctica during the winter months (Širović et al. 2009). Fin whales recorded off Elephant Island and the WAP showed a strong seasonality with most calls occurring during austral fall and no detected vocalizations in September (Širović et al. 2004, Širović et al. 2009, Meister et al. 2017). In contrast the acoustic data of this study indicate that in 2014 and 2015 at least part of the population stayed off Elephant Island also during austral winter. Similar to other baleen whales species, fin whales might exhibit a more complex, such as partial or differential, migratory behavior. This is in line with findings from Simon et al. (2010) reporting vocal activity of fin whales in the Davis Strait (Arctic) during November and December (northern fall and winter), indicating some animals to overwinter in high-latitude areas.

Overall, the acoustic presence of four baleen whale species during austral winter off Elephant Island indicates that part of the populations overwinters in the South Shetland Island region and provides further evidence for a more complex migration behavior in these species.

### 4.4 Occurrence of anthropogenic noise off Elephant Island

Anthropogenic sounds may affect marine mammals in several ways (e.g. Gordon et al. 2003, Nowacek et al. 2007, Southall et al. 2008, Van Opzeeland 2010, Castellote et al. 2012, Richardson et al. 2013, Finneran 2015). First, it can mask marine mammal vocalizations and hence reduce their communication range or affect the likelihood of detecting prey and potential predators (Clark et al. 2009, Richardson et al. 2013). Second, it may trigger behavioral responses, such as an increase or decrease in vocal activity, avoidance reactions or anomalous migratory routes (Southall et al. 2008, Weir 2008, Di Iorio & Clark 2010, Castellote et al. 2012, Blackwell et al. 2015). Third, it may result in temporal or permanent threshold shifts in hearing (Finneran 2015). And last, one or the collaboration of the mentioned effects of anthropogenic noise may finally lead to injury or death of marine mammals (Cox et al. 2006, Zimmer & Tyack 2007).

Two different sounds of anthropogenic noise (seismic signals and vessel noise) were present off Elephant Island, mainly from January to May, i.e. during austral summer and fall. During this period up to 60 % of days per month contained sounds of anthropogenic noise. Seismic signals were probably produced for research purposes (Hildebrand 2009). Sounds of vessels might have been originated from ships used for both research and tourism. In this study, no direct correlation between the occurrence of anthropogenic noise and the acoustic presence of marine mammals was found. However, it cannot be ruled out that anthropogenic noise influenced the vocal behavior of both whales and seals. Further research on the short- and long-term effects of noise pollution in the Southern Ocean and worldwide on marine mammals is urgently needed to help interpreting passive acoustic data. Besides understanding the impacts of anthropogenic noise on marine mammals is necessary to uncover potential threats in the context of MPA designation and to develop effective management and conservation strategies (Nowacek et al. 2007, Weilgart 2007, Tyack 2008, Codarin et al. 2009).

# 5 Conclusion

This study provides seasonally unbiased, multi-year information on the acoustic biodiversity and temporal patterns in the distribution patterns of marine mammals in the Elephant Island region.

Eight species of marine mammals (Antarctic blue, fin, Antarctic minke, humpback, killer, and sperm whales; leopard, and crabeater seals) were identified based on their characteristic vocal signatures in passive acoustic data collected off Elephant Island. All detected marine mammal species were acoustically present off Elephant Island within each recording year from 2013 to 2015. These results provide evidence that the Elephant Island region serves as an important habitat for several marine mammal species.

Temporal patterns in a focal species' acoustic presence can provide information on the ecological importance of a study area. Overall, the acoustic presence of four species (Antarctic minke whales, killer whales, leopard seals, crabeater seals) exhibited a clear intra-annual pattern, suggesting a link between the acoustic presence and environmental parameters, such as availability of prey, sea-ice formation, and inter-specific interactions. The acoustic presence of four baleen whale species during austral summer and autumn months, i.e. during the main baleen whale feeding period, suggests that the whales were feeding off Elephant Island. The hypothesis that Elephant Island serves as an important feeding ground for both baleen and toothed whales is further supported by the detection of Fm-calls (produced by baleen whales) and clicks of killer and sperm whales, which were reported to be produced in a feeding context. Regarding seals, the strong seasonality in the acoustic presence suggests that both species were breeding during austral spring and summer off Elephant Island. Antarctic blue whales, fin whales, and humpback whales were acoustically present year-round off Elephant Island, indicating that part of the populations remains in the Southern Ocean year-round. Hence, this study adds further evidence to the hypothesis of a complex migratory behavior of baleen whales, including a variety of migratory strategies such as partial migration.

Anthropogenic noise, originating from vessels and seismic surveys, was recorded regularly in austral summer and fall (from January to May) and occasionally during the rest of the year.

Anthropogenic noise has been shown to affect marine mammals in various ways, and could potentially have impacted the vocal behavior of marine mammals off Elephant Island. To help interpreting passive acoustic data and assess potential effects of the exposure of marine mammals to anthropogenic noise in key habitats, further research on the abiotic and biotic parameters influencing the acoustic behavior of whales and seals should be done.

Passive acoustic long-time monitoring can provide invaluable information on spatio-temporal patterns in the distribution and habitat-use of marine mammals and can directly benefit the identification of ecologically important habitats with high biodiversity. Such knowledge is essential for the development of effective conservation and management strategies for marine mammals, particularly in the context of identifying and designating future MPAs.

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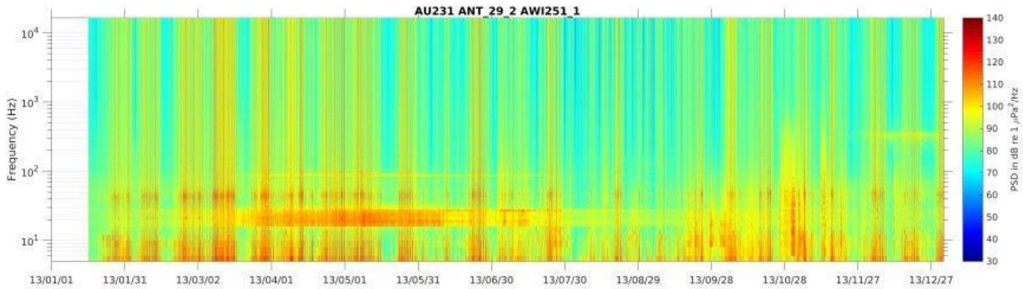
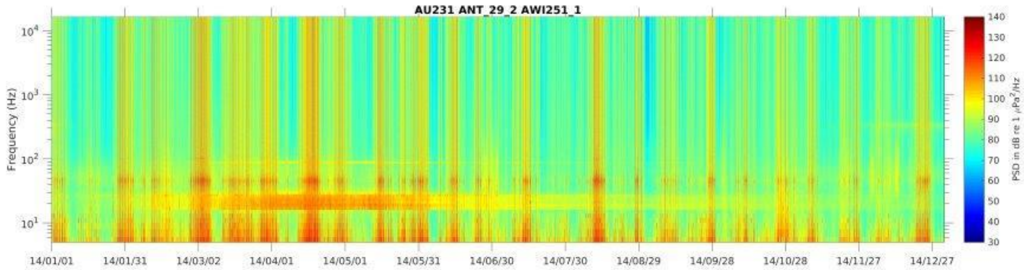
## Appendix

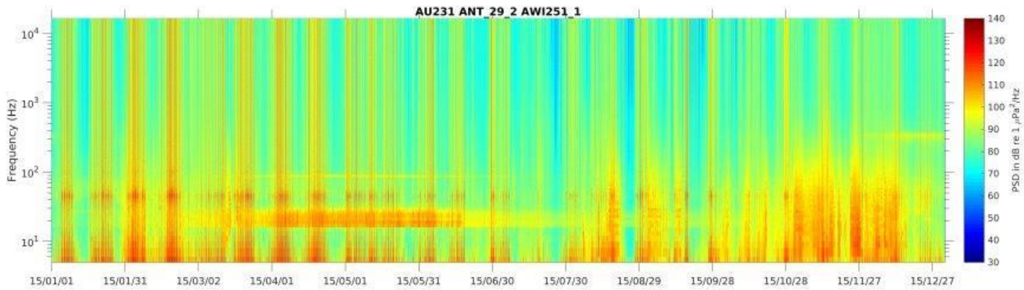
### Long-term spectograms



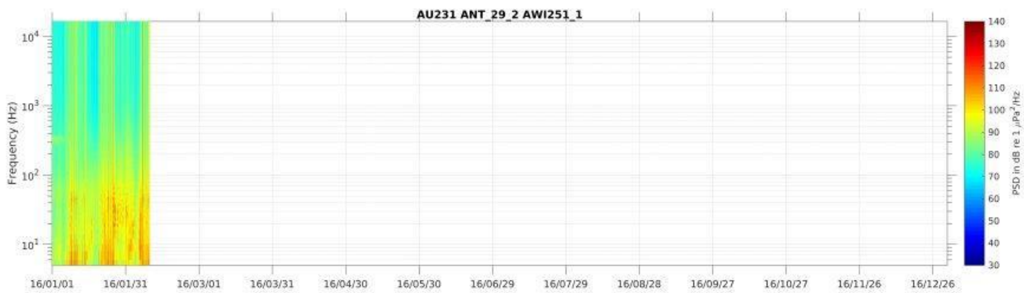

A 1. Long-term spectrogram of passive acoustic data recorded off Elephant Island from 16 January 2013 to 31 December 2013.




A 2. Long-term spectrogram of passive acoustic data recorded off Elephant Island from 1 January 2014 to 31 December 2014.

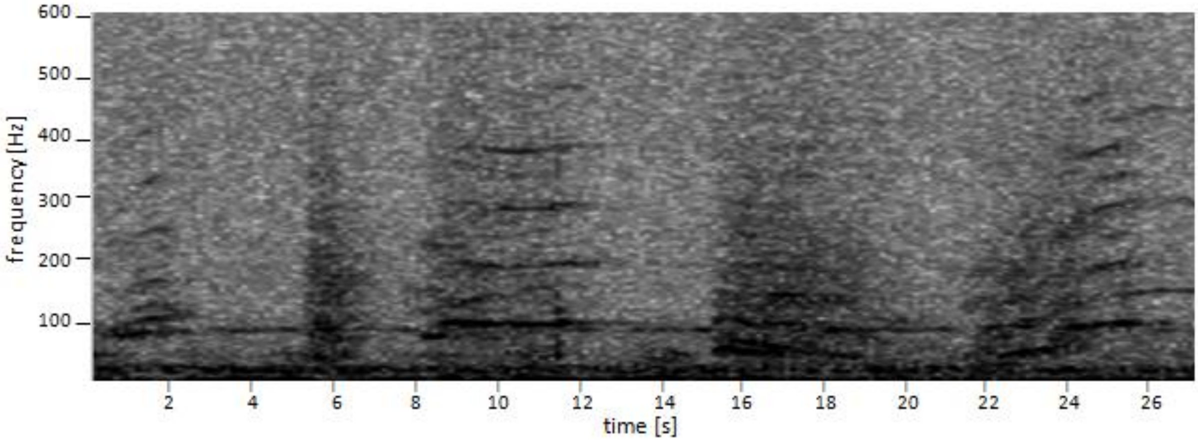



A 3. Long-term spectrogram of passive acoustic data recorded off Elephant Island from 1 January 2015 to 31 December 2015.

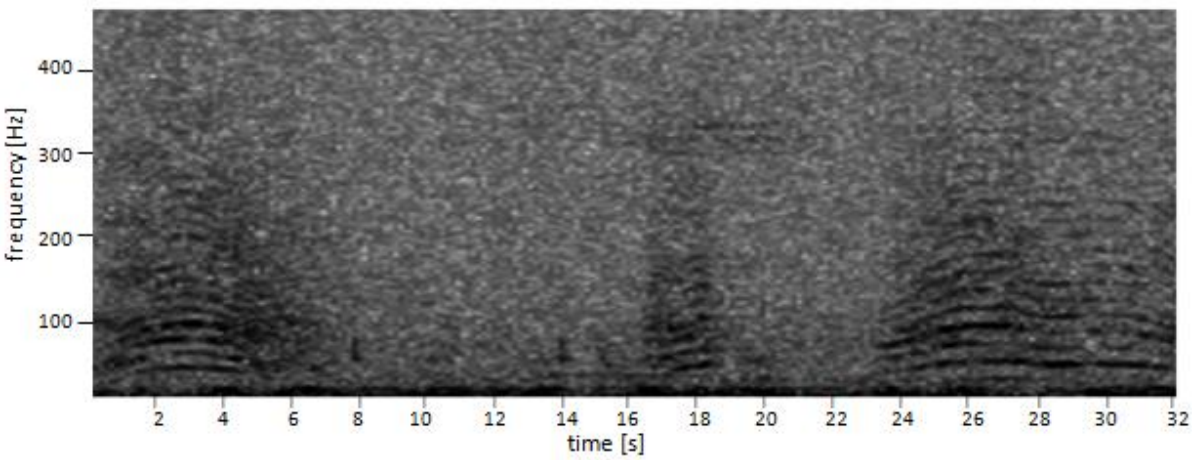



A 4. Long-term spectrogram of passive acoustic data recorded off Elephant Island from 1 January 2016 to 10 February 2016.

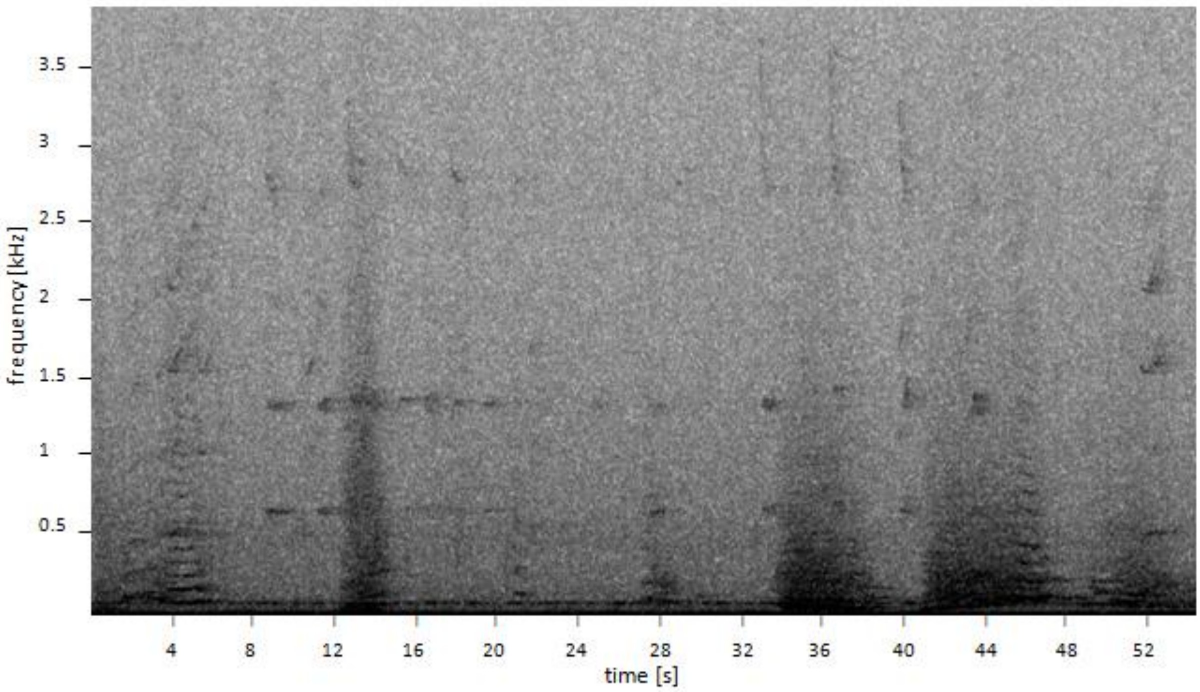
**Low-frequency calls**



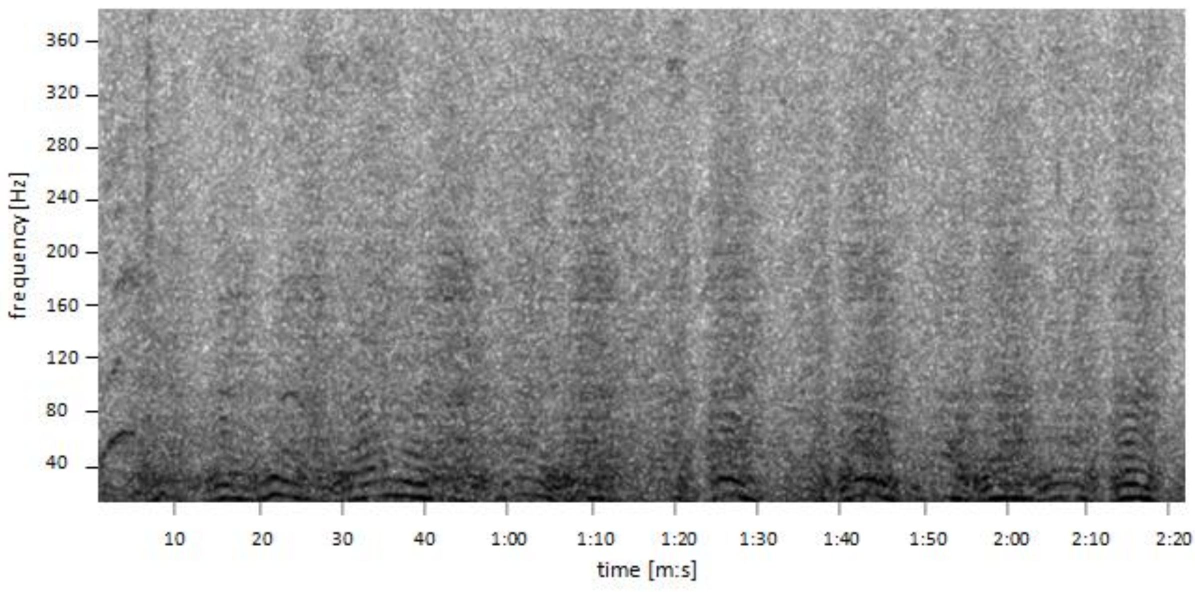

A 5. Spectrogram of low-frequency humpback whale vocalizations (9,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 26 June 2013.




A 6. Spectrogram of low-frequency humpback whale vocalizations (9,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 26 June 2013.




A 7. Spectrogram of low-frequency and high-frequency humpback whale vocalizations (10,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 20 September 2014.




A 8. Spectrogram of low-frequency humpback whale vocalizations (20,000-point FFT, 50% overlap, Hanning window) recorded off Elephant Island, 02 October 2015.

## Declaration

Universität Bremen

Nachname Meister Matrikelnr. 4219129

Vorname/n Marlene

Diese Erklärungen sind in jedes Exemplar der Bachelor- bzw. Masterarbeit mit einzubinden.

### Urheberrechtliche Erklärung

Hiermit versichere ich, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.
Alle Stellen, die ich wörtlich oder sinngemäß aus anderen Werken entnommen habe, habe ich unter Angabe der Quellen als solche kenntlich gemacht.

**10.07.2017**

Datum Unterschrift

### Erklärung zur Veröffentlichung von Abschlussarbeiten

Die Abschlussarbeit wird zwei Jahre nach Studienabschluss dem Archiv der Universität Bremen zur dauerhaften Archivierung angeboten.
Archiviert werden:

1) Masterarbeiten mit lokalem oder regionalem Bezug sowie pro Studienfach und Studienjahr 10 % aller Abschlussarbeiten
2) Bachelorarbeiten des jeweils der ersten und letzten Bachelorabschlusses pro Studienfach und Jahr.

- (x) Ich bin damit einverstanden, dass meine Abschlussarbeit im Universitätsarchiv für wissenschaftliche Zwecke von Dritten eingesehen werden darf.
- ( ) Ich bin damit einverstanden, dass meine Abschlussarbeit nach 30 Jahren (gem. §7 Abs. 2 BremArchivG) im Universitätsarchiv für wissenschaftliche Zwecke von Dritten eingesehen werden darf.
- ( ) Ich bin nicht damit einverstanden, dass meine Abschlussarbeit im Universitätsarchiv für wissenschaftliche Zwecke von Dritten eingesehen werden darf.

**10.07.2017**

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