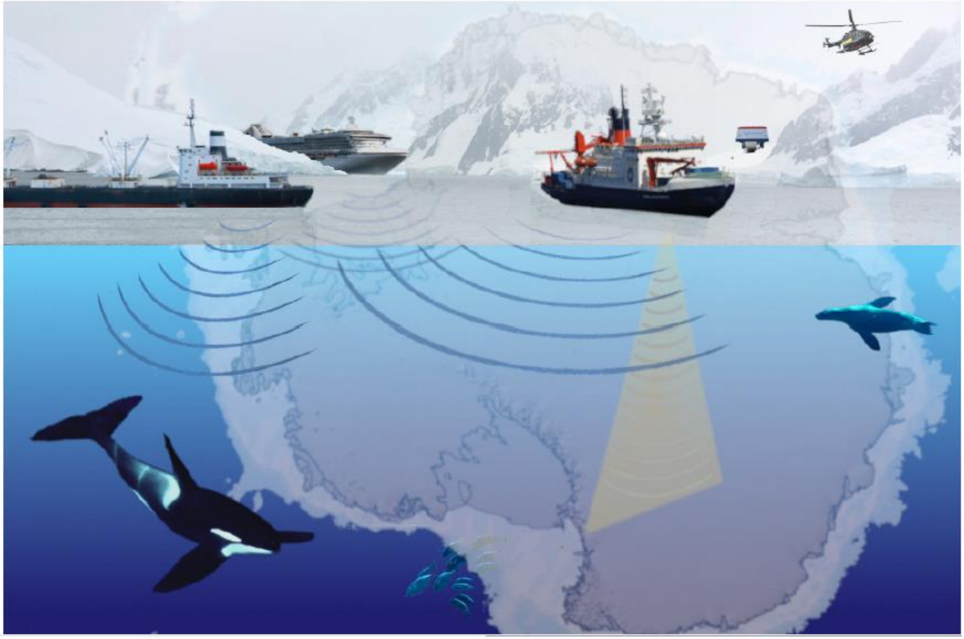
Environmental management of Antarctic cruise tourism: Does ship presence affect marine mammal acoustic behavior?

A multi-year case study on the acoustic occurrence of Ross and leopard seals in relation to the presence of the German research icebreaker Polarstern

Bachelor thesis

Department 2/ Study course: Cruise Tourism Management,
University of Applied Sciences Bremerhaven
In cooperation with Alfred Wegener Institute,
Helmholtz Centre for Polar and Marine Research



Source: Erbe et al., (2019)

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Bremerhaven; August 05, 2020

Hochschule Bremerhaven

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“Sound is the heartbeat of the biosphere, the places on Earth where life exists.”
(Farina & Gage, 2017, p.2f.)

Acknowledgement

First of all, I would like to thank Prof. Dr. Dr. Papathanassis, for enabling the thesis topic and the (rather unusual) cooperation with the AWI. I would like to thank him as well, not only for his general support and the pleasant communication, but also for his understanding of all my projects during the thesis and not least for his patience.

Even if the MOSAiC Expedition is not related to my thesis project, I would still like to mention it here, since without writing the thesis at AWI and the thereby resulting contacts, the participation in Leg 2 would probably never have happened. Now I have some theoretical experience of the Antarctic and some practical one of the Arctic. Special thanks I would like to direct at this point to Benjamin Rabe for getting me literally on board and to Team Ocean/Leg 2 for the good teamwork. Without you, I would have never learned so much (Volker & Ivan) and had so much fun during those four cold and dark months. Furthermore, I would like to thank the whole Leg 2 Team for sharing this gigantic adventure and unforgettable life time experience. Nina (the best cabin mate), Ashild, Julia and Eric, thank you for your friendship, you were especially inspiring me! Julienne, Marcus, Vishnu, Arttu and Daniela thank you for your support and your motivating manner to continue writing the thesis on board. Hope to see you all again.

Further extremely important people who have accompanied me during my studies and whose friendship is indispensable are: Sophie, my best study buddy and MS4 companion. My two Italian friends Eleonora and Simone, “pasta fresca già cotta” wouldn't have been half as good without you – grazie mille. Mis dos colombianas favoritas Susi y Maria, gracias por su amistad, sus buenos consejos y conversaciones. My surfing and sailing buddies Hauke and Nils, who took care that I could always receive enough fresh air and had a good time as a bavarian in “Fishtown Bremerhaven”. Moreover, I would like to thank Arianna (and Maitri), my angel always ready to listen and to support – um abrazo grande para voces. And last but not least my best friend Vee, who has been loyally endowing me with her friendship for over 15 years - I wouldn't know what to do without you!

Endless thanks and love goes to the best parents in the world! Thank you for always being there for me and constantly supporting me in all my projects. Nikolai, you are the best brother I can imagine and I hope we have some good time ahead working, kitesurfing and traveling together!

Another thanks goes to the AWI Ocean Acoustics department (esp. to Ahmed, Elena, Diego, Karo and Olaf), who have helped me in many questions and with ideas. Also worth mentioning are Katharina (and Smilla), Liz, Lea and Ramona, my office buddies, who were not only responsible for good conversations during "pauses of reflection", but also for a good portion of motivation.

I would also like to thank Dr. Stefan Hain, who took the time to take the complexity out of the ATS and answered my questions about it.

The most important role during the whole thesis project however had my supervisor Ilse. 1000 thanks for your motivating and always inspiring positive style. You always had an open ear for me and excellent ideas and suggestions when I was unsure about the next step. Thank you as well for your patience and understanding regarding my projects next and during the thesis. I could not have imagined or wished for a better support.

I. Abstract

Tourism in Antarctica is increasing, with visitors mostly choosing ship cruises often advertised as "Last chance tourism" taking advantage of increasing climate change awareness. While the existing guidelines for tourist operators are designed to protect this fragile region, many aspects of the local fauna, such as animal distribution and behavior, are still largely unknown due to difficulties studying these species. Without supporting data, it is challenging to design effective measures that minimize negative impacts of cruise ships on the Antarctic environment. A potential negative impact is the anthropogenic underwater noise generated by the vessels visiting the areas. Marine mammals rely on sound for many purposes such as foraging, orientation and reproduction. Ship noise can therefore potentially affect critical life phases of these species.

Here we present a case study investigating how vessel acoustic presence affects the vocal behavior and timing of acoustic presence of leopard seals (*Hydrurga leptonyx, LS*) and Ross seals (*Ommatophoca rossii*, RS). RS are one of the least studied Antarctic species. Both pinniped species are known to mainly produce underwater sounds during the mating season, presumably to attract mating partners in pack-ice areas. The German research icebreaker Polarstern (PS) annually resupplies Neumayer Station III (NS) - the German Antarctic Research Facility. Its arrival at the pier where cargo is unloaded has been noted to coincide with the onset of pinniped vocal activity in this area. Here, we use passive acoustic data that were recorded close to the pier over a 5-year period to investigate and compare how seal vocal behavior and vocal activity relate to the timing of ship arrival, presence and departure.

The seals' behavior over the relatively short analysis period of 5 years was complex due to their natural calling variation within life phases (before, during and after mating season). Thus, interpretation was not always straightforward. The arrival timing of the PS had an effect on RS, which delayed their appearance in 2010 and 2011 coinciding with the anticipated arrival of the icebreaker. However, once arrived, both species showed no avoidance behavior and calling times remained unchanged despite PS. LS and RS calling activity decreased significantly during PS presence, but tended to recover instantly post PS departure. It is therefore unlikely that the animals left the area completely and decrease in calling may instead be related to masking. However, further research is needed to further explore what caused the decrease in calling. Both LS and RS seemed to use higher frequency call types during PS presence. The seals' arrival times are also affected by prevailing ice conditions and associated food distribution. LS arrival time differed within the 5 years, whereas the RS arrived slightly earlier each year. The marine soundscape planning approach was applied to explore how ship arrivals can be timed to minimize potential disturbances. Ship quietening techniques and reduced ship speeds can also contribute to reduced underwater noise levels. Lastly, stricter legislative measures are needed to regulate which regions during which periods can be used for tourism.

II. Author's Declaration

Hereby I declare that I have written this thesis on my own and without assistance of others. All data collected from external sources are disclosed in the text and included in the reference list. This thesis has never been published or presented to another examination committee before.

Bremerhaven; August 05, 2020 Maria Patricia Mallet

III. Table of Content

IV. List of Figures

V. List of Graphs

VI. List of Tables

V. List of Abbreviations

Organization /-related

ASMAs – Antarctic Specially Managed Areas

ASPAs – Antarctic Specially Protected Areas

AT – Antarctic Treaty

ATS – Antarctic Treaty System

ATCMs – Antarctic Treaty Consultative Meetings

CP – Consultative Parties

CEE – Comprehensive Environmental Evaluation

CEP – Committee for Environmental Protection

EIA – Environmental Impact Assessment

IAATO – International Association of Antarctica Tour Operators

IEE – Initial Environmental Evaluation

IMO – International Maritime Organization

IUCN – International Union for Conversation of Nature

MEPC – Marine Environment Protection Committee

NCP – Non-Consultative Parties

PA – Preliminary Assessment

Thesis internal

LS – Leopard seal

NS – German Antarctic Neumayer Base III

PALAOA – PerenniAL Acoustic Observatory in the Antarctic Ocean

PAM – Passive Acoustic Monitoring

Pax – Passengers

PS – Polarstern

PTS – Permanently threshold shift

RS – Ross seal

ToA – Time of Arrival

TTS – Temporary threshold shift

V&A – visible and audible (either referred to seals or Polarstern)

1. Introduction

Antarctica was for a long time one of the last places on earth untouched by human activity. With the exception of a few explorers around the turn of the 19th century, this condition remained until seal hunters and whalers arrived. Around the same time, Antarctica received additional attention from the scientific community, which showed research interests. The first steps towards tourism began in 1969, when Lars-Eric Lindblad's "Lindblad" expedition brought the first tourists on ships to Antarctica. Since then, Antarctica has developed into an international travel destination, especially with the beginning of the 21st century (IAATO, 2019).

1.1 Polar tourism

Polar tourists are attracted by Antarctica because of its remote and unique wilderness. However, as the consequences of climate change are especially noticeable and visible in the polar regions, Antarctica is suffering various threats (Lamers et al., 2012; as retrieved from IPCC, 2007). Through media and smartly adjusted marketing campaigns by tourism operators, the image of a disappearing Antarctic region in the near future is created (Lamers et al., 2012). This has led to the concept of “last chance tourism”. Ironically, though, tourism activities themselves (e.g. CO_2 emissions by flights and ships) add further negative impacts on the Antarctic flora and fauna.

The Antarctic Treaty (AT), signed in 1959, can be seen as the first attempt to regulate the Antarctic region and still is the most important agreement governing activities in this region for almost 60 years. It has created the basis for transnational peaceful collaboration in the region, which has established further agreements in order to control human activities there. The AT had its focus on general protection mechanisms regarding all kind of aspects in and around Antarctica. Its approach towards tourism activities in particular has been relatively vague, which is why the IAATO (International Association of Antarctica Tour Operators) has virtually completely taken over this role of addressing tourism related concerns, although it takes the AT as a basis (IAATO, 2018).

1.2 Effects of tourism

As the number of visitors to Antarctica has steadily increased, so has the concern for negative impacts on wildlife and fauna. While human presence can have a direct impact on the ecosystem by trampling fauna, disturbing wildlife or introducing non-native species, cruise ships, which bring the majority of tourists to the Antarctic region, add additional impacts: potential for black carbon and sulphur dioxide emissions from burning of fossil fuels, garbage and sewage disposal, chemical/oil spills, and underwater noise pollution. Underwater noise pollution presents an increasing disturbance factor for marine wildlife, yet it is a hardly explored field in Antarctica, especially with regard to the noise generated by expedition cruise ships.

1.3 Use of sound for marine mammals

Marine mammals are vocally active and use sound to communicate underwater, to navigate, to detect food and predators and to find mating partners. One of the first studies, evaluating the impacts of anthropogenic noise on marine mammals was carried out by Payne and Webb (1971). Since then, more studies (Weilgart, 2007; Wright et al. 2007; Tyack 2008; Hildebrand 2009; Rako-Gospić & Picciulin 2018) confirmed that underwater noise is detrimental to many aspects of marine wildlife.

However, as marine species primarily spend most of their time underwater and are therefore barely visible, assessing noise impact on marine wildlife is challenging in temperate waters, let alone in polar regions where whales and seals often have their habitat in remote and partly inaccessible areas (i.e. ice-covered waters). In order to fill potential observation gaps, technical developments such as passive acoustic monitoring (PAM) have improved our ability to observe marine mammals. With PAM, scientists can identify marine animal sounds in order to investigate their behavior, migration pattern and abundance (Cato et al., 2006). PAM also allows for monitoring the impacts of underwater noise on marine life (Rako-Gospić & Picciulin, 2018).

The aim of the thesis is to investigate the call behavior of two different Antarctic pinniped species with respect to ship noise. This will be investigated using the case study of leopard seals (LS) and Ross seals (RS), whose acoustic presence in Atka Bay overlaps with the annual docking of PS to resupply the German Antarctic Neumayer Base III for several days each year between November and February. The analysis comprises a quantitative assessment on how PS presence overlaps with LS and RS acoustic presence and how the timing of arrival and departure affects the species vocal behavior (i.e., call activity, duration of vocal period and repertoire usage). In addition, the thesis will review which regulations exist with respect to underwater noise, particularly with regard to ship-based tourism, as this is a major contributor to underwater noise caused by the growing number of ships in operation. On the basis of the concept of soundscape planning, possibilities to reduce overlap are explored.

2. Literature Review

2.1 Last Chance Tourism

In addition to the increased popularity of polar tourism, climate change has led to another concept, referred to as “last chance tourism" (Lamers et al., 2012). This is a niche market in which tourists visit specific places whose landscape, natural and/or social heritage is at risk of disappearing in the future (Lemelin et al., 2010). Eijgelaar et al. (2010, p. 337) calls the process of last chance tourism *“[…] an opportunity out of a threat by marketing destinations that are threatened by climate change […]”.* This applies fully to the southern polar region. Antarctica is predestined to become one of these 'last chance' tourist regions. It is marketed as the last frontier on this planet that has been preserved from human activity until now. However, even Antarctica is not immune to change, which makes this image fragile (Lamers et al., 2012). For example, seven Antarctic glaciers have already disappeared due to rising temperatures (3° Celsius over the last 50 years) around the Antarctic Peninsula (Lamers et al., 2012). This is one example of an environmental change that has resulted in a threatened tourist attraction drawing many tourists to see Antarctic glaciers before they are gone.

Another argument for visiting these regions is the indication that these visits should be made before they are overrun by other visitors (with the same intention) or before the area will be closed for tourism entirely (Lamers et al., 2012).

Antarctica will have to cope with major changes over the next few years, including increased impacts from global climate change as well as impacts triggered by increasing human activity (e.g. tourism) (Lamers et al., 2012).

Among the many impacts of climate change, the following are particularly relevant for tourism: the most visited region in Antarctica, the Peninsula, is warming up rapidly, the diversity of species and the distribution of Antarctic Wildlife will change in response to this warming and due to the decreasing sea ice, the ship access and therefore tourism (especially Expedition Cruise Tourism) of these former remote regions will increase (Lamers et al., 2012). It is therefore assumed that tourism and climate change clearly influence each other. Climate change is not only a leading factor increasing the number of visitors to Antarctica, but also intensifies the negative development of climate (Lamers et al., 2012).

2.2 Governing bodies of Antarctic Tourism

2.2.1 Antarctic Treaty

The AT is the most important international agreement with respect to the governance of the Antarctic Region. By definition the AT comprises *"the area south of 60° South Latitude, including all ice shelfs"* (ATS, 1959), which is shown in the Figure 1.

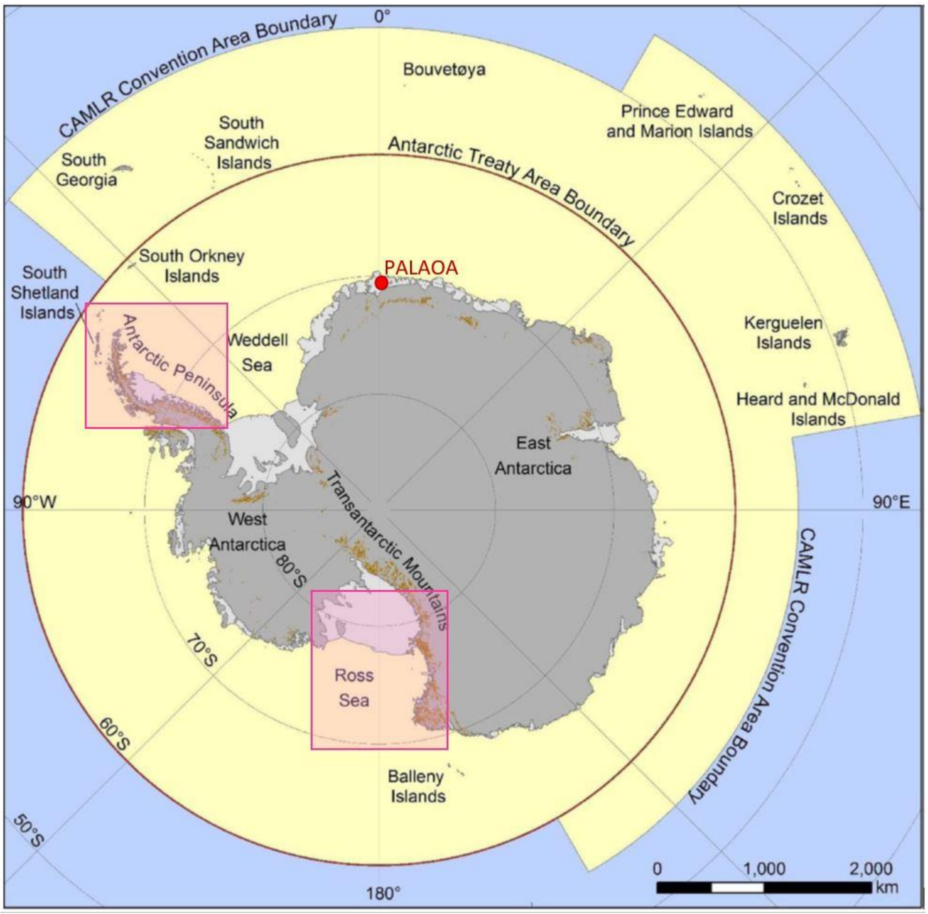


Figure 1 Map of the Antarctic Treaty and CAMLR Convention areas. *Shows in addition the autonomous listening Station PALAOA (red dot), the Antarctic Peninsula (1st place) and the Ross sea (2nd place), being the most visited regions (pink squares) by Antarctic tourists. Adapted from Hughes et al. (2018).*

The overall goal of the AT is the protection of the unique and pristine wilderness of this fragile continent. Most important therefore is the use Antarctica only for peaceful purposes (Art. I) and the perpetuation of freedom for scientific research (Art. II).

The Treaty was originally signed on 1 December 1959 by 12 countries (whose scientists worked in the Antarctic – the original Consultative Parties) and came into force in 1961. Since then, many nations have joined and nowadays the AT comprises 54 Parties. (ATS, 2020c).

Each year an “Antarctic Treaty Consultative Meeting” takes place, inviting its signatory governments (=Treaty Parties) to discuss and make decisions regarding new measures or the extension of existing ones. Out of the 54 Treaty Parties, 29 are Consultative Parties (CP), which have the right to vote, being recognized to conduct scientific research in Antarctica. (ATS, 2020b) The remaining Non-Consultative Parties (NCP) have the role as observers. New measures only enter into force if there is unanimity along all members (UBa, 2016b).

The AT itself does not contain any proposals with regard to the protection of the environment in Antarctica. In order to govern the Antarctic continent, “a unique system of international governance” (Hughes et al., 2018, p. 88) - the Antarctic Treaty System (ATS) was created. It is a complex set of measures, comprising not only the AT itself and all agreements added in a later stage, but also the affiliated political organs (Hughes et al., 2018). Amongst the most important conventions (also with regard to this thesis) are:

***Table 1 Important conventions within the ATS*.**

Name of Convention	**Year of signature**	**Purpose**
Convention for the Conservation of Antarctic Seals (CCAS)	1972	Regulating sealing at that time (Hughes et al., 2018)
Convention for the Conservation for Antarctic Marine Living Resources (CCAMLR)	1980	Conservation of the Antarctic marine ecosystem and its marine livings (finfish, molluscs, crustaceans, seabirds). Prevention of overfishing of krill (harvesting levels - important food source for whales, seals, seabirds and finfish). (CCAMLR, 2020)
Protocol on Environmental Protection to the Antarctic Treaty (Madrid Protocol/Environmental Protocol)	1991 in Madrid	Better protection and conservation of Antarctica's environment. (Hughes et al., 2018)

In order to better understand the complex system of the ATS, Figure 2 gives a visualized overview and shows the relationship among the varies parties involved.

In addition to the Environmental Protocol, the Committee for Environmental Protection (CEP) was formed. Its task is to advise and give recommendations to the ATCM regarding issues of the Environmental Protocol. (ATS, 2020a) Amongst others, advise should be given on “(a) means of minimizing or mitigating environmental impacts of activities in the AT area.” (Hughes et al., 2018, p. 88) Furthermore, the CEP enables informational exchange and collaboration concerning Antarctic topics between the participating nations (BAS, 2015).

Among the prioritized topics of the CEP are the adequate management of tourism and non-governmental activities and their impacts on the environment and the extension of protected areas, with the marine environment included (Hughes et al. 2018).
The Environmental Protocol incorporates six annexes, which contain specifications relating to environmental protection and its organization (Hughes et al., 2018).

Six annexes of the Environmental Protocol

I. Environmental Impact Assessment
II. Conservation of Antarctic Fauna and Flora
III. Waste Disposal and Waste Management
IV. Prevention of Marine Pollution
V. Area Protection and Management
VI. Liability Arising from Environmental Emergencies (not in force)

(ATS, 2020a)

Of particular interest is Annex I with the Environmental Impact Assessment (EIA), which means a prior assessment of all human activities in Antarctica. This includes also tourism (Amelung & Lamers, 2005). The goal of EIA is to identify potential environmental hazards of any activities planned in the southern polar region beforehand. EIA consists of a Preliminary Assessment (PA) (Article 1), an Initial Environmental Evaluation (IEE) (Article 2) and a Comprehensive Environmental Evaluation (CEE) (Article 3). These three levels (Articles 1 – 3) are used in advance to analyze the potential impacts of a planned activity in order to decide whether it can take place at all, in the proposed way or in a modified version. In Addition, Article 5 states that the monitoring of the environment is a further crucial part for the evaluation, comprehension and management of human impacts in the region (Tin et al., 2009).

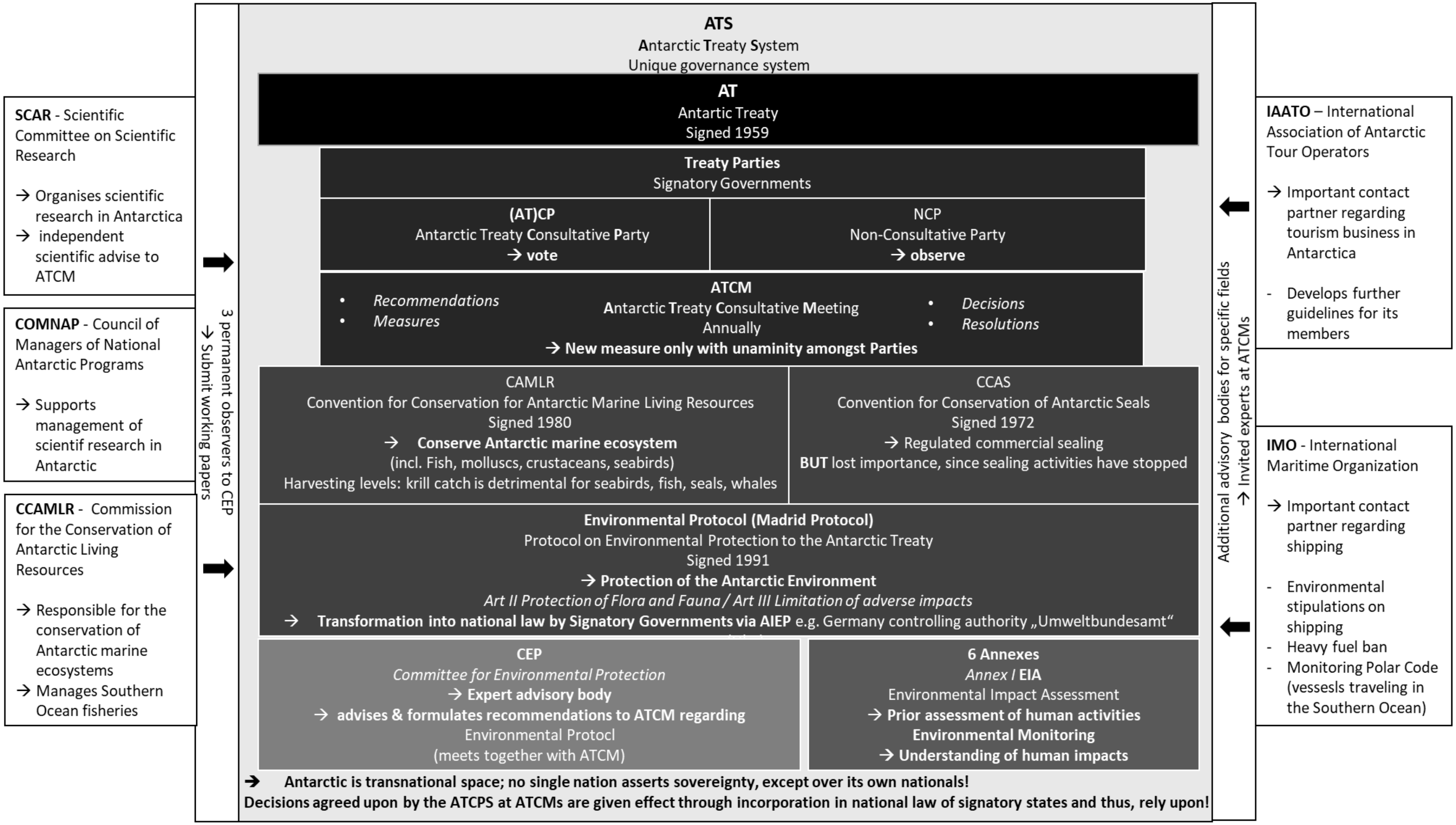


Figure 2 Overview of the ATS and its main bodies.

2.2.2 Regulation of Antarctic tourism

Although tourism is addressed in the Madrid Protocol, it was considered at that time as a simple human activity in Antarctica. Tourism as a specific activity was given greater importance for the first time 1994 in the ATCM (XVIII) in Kyoto (ATS, 1994). The resulting Recommendation XVIII-1 emphasizes amongst other things "the need for visitors and organizers to have practical guidance on how best to plan and carry out any visits to the Antarctic" (ATS, 1994). It contains "Guidance for visitors to the Antarctic" and "Guidance for those Organizing and Conducting Tourism and Non-governmental Activities in the Antarctic" (ATS, 1994).

In 2011 at the ATCM (XXXIV) in Buenos Aires the Resolution 3 was adapted by the Treaty Parties. It renewed the former visitor guidelines (ATS, 2020c; IAATO, 2020b), stating "the desirability of providing contemporary advice to visitors to Antarctica to guide them in minimizing their impacts at all sites" (ATS, 2011).

Visitor Guidelines

- *Protect Antarctic Wildlife*
- *Respect Protected Areas*
- *Respect Scientific Research*
- *Be Safe*
- *Keep Antarctica Pristine*

(IAATO, 2020b)

This resulted in "General Guidelines for Visitors to the Antarctic" (ATS, 2020c; IAATO, 2020b). The guidelines contain general advice for visitors to prevent adverse impacts on the Antarctic environment (ATS, 2011).

The section "Protect Antarctic Wildlife" indicates amongst other things the extreme sensitivity of animals towards disturbance. Sounds and noise should be reduced to a minimum, while distance should be kept (ATS, 2011; IAATO, 2020b). Moreover, the landing and transport requirements in the visitor guidelines elaborated further of the IAATO, emphasize additionally not to use amongst others, vessels and small boats in a manner that disturb wildlife at sea (ATS, 2011). However, to date there is no actual monitoring program in place to observe if such disturbances occur.

2.3.2 IAATO

The IAATO, founded in 1992 by seven Antarctic Tour Operators in response to the growing number of tourists (IAATO, 2018), plays the most important role regarding the Antarctic tourism business (Hall & Saarinen, 2010). The aim of IAATO was to establish and apply environmentally friendly and sustainable rules governing tourism in Antarctica in order to protect its fragile ecosystem. Specially, its guidelines state that

“ *[…] operations are conducted in a safe and environmentally responsible manner, and that tourism activities are planned to have no more than a minor or transitory impact on the Antarctic environment.”* (IAATO, 2018, p. 7) .

AT and IAATO are strongly intertwined. The organization is invited to the annual ATCMs as an invited expert for tourism issues (ATS, 2020d). Through its advisory function there it has contributed to the establishment of international valid regulations for the ATS (IAATO, 2020b). Furthermore, the IAATO transfers and integrates those arrangements into the organization’s own guidelines. In addition to the regulations set by the ATS, the IAATO guidelines are binding for more than 100 members involved in tourism from all over the world. Basically, it can be said that while the ATs provides the framework for many regulations, IAATO takes them as a basis and translates them to (often even stricter) concrete guidelines that can be used in the field. Beyond this, IAATO has created further additional, organization-specific guidelines. The vast majority of tourism operators are members of IAATO, making the organization the main hub for tourism issues (Student et al., 2016). A risk for IAATO is presented by Non-IAATO members, who do not have to follow the organization`s regulations, but their actions could be negative for the whole industry (Amelung & Lamers, 2005).

In general, tourism activities must be in accordance with the Antarctic Treaty, the related Protocol on Environmental Protection and other arrangements developed by the ATCM. This means, they are only permitted if the responsible "national authority" has deemed all necessary regulations are complied with, and has given its approval (ATS, 2011). The IAATO has enforced that all its members must comply with the requirements of the Environmental Protocol, including the EIA, even if their countries have not signed the EP and therefore their national executive body does not demand it (IAATO, n.d.). Figure 3 shows the cascading agreements, which have to be followed if a party signed it, or in case of IAATO, is a member of it. A top priority for IAATO and its tourism operators is to safeguard that the activities they carry out in Antarctica have no more than a minor or transitory impact.

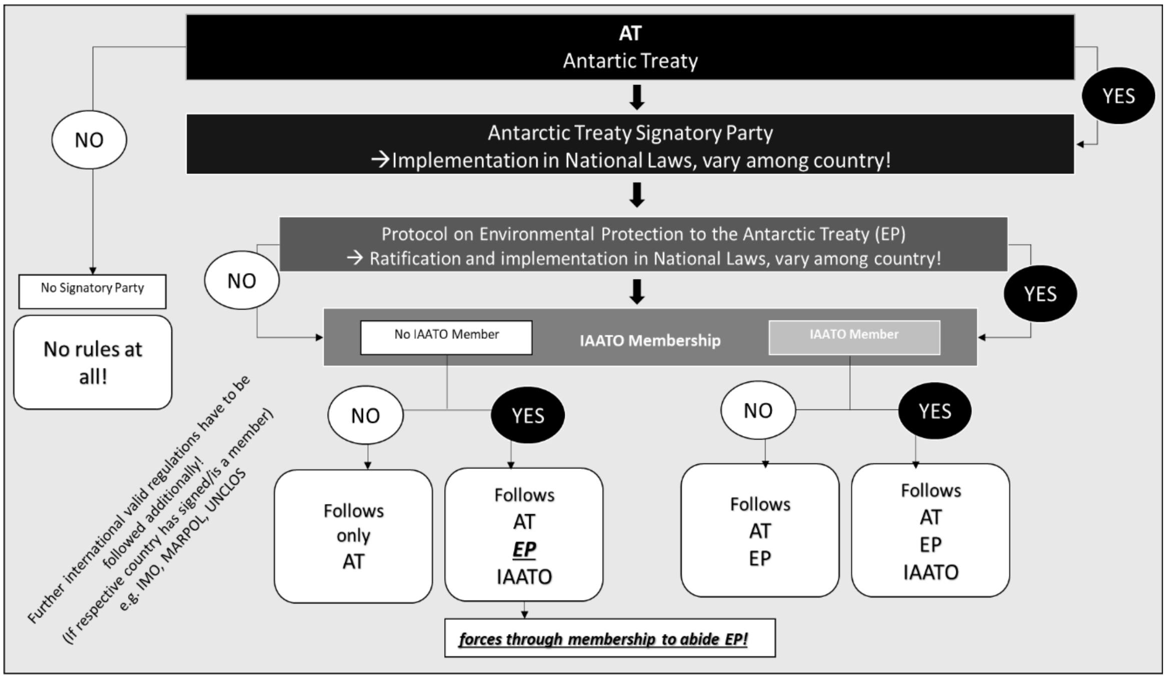


Figure 3 Overview of the respective agreements to be followed at the time of signature or membership.

One of the most important guidelines established by the organization is the "IAATO General Information for Wildlife Watching". It refers to the observation of animals (birds, cetaceans and seals) in their natural habitat. The goal of this guideline is to prevent the interference with the animals as much as possible. Moreover, in order to avoid negative impacts on daily and seasonal behavior of wildlife, the proper handling of smaller boats (e.g. Zodiacs for cruising/landings) is stated. Ship activity can stress the animals or even lead to a behavioral change. This includes underwater noise emitted by ships as a potential hazard, and is explicitly addressed under the heading "Reduce Possible Impacts from Vessels" (IAATO, 2016a).

Impacts to be prevented by IAATO Guidelines

- *Displacement from important feeding areas*
- *Disruption of feeding*
- *Disruption of reproductive and other socially important behaviors*
- *Changes to regular migratory pathways to avoid human interaction zones*
- *Stress from interaction*
- *Injury*
- *Increased mortality or decreased productivity/ survivorship (and therefore population decline)*

(IAATO, 2016b)

IAATO also monitors and reports on annual tourism numbers including both the terrestrial and shipborne touristic activities its members are engaged in. Regarding vessel activities, the organization distinguishes generally between "Cruise-only tourism" and "Ship-based tourism", of which the latter forms the bulk of tourism. Ship-based tourism comprises smaller and medium sized ships with less than 500 passengers on board. These ships are allowed to carry out additional activities ashore with no more than 100 passengers at a time. Vessels with more than 500 passengers, belong to the category “Cruise-only”. Due to their high number of passengers, they are not allowed to do landings. Furthermore, only one ship per site is allowed. (IAATO, 2018)

Since the beginning of IAATO records, there has been a steady increase in number of tourist operators, ships and yachts, voyages and passengers. An extract of the most important numbers is illustrated in Table 2. Furthermore, Antarctic cruise tourism is expected to increase further over the next years (IAATO, 2018).

Table 2 Important years in Antarctic cruise tourism development. *During the first year of records (1992/93), 12 ships and yachts were in operation with 6,704 pax “making landings”. The first peak was reached in 2007/08. After a slight decline in 2011/2012 (IMO ban on heavy fuels), passenger numbers increased again. By 2017/18, there were 50 ships and yachts operating with 42,576 “pax making landings” and 9,131 “cruise only pax”. (IAATO, 2018) Adapted from (IAATO, 2018)*

Year	Ships & yachts	Ship-based-tourism (pax)	Cruise only tourism (pax)
1992/1993	12	6,704	-
1999/2000	21	13,687	936
2007/2008	55	3,637	13,015
2011/2012	**Slight decline!**		
2017/2018	50	42,576	9,131
2018/2019	**Tendency increasing!**		

The bulk of cruise expeditions are carried out around the Antarctic Peninsula between November and March (austral summer), which is pictured in Figure 4 (IAATO, 2018).

During this season, sea ice conditions are less heavy and Antarctica is therefore easier to access via ship. However, this rather short time frame is also of great importance for the Antarctic wildlife, which often seasonally rely on specific areas for foraging and mating.

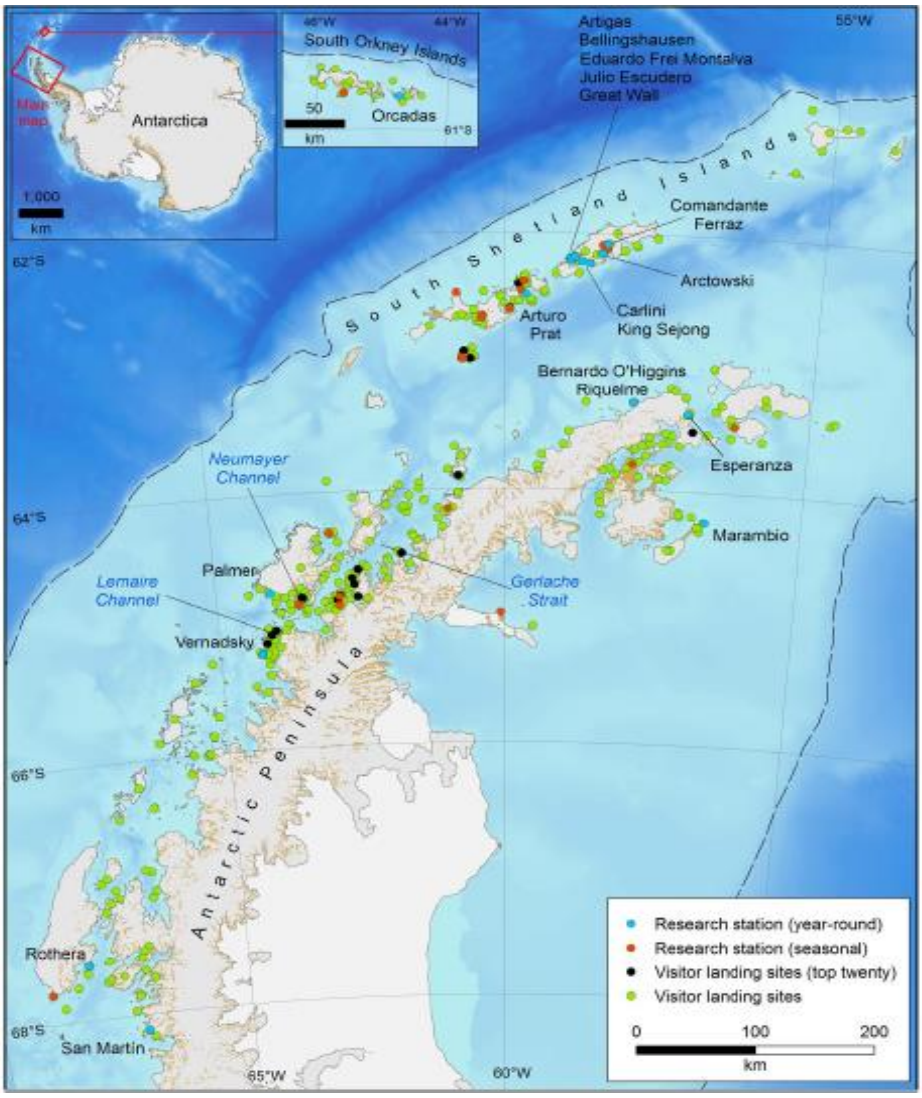


Figure 4 Map of Antarctic Peninsula *with the main tourist locations (green & black dots) and research stations (blue & red dots). The dashed line shows the frame of the continental shelf at 1,000 m depth around the Antarctic Peninsula. Source: Hughes et al., (2020).*

2.3 Impacts of Tourism

Human activities influence and impact the Antarctic flora and fauna (Tin et al., 2009). The majority of visitors in Antarctica consists of tourists (42.000 in 2017/2018) (IAATO, 2018), followed by a maximum of 5,400 scientists (Tin et al., 2014, p.10). Especially tourism visits have negative effects on this very sensitive environment (Tin et al., 2009). Since the Antarctic continent is basically considered to be unpopulated, its vulnerability is particularly high due to the rapid and above-average increase in tourists and the associated diverse and varied activities. The great danger is that neither the environment in general, nor the animals and plants in specific can cope with the diversity of influences.

Figure 5 gives an overview over the possible impacts. The Appendix A 1 contains further information regarding the main problems of non-native species, habitat destruction and pollution.

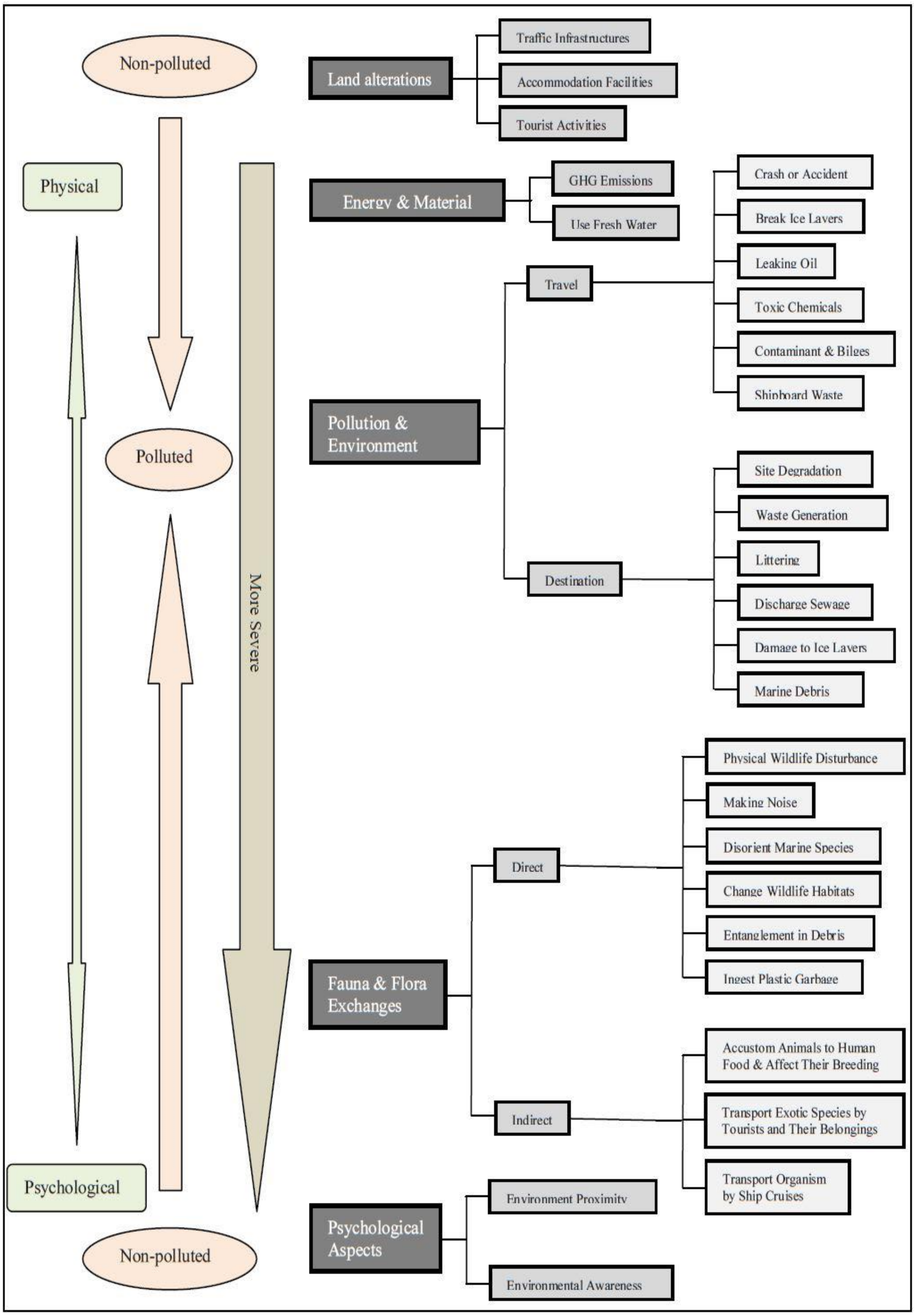


***Figure 5 Overview of the various impacts resulting from Antarctic tourism**.*
Source: Kariminia et al. (2013).

2.4 Sound and noise in the marine environment

2.4.1 Sound

While from a human perspective the underwater world appears as a silent world, the oceans are rich with natural sound (Moore et al., 2012). Every part, from coastal or offshore areas, has a specific sound signature or soundscape (Farina, 2017). The underwater world can be a dark habitat with low visibility due to turbid water, sediment turbulence or at greater water depths. Therefore, animals living in an aquatic environment have adapted during their evolutional process to use instead of visual cues rather sound. Marine mammals can capture sounds in a range of 3-50 kHz (hearing threshold of 60-70 dB) (Farina, 2017). Depending on intensity and frequency, sound may travel thousands of kilometers in the ocean and is therefore extremely helpful for marine animals to transmit information (Filiciotto & Buscaino, 2017). When marine mammals use sound for communication, they have to deal with the fact that their calls suffer propagation loss, scattering and absorption while on their way to the receiver. The position, not only of the sender but also of the listener plays an important role, as it makes the difference in how the call characteristics will be perceived by the receiver (Erbe et al., 2016). They use sound for several different biological purposes, including communication, foraging, mating, predator avoidance, navigation and exploring their environment. In order to avoid too much overlap in underwater communication in terms of e.g. frequency and signal characteristics, marine animals are known to produce sound over a wide range of frequencies, from infrasound to ultrasound (Filiciotto & Buscaino, 2017).

2.4.2 Noise

Whether different sonic effects are sound or noise cannot always be clearly defined and often depend on the individual listener. Noise can be of physical, geological (earthquakes 1-100 Hz), biological (aquatic organisms 10-200 kHz) and anthropogenic origin. Concerning physical sources, wind is the key generator of ambient noise (150-200 Hz) in all regions for the world`s oceans.(Moore et al., 2012; as retrieved from Zhang et al., 2006) Interestingly, wind over the sea surface of a certain velocity can have the same sound as a ship passing at distance. A fairly recently introduced source but one that is virtually omnipresent and rapidly expanding, is anthropogenic noise.

According to Southall et al. (2007; 2019), there are two major types of human made noise underwater, varying notably in intensity. One is the impulsive noise, resulting from a particular noise source that releases short pulses interrupted by gaps of silence. Those impulsive sounds can result from e.g. seismic surveys (airguns) or offshore construction (pile driving). They have high energy and lead to acute exposure for animals. However, these high frequency sounds are not present continuously and are limited in range. (Southall et al., 2007; Southall et al., 2019; Filiciotto & Buscaino, 2017)

The other noise type is continuous noise, which can be understood as a form of background noise, often resulting from vessels. These low frequencies between 5-500 Hz are not as loud as impulsive sounds, but can block certain frequency bands entirely thereby restricting the acoustic range over which animals can emit and receive sounds over longer periods. Furthermore, due to the long distance sound propagation of the lower frequencies of such sounds, these sources can influence huge areas. (Southall et al., 2007; Southall et al., 2019; Pensieri & Bozzano, 2017)

2.5 Ship noise

Ship traffic is the major source of noise in the oceans and the reason of 10 dB increased ambient noise in the past century (Pavan, 2017; as retrieved from Andrew et al., 2002). This applies also for the surroundings of the Antarctic continent, outlined in Figure 6.

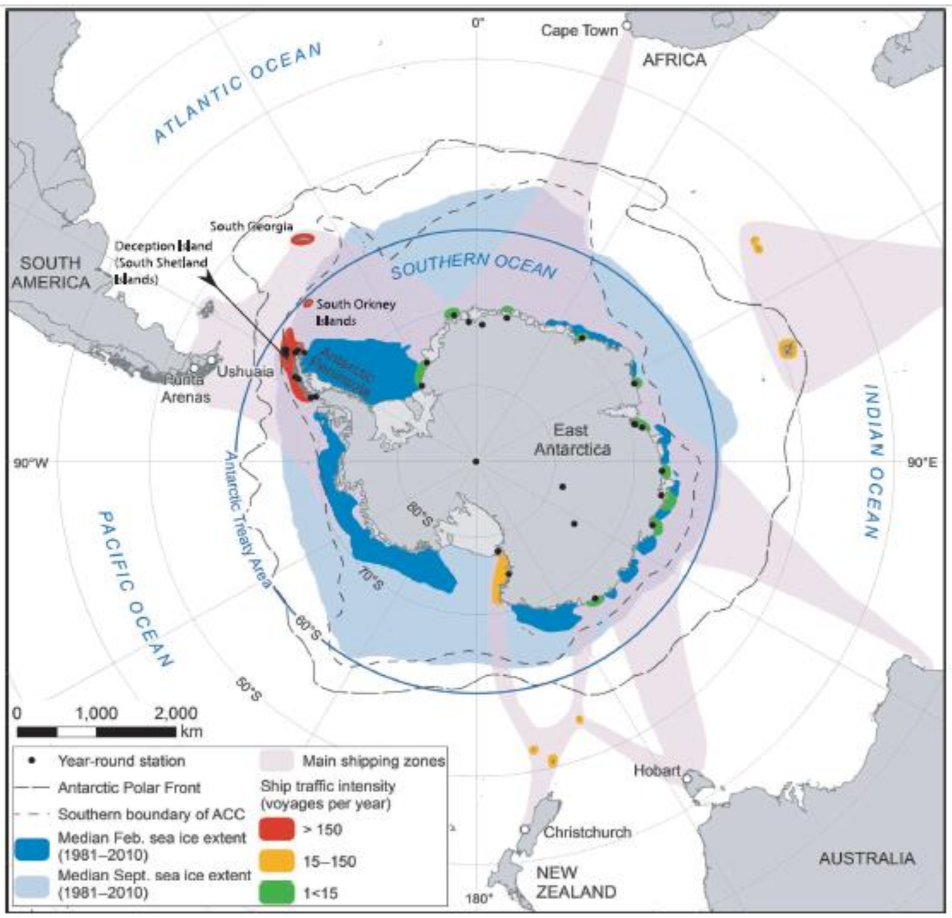


***Figure 6 Map of intensity of ship traffic in the Antarctic region**. It displays research stations, ports of departure and the Antarctic Treaty area. The lane coverage of Marine Traffic (MarineTraffic 2018) is considered to be the basis for this estimate. In addition it includes some physical factors such as the sea-ice extent for both summer and winter season. Source: McCarthy et al., (2019).*

The omnipresence of this chronic pollutant has the potential with its low frequencies (50-500 Hz) (Farina, 2014; Farina, 2017) to negatively impact marine underwater soundscapes on a global scale (Williams et al., 2015).

The propulsion system of a ship (engine and propellers) (Pavan, 2017), as well as cavitation (Hildebrand, 2009) are the main noise producers, which is shown amongst other factors in Figure 7.

> ***Cavitation***
>
> *In the cavitation process bubbles are produced at the propeller blade tips whose collapse result into loud noise (comparable with the effect of boiling water)*
>
> (Hildebrand, 2009).

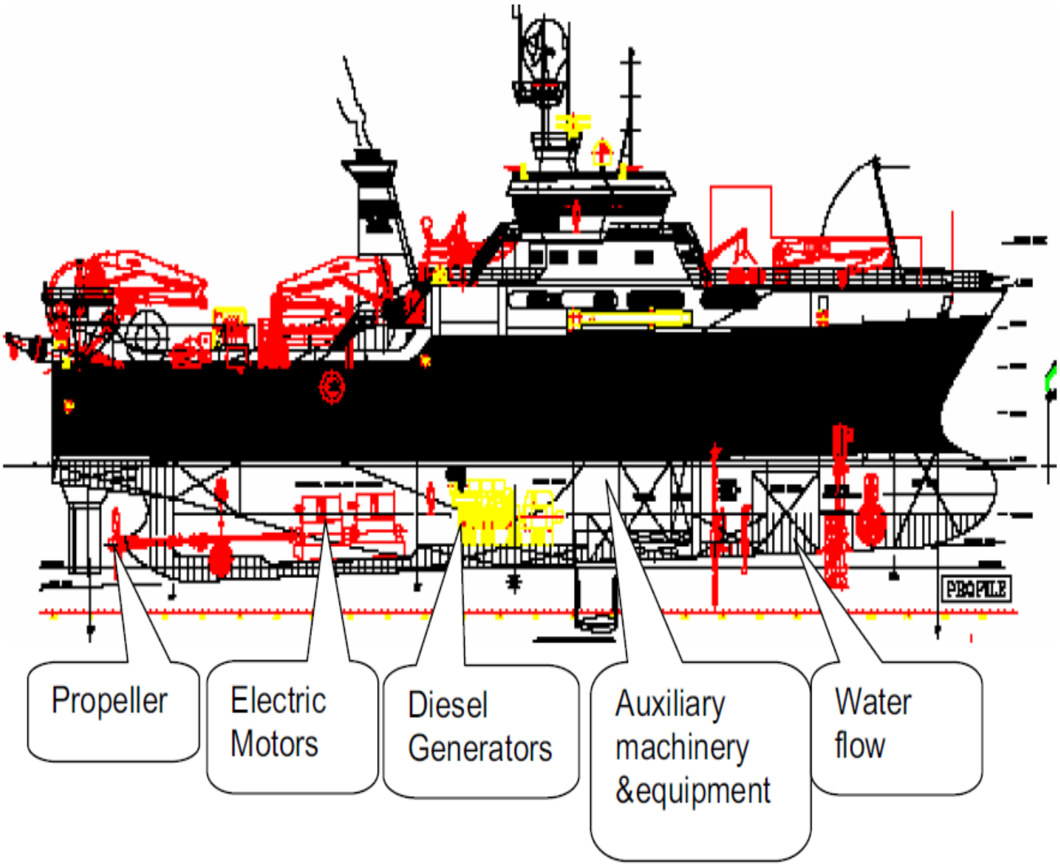


***Figure 7 Ship parts usually responsible for noise**. Source: Abrahamsen, (2012).*

2.6 Impacts of noise on marine mammals

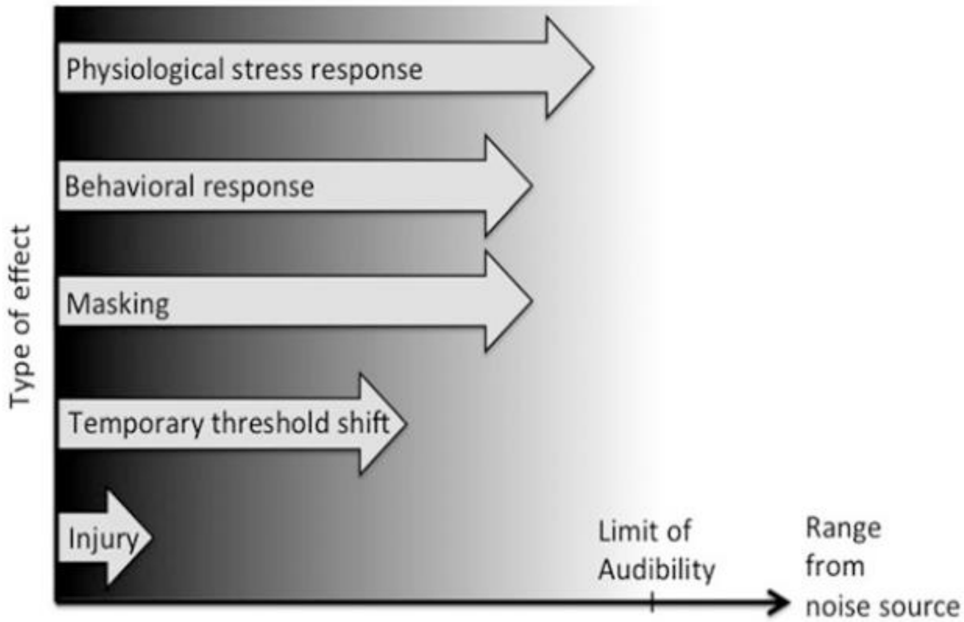


Figure 8 Impacts of noise on marine mammals. *Various types of effects (y-axis) are possible to occur, when animals are exposed to certain ranges of noise (x-axis). The color gradient implies the decrease in noise level, from very strong (black) over deceasing noise (dark grey – light grey) until the limit of audibility (white). If close to the source all 5 effects are possible to occur. The effects of stress, behavioral responses, and masking are to be dealt with even further away. The range length up to which the animals can still suffer from the effects and the order in which they are affected, depends on the kind of noise (spectral and temporal characteristics), as well as the conditions under which the noise is dispersed and the natural background noise. Furthermore, the hearing ability of the animals exposed to the noise, their health status and any previous experience with the noise play a role. Source: Erbe et al., (2018).*

The impact of underwater noise on marine mammals is a research topic that has led to heavy debates and, despite intensive scientific effort, there is no unanimous applicable knowledge on its effects.

The impacts may vary not only among species or individuals (Farina, 2014a), but responses towards the same noise can even vary among species with comparable hearing abilities (Weilgart, 2007). Reactions can even vary within species, depending on behavioral state and previous exposure experiences (Southall et al., 2007). Anthropogenic sounds can affect marine mammals in various ways, disrupting feeding, breeding, resting or migratory behavior, noise can mask sounds that are crucial to survival (e.g., presence of predators) or communication, noise can cause temporary or permanent hearing loss, it can also lead to physiological stress or physical injury *(*Rako-Gospić & Picciulin, 2018*).* The effects of noise on animal behavior are difficult to determine, as marine mammals do not always react immediately to them, as they would to other effects such as chemical pollution (Farina, 2017).

TTS & PTS

Temporary and permanent threshold shifts (TTS, PTS) are temporary or permanent physiological damages of the inner ear which can affect acoustic capabilities. During a temporary threshold shift (TTS) animals suffer partly from hearing loss (deafness or "auditory fatigue"), but are able to recover). The permanent threshold shift (PTS) is a remaining loss of hearing and cannot be recovered (Pavan, 2017).

Animals generally have to struggle more with TTS (long noise exposure and high-pitched sounds) (Rako-Gospić & Picciulin, 2018). Especially PTS, but also TTS can lead to indirect death (Weilgart, 2007).

Masking

Masking, a type of acoustic interference (Clark et al., 2009) is considered as the most pervasive and omni-present impact of anthropogenic underwater noise, occurring when one sound source is louder than another, thus blocking the perception of the first source. Masking can result in the reduction of a receiver's performance, to effectively perceive, recognize or decode sound sources from its environment (Clark et al., 2009).

For marine animals, it leads to a reduction in perception of acoustic information which can be vital for survival and can therefore have long-term effects (Clark et al., 2009; Erbe et al., 2016). Affected hereby is the communication between individuals or populations, the detection of prey or predators and navigation. Changes in foraging, mating, gathering for social reasons and predator detection can be the undesirable result.

Physiological stress

Concerning "Physiological Stress", noise can trigger changes in the hormonal systems, resulting e.g. in rising heartbeat and/or higher consumption of oxygen. Such changes affects individual foraging frequency and reproduction, and might affect whole populations (Farina, 2017; Southall et al., 2007; Wright et al., 2007).

Aim of the thesis

In this thesis I investigate the call behavior of two different Antarctic pinniped species during the presence of ship noise. The simultaneous presence of two sources does not necessarily mean that masking occurs, since animals have developed various mechanisms to adapt their vocal behavior to overcome masking (see Brumm and Slabbekoorn, 2005 for a review). Increasing call rates, changing repertoire as well as timing of calling are examples of strategies with which animals can counter masking of their calls. By investigating various calling parameters pre- during and post ship presence I aim to explore if and to what extent ship presence potentially affects their acoustic behavior.

3. Methodology

3.1 Data selection

Information on PS arrivals and departures at and from NS were obtained from ´PANGAEA – Data Publisher for Earth & Environmental Science` (https://www.pangaea.de/). The timeframes of PS at NS were derived either from the cruise report or the weekly reports of the respective cruise. In addition, and in order to get a precise arrival and departure time, these dates were double checked with PS` GPS data from D-Ship online platform (https://dms.awi.de/Polarstern.html) into which the collected scientific and, in the case of research vessels, related nautical data from expeditions are entered. The GPS location of the NS (Lat -70°30`4.79" S / Long -8°16`1.20" E) was used as a point of orientation in order to retrieve PS "parking" location when supplying the NS. This, and further data resulting from first data scans were transferred into an Excel table (see B 3 Appendix) in order to have a better overview and served in the later as basis for the data analysis.

During the initial data analysis, information on the acoustic presence of the ship was obtained. Information from publications on the acoustic presence of the two study species at PALAOA (Kreiß, 2008; Seibert, 2007; Van Opzeeland et al., 2010) allowed reducing the searching time frame of the passive acoustic data set. Ross seals are known to be acoustically present from December until February and leopard seals between October until February. Based on this information the passive acoustic data within these time frames were further screened in search of the first and the last call of both species (Variables: ´1st call RS/LS - Arrival ` and ´last call RS/LS - Departure`. These variables of arrival respectively departure of the animals was determined by less than 10 calls detected during a five-minute file. Acoustic data were visualized in spectrograms using the Raven Pro 1.5.0 software (Cornell Lab of Ornithology, n.d.).

Initially, the timeframe from 2010 until 2019 was considered as potential years for analysis. During a first data scan, some years (2014, 2015/2016, 2016/2017) had to be discarded due to missing records, related to technical problems with the observatory and maintenance. Finally, based on data availability and variety, the years 2010, 2011, 2013/2014, 2018 and 2019 were chosen for the data analysis, in order to have a suitable representation of case scenarios during December and January.

Table 3 Overview of selected years with precise data of analysis.

Arrival at NS	-5 days	*Neumayer Arrival*	*Neumayer Departure*	5 days	Stay at NS
late	08.01.2019_12.01.2019	*13.01.2019*	*17.01.2019*	18.01.2019_22.01.2019	intermediate (4)
very late	23.01.2018_27.01.2018	*28.01.2018*	*30.01.2018*	31.01.2018_04.02.2018	short (3)
intermediate	25.12.2013_29.12.2013	*30.12.2013*	*31.12.2013*	01.01.2014_05.01.2014	short (2)
early	12.12.2011_16.12.2011	*17.12.2011*	*22.12.2011*	23.12.2011_27.12.2011	long (6)
early	15.12.2010_19.12.2010	*20.12.2010*	*22.12.2010*	23.12.2010_27.12.2010	short (3)
	prior	**during**		**post**	

Timeframes include early (green-marked), intermediate (yellow-marked) and late arrivals (red-marked), as well as short (green-marked), intermediate (yellow-marked) and long stays (red-marked). The scenario 2013/2014 is considered an exception in the designation of the years, as its period of analysis extends the turn of the year, which is why it is designated with both years in contrast to the other scenarios.

Data from 5 days before the arrival of PS to NS until 5 days after departure were included in the analysis. During these 5 days, 5 consecutive minutes were analyzed every 2nd hour (12 am/pm, 2 am/pm, 4 am/pm, 6 am/pm, 8 am/pm, 10 am/pm).

3.2 Raven Pro Analysis Data

The entire data set was retrieved from the archives of the AWI server and sorted by year and exact date (Table 3 and more detailed B 3 Appendix).

The data from 2010, 2011 and 2014 consist of 24-hour mp3 records split into consecutive one-minute files (1440 files per day). For 2010, recordings from 21 Dec 14:00 until 22 Dec 8:00 are missing due to technical problems with the observatory. The year 2013 did not exhibit consecutive records, but recorded on a duty cycle of one-minute mp3 records every hour (in total 24 files per day). For 2013, only one minute was analyzed every second hour. For 2018 and 2019, data were collected continuously in wav format and files were split into ten minutes (864 files per day). For these years, five min out of the ten minutes for every second hour were analyzed. Data are missing between 13 January 16:00 until the 15 January 12:00 in 2019. Within the data set are still some missing records. However, given that these were only brief periods, the gaps could be compensated. Usually, the first five minutes of every second hour were measured. In the event of failure, the closest five minutes available to the missing ones were selected (e.g. 22 December 2010: the missing minutes from 08:00 - 08:04 were replaced by 08:04 - 08:08). An overview is given in Table 4.

Table 4 Summary of data retrieved by the AWI server and used for analysis.

Year	Data	File length	Period analysed	Analysis protocol	Format	Missing data
2010	continuous data	1 min	15.12.2010-27.12.2010	5 consecutive min of 1 min files	Mp3	21.12 - 22.12 14:00 – 08:00
2011	continuous data	1 min	12.12.2011-27.12.2011	5 consecutive min of 1 min files	Mp3	none
2013	1 min each hour	1 min	25.12.2013-31.12.2013	1 min	Mp3	none
2014	continuous data	1 min	01.01.2014-05.01.2014	5 consecutive min of 1 min files	Mp3	none
2018	continuous data	10 min	23.01.2018-04.02.2018	5 consecutive min of 10 min files	WAVE	none
2019	continuous data	10 min	08.01.2019-22.01.2019	5 consecutive min of 10 min files	WAVE	13.01 – 15.01 16:00 – 12:00

Due to different sampling rates of the data from various years, different presets were used in the Raven Pro software to achieve the best resolution for data analysis (see Table 5).

Table 5 Data pre-settings

Year	Sampling Rate (Hz)	Frequency (Hz)	Type	Overlap (%)	DFT Size (no. of samples)
2010, 2011, 2013/2014	48000	24000	Hann	80	8192
2018, 2019	24000	12000	Hann	80	4096

3.3 Passive acoustic data

Passive acoustic monitoring (PAM) from the Antarctic recording station PALAOA, constituted the entire acoustic data used in the thesis. It was originally designed as an autonomous listening station, delivering acoustic underwater recordings in real-time throughout the year (Boebel et al., 2006). In 2014, the station was transformed into an offline recorder with one hydrophone in operation. Extensive information about PAM and PALAOA are attached in the Glossary.

3.4 Call types at PALAOA

Ross seals and leopard seals breeding calls were recorded during the austral summer (around December-January) at PALAOA.

Within the same time frame, the German research icebreaker Polarstern takes advantage of the summer ice conditions and enters the area in order to resupply the German research station Neumayer, which is located near Atka Bay. This coincidental overlap of PS during the time that LS and RS are active in Atka Bay forms the basis for this thesis.

3.4.1 Leopard seal

Kreiß (2008) identified eight call types around PALAOA (illustrated in Figure 9, further elaborated in Table 6), which provided the basis for call identifications in this thesis.

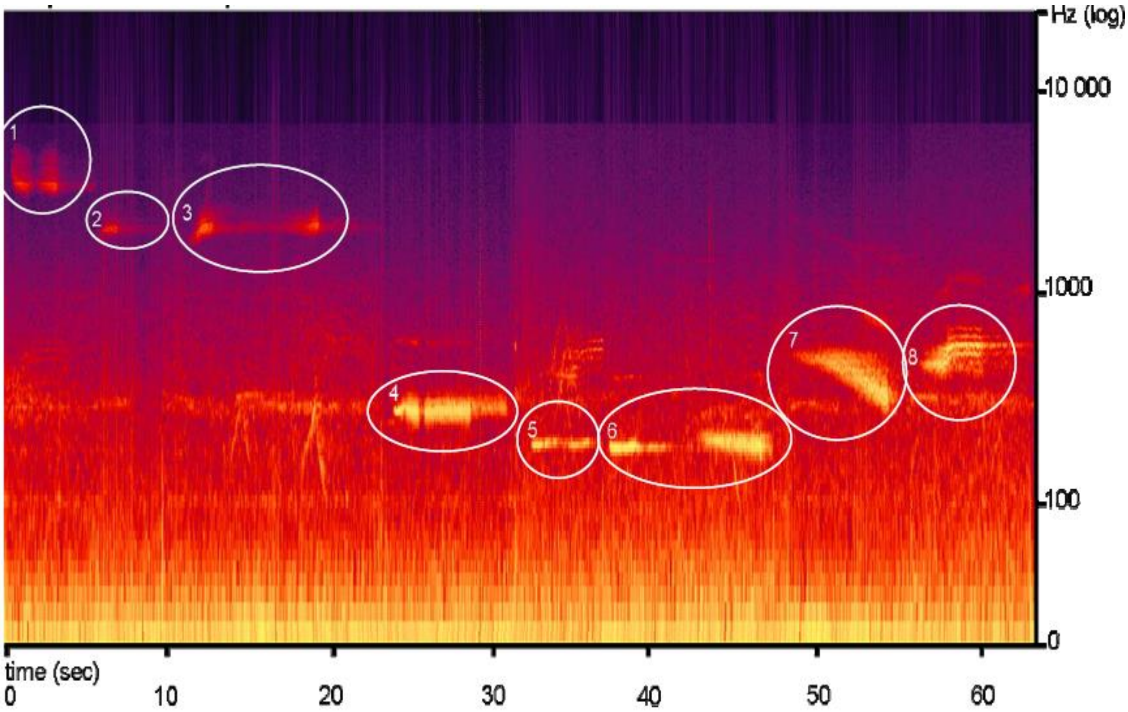


Figure 9 Leopard seal call repertoire at PALAOA. *The spectrogram extract comprises the eight leopard seal call types (1 High Double Trill, 2 Medium Single Trill, 3 Medium Double Trill, 4 Low Double Trill, 5 Hoot, 6 Hoot with single Trill, 7 Low DeScending Trill, 8 Low AScending Trill), known at PALAOA. Source: Kreiß (2008).*

*Table 6 **Overview of the 8 leopard seal call types identified at PALAOA**. Adapted from Kreiß (2008)*

Leopard seal call types at PALAOA				
Name	**Abbre-viation**	**Description**	**Frequency (Hz)**	**Duration (sec)**
"High Double Trill"	HDT	„broadband high frequency call, [consisting] of two pulsed elements	2500 - 4450	2,2 - 8,7
"Medium Single Trill"	MST	„mid frequency call [consisting] of a single pulsed element“	1300 - 2400	2,9 - 6,7
"Medium Double Trill"	MDT	„mid frequency call [consisting] of two pulsed elements“	1400 - 2500	6 - 9
"Low DeScending Trill"	LDST	„low frequency call, [consisting] of a single pulsed element of decreasing frequency“	270 - 800	4 - 6,8
"Low AScending Trill"	LAST	„mid frequency call, [consisting] of a single pulsed element of ascending frequency“	400 - 950	3,4 - 6,2
"Low Double Trill"	LDT	„low frequency call, [consisting] of two pulsed elements and an initial narrow-band component“	230 - 470	1,9 - 9,5
"Hoot"	H	„mid frequency call, [consisting] of a single pulsed element“	150 - 290	1,5 - 3,5
"Hoot with Single Trill"	HST	„low frequency call, [consisting] of a narrow-band component followed by a single pulsed element“	170 - 310	3 - 9,5

3.4.2 Ross seal

Around the listening station PALAOA, Seibert (2007) identified four different RS calls (high siren, mid siren, low siren and whoosh), whereas the call type whoosh comprised both the whoosh broadband component and the whoosh tonal component, which are presented in Figure 10 and details are shown in Table 7.

Although the work of this bachelor thesis is based on the results of Seibert (2007), here the Whoosh (WBC and WTC) was considered as a single call for simplicity reasons. Thus, in this thesis 5 different call types will be analyzed. The Bowl, which belongs to the high siren call, as defined by Seibert (2007), was not identified in the data (possibly only audible/visible in very clean material, due to ship periods material is probably already too polluted) and is therefore left out.

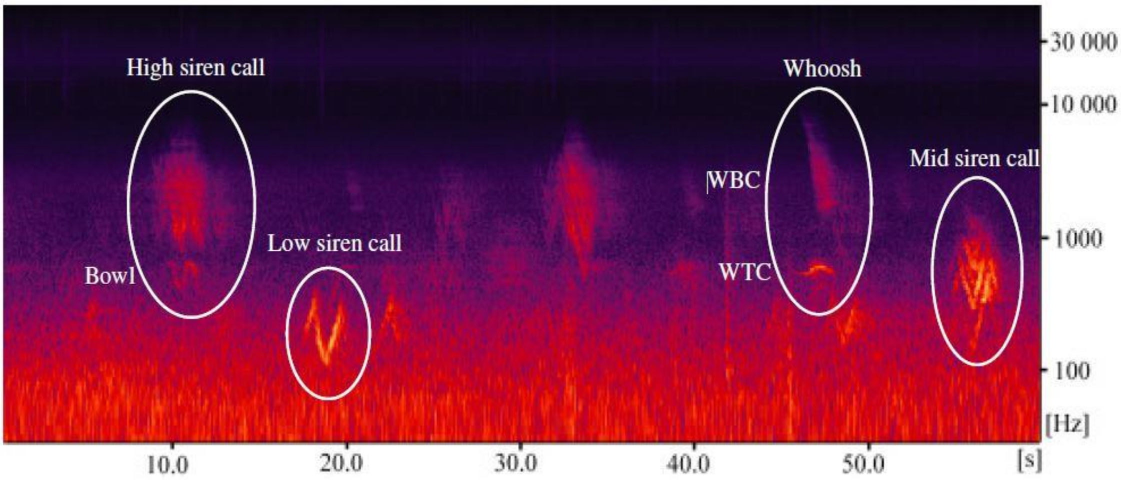


***Figure 10 Ross seal call repertoire at PALAOA**. The spectrogram extract comprises the 5 Ross seal call types (High siren call with a Bowl below – Bowl was not found in present data, Low siren call, Woosh broad-band component (WTC), Woosh tonal component (WTC) – Seibert comprises WBC and WTC simply under Whoosh, Mid siren call), known at PALAOA. Source: Seibert (2007).*

Table 7 Overview of the 5 Ross seal call types identified at PALAOA. *Adapted from Seibert (2007)*

Ross seal call types from PALAOA				
Name	**Abbre-viation**	**Description**	**Frequency (Hz)**	**Mean Duration (sec)**
"High Siren"	HS	„alternating up- and downsweeps“	592,18 - 7129,38	3,37
"Mid Siren"	M	„alternating up- and downsweeps“	168,42 - 2010,38	3,29
"Low Siren"	L	„alternating up- and downsweeps“	132,54 - 449,14	2
"Whoosh Broadband Component"	WBC	„diffuse downsweep at relatively con-stant rate“	1439,26 - 10996,54	2,51
"Whoosh Tonal Component"	WTC	„single upsweep, followed by a plat-eau and eventually a downsweep“	574,18 - 591,5	2,33

3.5 Raven Pro Analysis of Sighting Data

Calls were only included in counts when they were both visible in the spectrogram and audible at the same time. In certain cases, the animals were either visible or audible, which was treated as an exclusion criteria. This happened amongst others when many individuals were calling at the same time, resulting in call overlaps or when PS noise strongly over-lapped the calls acoustically.

__Table 8 Species call type abbreviations__. The calls were boxed collectively (RS), if the number of calls exceeds a specified amount (R, S, N – marked in grey).

Ross seal (RS) - Ommatophoca rossii		**Leopard seal (LS) - Hydrurga leptonyx**	
HS	**H**igh **S**iren call	**HDT**	**H**igh **D**ouble **T**rill
M	**M**id Siren call	**MST**	**M**id **S**ingle **T**rill
L	**L**ow Siren call	**MDT**	**M**id **D**ouble **T**rill
WBC	**W**oosh **B**roadband **C**omponent	**LDT**	**L**ow **D**ouble **T**rill
WTC	**W**oosh **T**onal **C**omponent	**H**	**H**oot
R	> 12 HS	**HST**	**H**oot with **S**ingle **T**rill
S	> 10 M	**LDST**	**L**ow **DeS**cending **T**rill
N	>8 L	**LAST**	**L**ow **AS**cending **T**rill

Calls were logged in Raven (see Figure 11) by boxing exactly around each call, a predefined set of information (´BeginDateTime`, ´BeginTime`, ´EndTime`, ´Duration`, ´Low Frequency`, ´High Frequency` and a ´Comment` containing the call type, etc) was automatically extracted and saved as txt file.

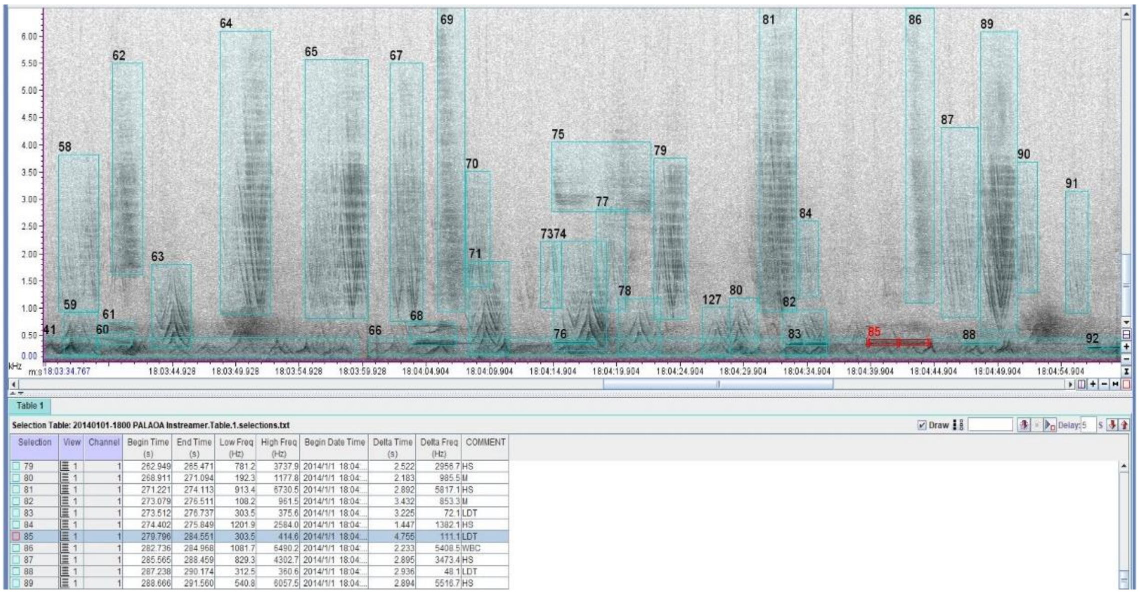


Figure 11 Overview of Raven boxing procedure and resulting information.

Raven text files were then imported into Excel (see ´AllDatasetsOrdered` appended in CD) for further statistical analysis.

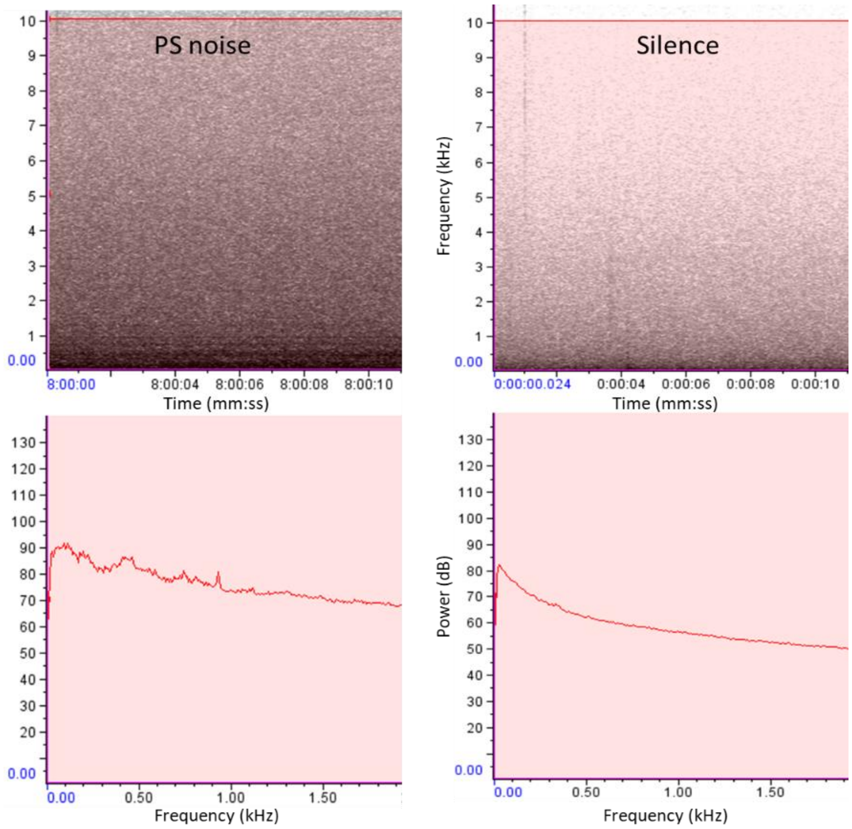
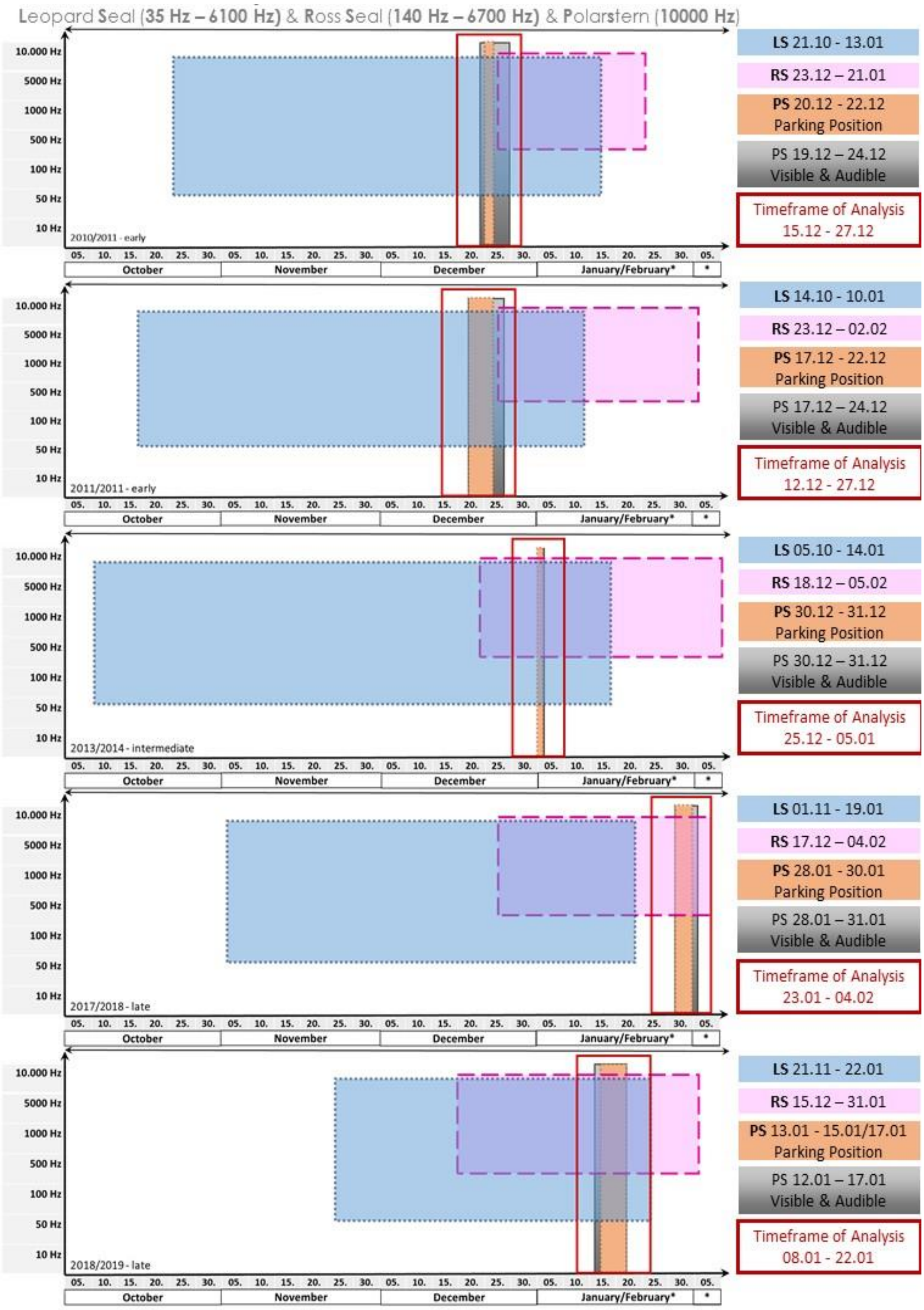


Figure 12 Comparison of sound at PALAOA *during (left) and without (right) PS presence, shown in a spectrogram out cut (upper picture) and in a power spectrogram (lower picture). Both PS noise and Silence are retrieved from the analysis year December 2010.*

The spectrogram out cut on the left (PS noise) shows that PS is very loud, especially at lower frequencies (darker/almost black shades; up to 1,5 kHz). However, PS produces noise as well in much higher frequency ranges (see dark grey colors) even up to 10,000 Hz in comparison to the silent status and its lighter colors on the right side.

4. Results

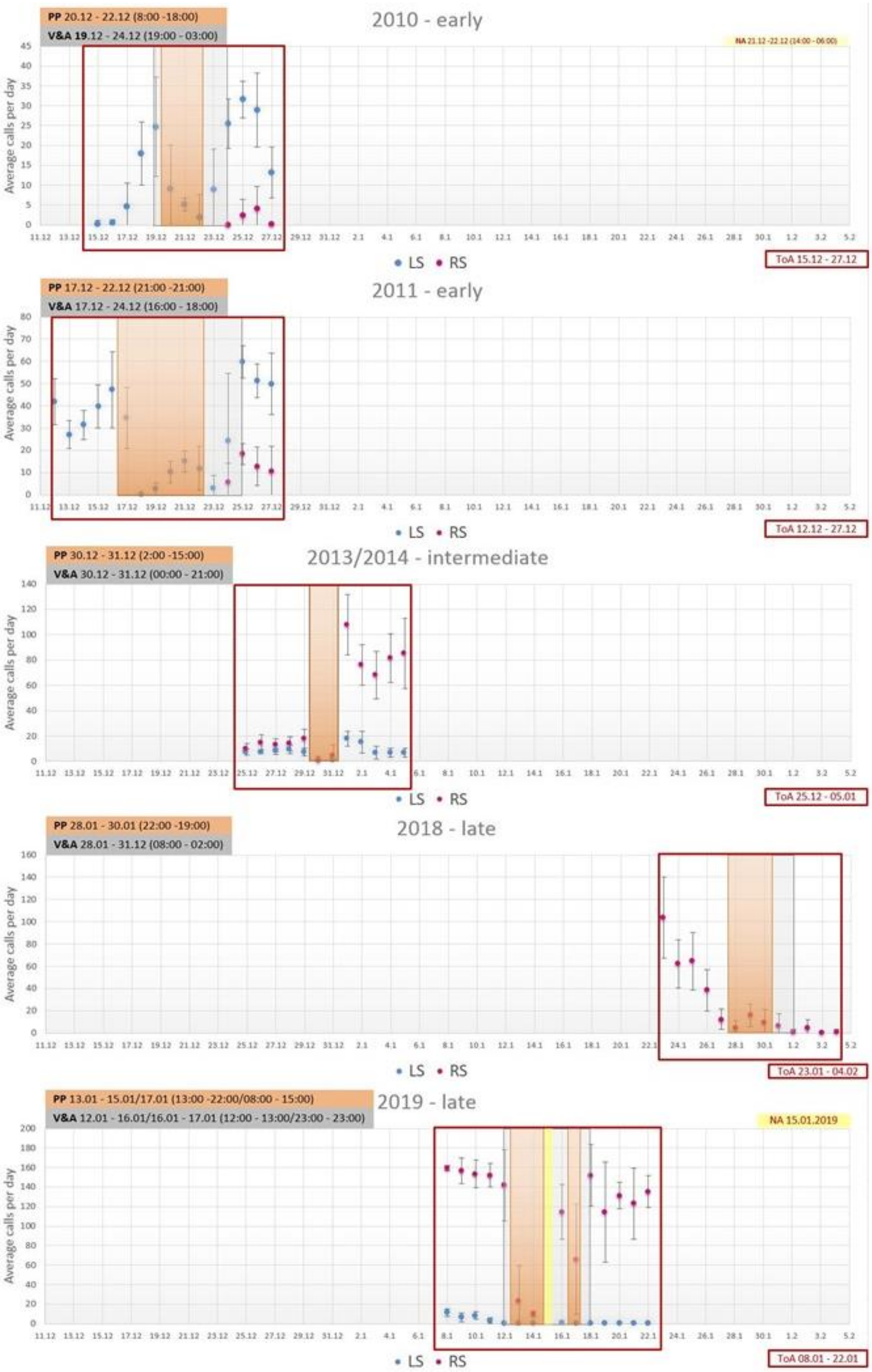
4.1 Presence Overlap – seals and PS



Graph 1 Presence Overlap – seals and PS *The presence of both species, LS (35 Hz – 6100 Hz, light blue) and RS (140 Hz – 6700 Hz, rose/pink), as well as PS in parking position (10.000 Hz, orange) and when still spectrographically V&A (grey) prior or post presence at NS/Atka Bay is shown over the 5 years (2010, 2011, 2013/2014, 2018, 2019) of analysis. The red square symbolizes the ToA. The x-axis displays the exact date every fifth day (October 5 - February 5) of the respective year, the y-axis the frequency range (10 Hz – 10.000 Hz). In the lower left corner of each graph, the PS arrival scenario is classified in i.e. early, intermediate or late. The ship occupies the entire frequency range until 10.000 Hz (see Figure 12, 3.5 Raven Pro Analysis of Sighting Data, Methodology for further elaboration).*

Evaluation – Presence Overlap				
	PS	*LS*	*RS*	*Main findings*
2010/2011	• ´early` arrival • ´short` stay (3 days) • V&A: 1 day prior arrival, 2 days post departure • ToA: 13 days	End of October – mid-January (85 days) • 22 days acoustically present post PS departure	End of December - end of January (30 days) **shortest presence**	• PS arrives in 2nd half of LS calling period • RS start calling 2 days post PS departure (overlap only in V&A) • LS arrival neither late nor early in October (compared to following years)
2011/2012	• ´early` arrival • ´long` stay (6 days) • V&A: 2 days post departure • ToA: 16 days	Mid-October - beginning of January (89 days) • 20 days acoustically present post PS departure	End of December - beginning of February (42 days)	• **PS earliest arrival** • PS arrives (again) in 2nd half of LS calling period • RS start calling 1 day post PS departure (similar to 2010) • LS arrive few days earlier (mid-October), leave few days earlier than 2010
2013/2014	• ´intermediate` arrival • ´short` stay (2 days) • V&A = PS presence • ToA: 12 days	Beginning of October – mid-January **(102 days)** **longest presence** • 14 days acoustically present post PS departure	Mid-December - beginning of February **(50 days)** **longest presence** • 36 days acoustically present post PS departure	• PS arrives in 1st half of RS calling period, in 2nd half of LS calling period (as in previous years) • both species **arrive far ahead of PS** (only year), stay in area post PS departure • LS arrive up to a month earlier (compared to other years)
2017/2018	• ´very late` arrival • ´short` stay (3 days) • V&A: 1 day post PS departure • ToA: 13 days	Beginning of November – mid-January (80 days)	Mid-December - early February **(50 days)** **longest presence** • 5 days acoustically present post PS departure, **leave simultaneously to PS**	• **PS latest arrival** • PS arrives post LS departure (beyond ToA) • LS start calling relatively late (compared to 2013/2014), but leave around same time as in 2013/2014 • RS remain faithful to arrival and departure, stay exact amount of days as in 2013/2014
2018/2019	• ´late`arrival • ´immediate` stay ➔ **4 days in total** **1st arrival 3 days,** **2nd arrival 0,5 day**, *(in-between PS 1 day at sea) • V&A: 1 day prior PS arrival • ToA: 15 days*	Mid-November - mid of January (63 days) **shortest presence** • 5 days acoustically present post PS departure, **leave simultaneously to PS**	Mid-December - end of January (48 days) • 14 days acoustically present post PS departure	• LS latest arrival in all 5 years, but departure is almost identical to 2018 • RS arrival and departure is almost identical with 2013/2014 and 2018
➔ LS tend (in general) to a later arrival over the 5 years ➔ RS change in 2013/2014 arrival pattern from earlier arrival (2010 & 2011) to later arrival (2018 & 2019)				

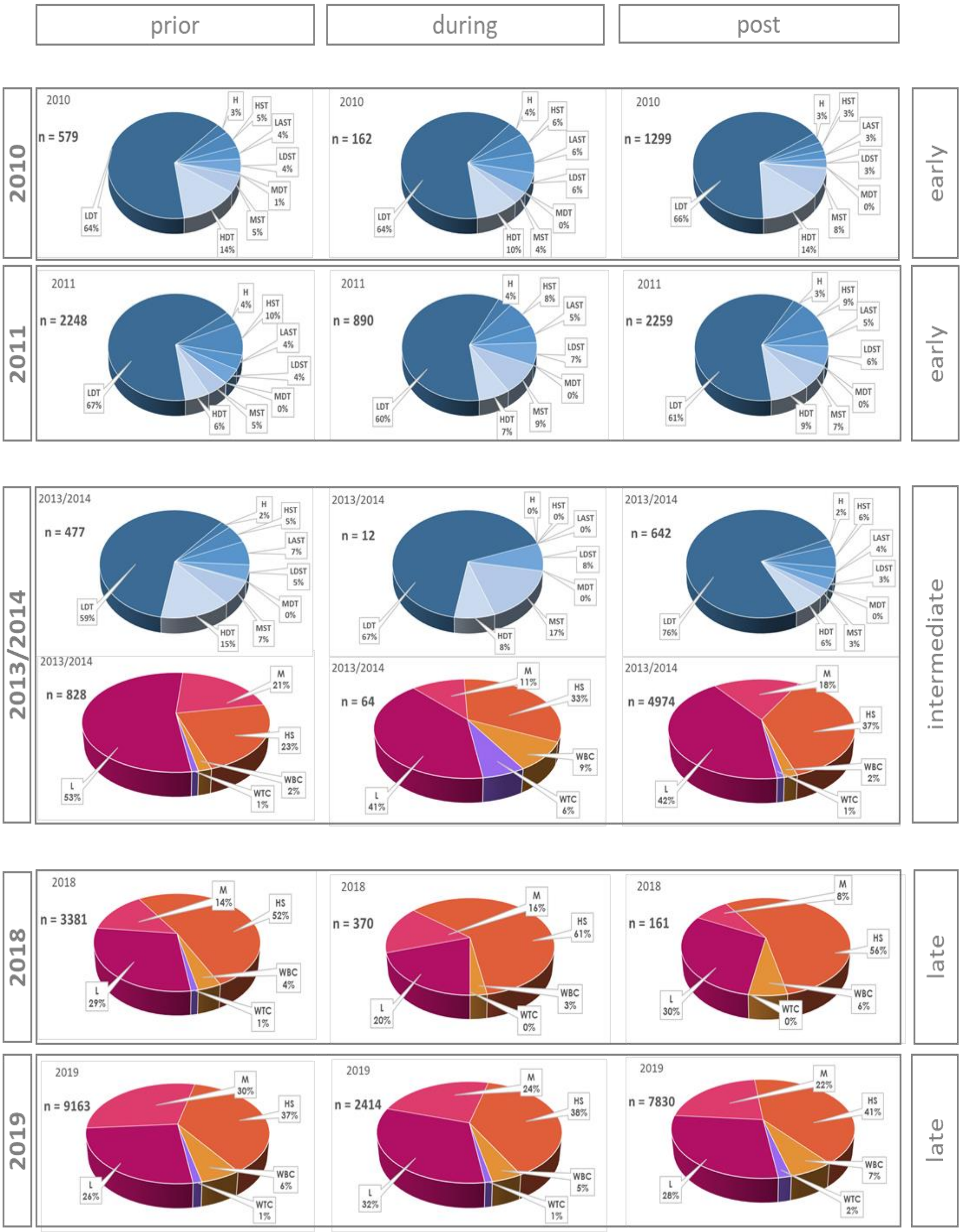
4.2 Call Activity



Graph 2 Call Activity *of Ross seals (RS) and leopard seals (LS) in the individual analysis years (2010; 2011; 2013/2014; 2018; 2019). The x-axis displays the exact date, while the y-axis indicates the average calls per day. LS are represented by blue points and RS are the pink ones. The dots show the average number of calls per day, the vertical lines indicate the standard deviation. The presence of the PS is marked as an orange square. The Time of Analysis (ToA) is marked with a red square. The year 2019 additionally contains a yellow coloration, which draws attention to a data leak on January 15. During the acoustic presence of PS, the call activity of both species is significantly decreased. The average call activity per day increases after PS departure to even higher call numbers in most of the analyzed years.*

Evaluation – Call Activity			
	General	*LS*	*RS*
2010	• large variability in average amount of calls over ToA	• 1^{st} days low average call activity (day 1prior: 0 calls, day 2prior: 1 calls) • latter 3 days until arrival of PS, average call activity increases from 5 to 25 calls, drops with PS arrival from 10 calls average to 2 average calls per day • calling increases again post PS departure, exceeds even levels prior to PS presence (peak: 32 average calls)	• only acoustically present post PS departure
2011		• average amount of calls prior PS arrival (day 1prior: 42 calls, day 5prior: 47 calls) • calls drop during PS presence, but recover/increase again (day 1: 35 calls, day 2: 0 calls, day 3-6: 12 calls) • call activity remains low (3 calls) 1^{st} day post PS departure, jumps from the 2nd day (24 calls) to 50 calls on last day	• only acoustically present post PS departure
2013/ 2014	• low average call activity of both species prior PS arrival • immediate drop of calls of both species to less than 1 call per day during PS presence • sharp change in behavior of both species post PS departure	• slightly lower call activity than RS (day 1prior: 7 calls, day 5prior: 7 calls) • call activity remains almost as low as prior PS arrival (day 1 post: 18 calls, day 5post: 7 calls)	• slightly higher call activity than LS (day 1prior: 10 calls, day 5prior: 18 calls) • increase average number of calls post PS departure (day 1 post: 108 calls), • then drop in calls for remaining days (day 2post: around 76 calls)
2018		• no calls, left prior PS arrival	• average call activity falls day 1prior: 104 calls day 5prior: 12 calls • call rate fluctuates during PS presence (day 1-3 during: 5, 16 and 9 calls) • average call activity decreases further post PS departure (day 4post: 1 call)
2019	• both species stick basically to number of calls prior/post PS arrival/departure	• average call behavior remains quite low over entire period (day 1prior: 11 calls, during: 0 calls, day 1post: 0 calls)	• very high average number of calls per day (day 1prior: 159 calls, day 5prior: 142 calls, day 1post: 152 calls, day 5post: 136 calls) • exception: 23 calls at PS 1^{st} arrival • call activity immediately high again while PS at sea 1 day (115 calls) • slight decreases in calls at PS 2^{nd} return (66 calls)
➔ Call activity of both species significantly decreased during PS presence ➔ Average call activity per day increases (in most years) post PS departure to even higher call numbers			

4.3 Call Repertoire - Piechart

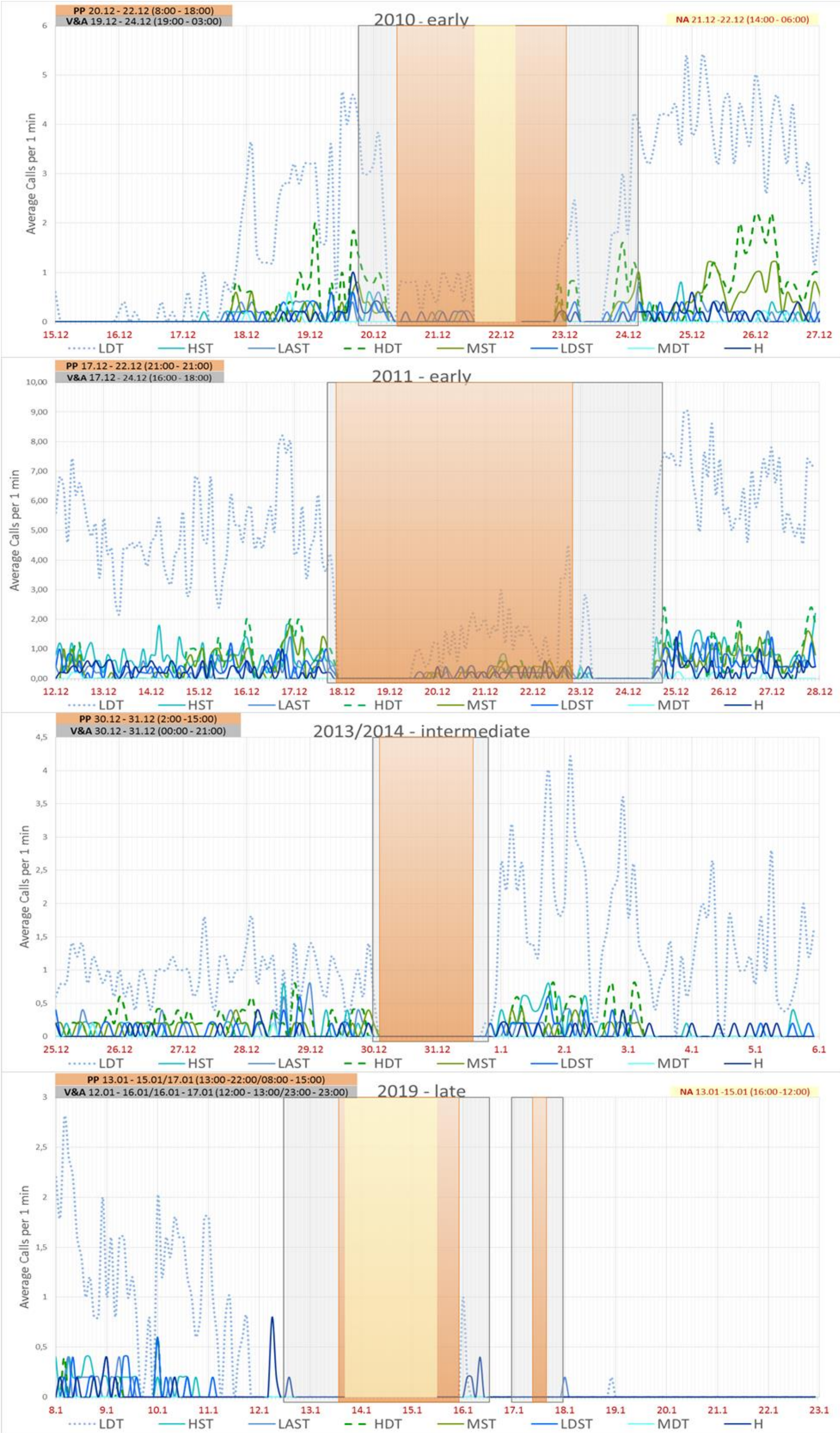


Graph 3 *The* ***Call Repertoire - Piechart*** *represents the individual call types of LS (bluish tones) and RS (reddish tones) during ToA. The repertoire analysis is divided into the different years (left side) and into the events ´prior, 'during', and 'post' (above), as well as into 'early', 'intermediate' and 'late' arrival (right side). The years 2010 and 2011 are not shown for the RS repertoire, as the animals have not yet been around PALAOA at this 'early' time. A similar situation applies for the LS in 2018 and 2019. The species is departing during ToA, which is why those years are not represented. In the repertoire analysis, the individual call types are compared among the different events and years. The amount of calls "n" decreases drastically during the presence time of PS.*

Evaluation – Call Repertoire - Piechart			
	General	*Call types*	*%*
Leopard seals	• LDT most common/frequently used call type over 3 years of analysis (coincides with analysis of Van Opzeeland (2010))	• *HDT*, *MST*, *HST* are dominant call types, but differ in dominance between years • 2010 & 2013/2014: *HDT* is 2nd most used, *MST* is in 3rd place, *HST follows* closely • 2011: *HST* is 2nd most used, *HDT* is in 3rd place, *MST* follows • *HST* and *MST* show similarities across 2011 & 2013/2014: *HST* call percentage decreases during PS presence, but rises again afterwards, *MST* call percentage increases during PS presence, but descends post PS departure • *LDT* increases (slightly) in all 3 years post PS • *LDST* shows opposite behavior of the *LDT:* increases in all 3 years slightly during PS presence, but descends post departure • *LDST* behavior applies also to *LAST,* except year (2013/2014)/event (2011 post)	• ´n` in % increases again by almost exact amount, lost previously due to PS presence • 2011: ´n` in % dropped by ~ 60 %, rose again by ~ 60 % (prior: 2248 calls, during: 890 calls, post: 2259 calls) • 2013/2014: ´n` in % shrank with PS arrival by ~ 97 %, increased again by ~ 98 % (prior: 477 calls, during: 12 calls, post: 642 calls) • except 2010: ´n` rose from prior ~71 %, somewhat higher post PS presence ~ 88 % (prior: 579 calls, during: 162 calls, post: 1299 calls)
Ross seals	• most commonly used call type varies & not always the lowest one (compared to LS) • M is always in 3rd place during all events • Whoosh (*WBC* and *WTC*) occur in extremely low numbers	• 2013/2014: LDT in 1st place (during all 3 events), order is L>HS>M • 2018 & 2019: *LDT* overtaken by *HS,* order is HS>L>M • *2013/2014 & 2019: HS* increases during/post PS presence, except *2018: HS* call rate drops slightly below value during PS presence • 2013/2014 & 2018: *L* changes from higher rate prior PS to lower one during PS presence, but increases again post PS departure	• 2013/2014: ´n` in % shrank with PS arrival by ~92%, increased again by ~99% post PS departure (prior: 829 calls, during: 64 calls, post: 4974 calls) • 2019: ´n` in % dropped by ~74% during PS presence, rose again by ~69% (prior: 9163 calls, during: 2414 calls, post: 7830 calls) • except 2018: ´n` constantly decreases over ToA (prior: 3381 calls, during: 370 calls, post: 161 calls)

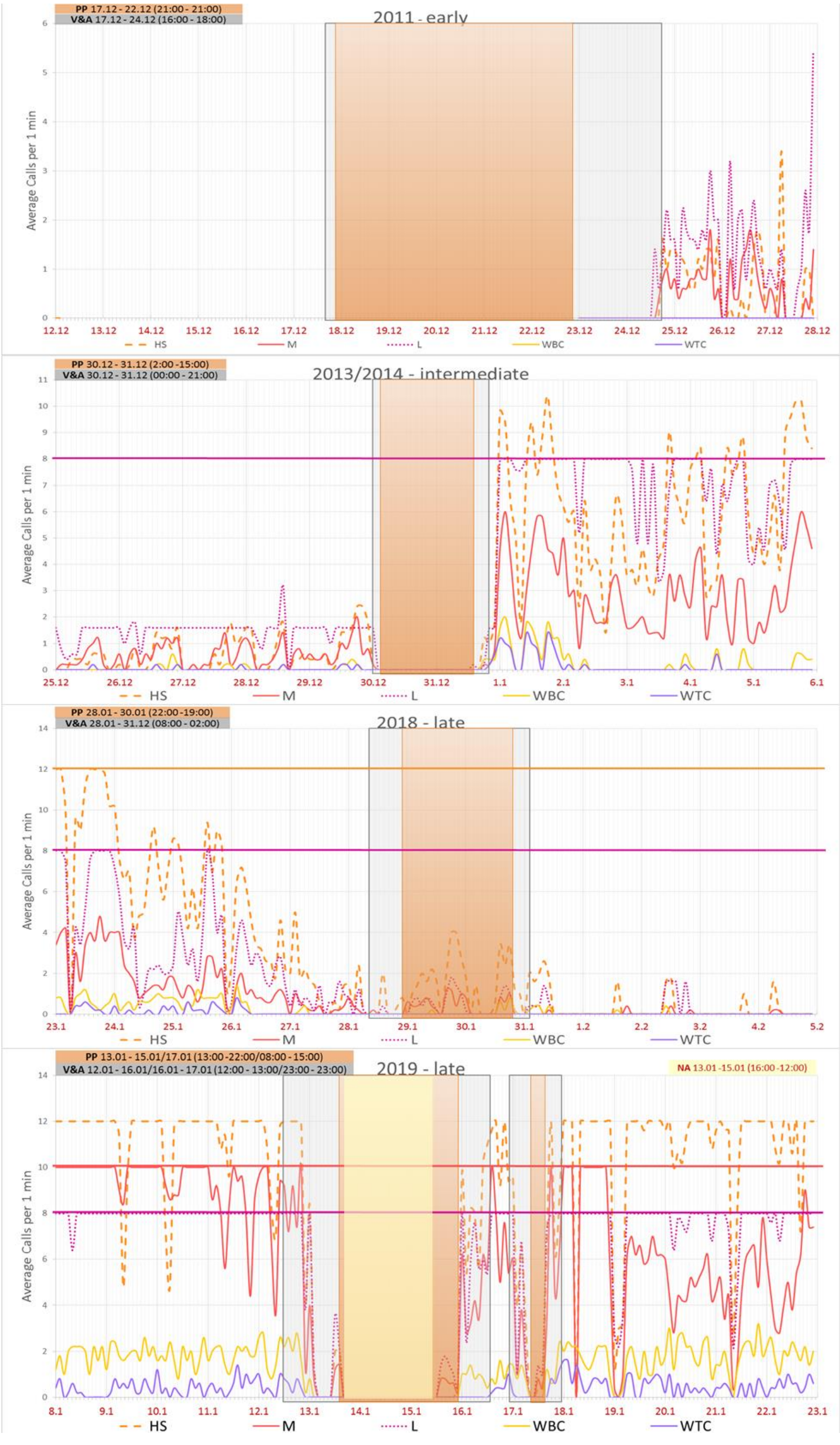
4.4 Call Repertoire – Linegraph

4.4.1 Leopard seal



Graph 4 Call Repertoire - Linegraph. *The x-axis comprises the date whereas the y-axis represents the average number of calls per minute. The orange box indicates the presence of PS, the grey V&A prior or post arrival/departure of PS. The corresponding boxes in the upper left corner contain the exact date and time of arrival/departure. The yellow box and the associated box in the upper right corner represent missing data. The graph shows the years 2010, 2011, 2013/2014 and 2019. The five different call types are assigned in the legend with their abbreviations and a corresponding color. LS calls generally decrease during PS presence, whereas there is a higher number of calls post PS departure. For 2018, the species had left prior to ToA, no call rate data in relation to PS presence were available.*

4.4.2 Ross seals



Graph 5 RS Call Repertoire – Linegraph. *The x-axis comprises the date whereas the y-axis represents the average number of calls per minute. The orange box indicates the presence of PS, the grey V&A prior or post arrival/departure of PS. The corresponding boxes in the upper left corner contain the exact date and time of arrival/departure. The yellow box and the associated box in the upper right corner represent missing data. The graph shows the years 2011, 2013/2014, 2018 and 2019. The five different call types are assigned in the legend with their abbreviations and a corresponding color. The horizontal lines (pink - L, red - M, orange - HS) indicate that the calls exceed a certain number and are therefore counted together. (R > 12 HS, S > 10 M, N > 8 L - see explanation Table 8). The call activity is decreasing (partly towards zero) during the PS presence. For 2010, no graph was established, since the species arrived when PS had already left again. 2011 is shown as an example. (2010 would look similar.)*

Evaluation – Call Repertoire – Linegraph		
	LS	*RS*
2010	• *LDT* has highest number of calls & peaks • *LDT* most dominant during PS presence • December 21 – 22, no calls between 2 pm – 6 am (data gap/technical failure – marked in yellow) • number of calls remain low after data gap until PS departure • V&A post PS departure: no calls on December 23 between 6 am to 2 pm	• only acoustically present post PS departure (no graph established)
2011	• *LDT* has highest number of calls & peaks • *LDT* most dominant during PS presence • number of calls during PS presence (especially *LDT*) little higher than 2010 • during PS presence: December 17 – 19, no calls between 10 pm – 10 am, **although observatory was functioning** • post PS presence: December 23 – 24, no calls between 6 am – 12 am, **although observatory was functioning**	• only acoustically present post PS departure (graph serves as example to demonstrate call behavior when RS arrive post PS departure)
2013/ 2014	• *LDT* has highest number of calls & peaks • *LDT* increases drastically post PS departure • HDT decreases sharply from January 3 on, post PS departure • no calls at all during PS presence (compared to 2010 & 2011, at least low call rate during PS presence)	• call activity prior PS presence quite low compared to strong increase post PS departure • no calls at all during PS presence • V&A: call activity starts to increase
2018	• no calls, left prior PS arrival	• call activity relatively high prior PS arrival • *HS* & *L* reach counting limit • (horizontal lines) • call activity decreases steadily over ToA • V&A prior PS arrival: call activity decreases further, but increases again slightly during PS presence, decreases again/further post PS presence
2019	• LS departure coincides with PS • call number prior PS arrival already quite low • January 13 – 15, no calls between 4 pm – 10 am (data gap/technical failure – marked in yellow) (graph serves as example to demonstrate call behavior when LS cease calling/leave area (prior)/simultaneously to PS)	• call activity prior & post PS presence quite similar/high • *HS, M* & *L* reach counting limit (horizontal lines) • January 13 – 15, no calls between 4 pm – 10 am (data gap/technical failure – marked in yellow) • little call activity (only *M* & *HS*) during 2^{nd} PS arrival • V&A: RS remain acoustically active, dominant calls are *HS*, *M* & *L*
➔ Call Repertoire – Linegraph confirms basically results from piechart regarding repertoire composition		

5. Discussion
5.1 Interpretation leopard seals
5.1.1 Presence Overlap
The arrival time of the LS fluctuated by almost one month (earliest arrival October 5, 2013/2014 and latest arrival November 1, 2018/2019) over the study period, which contrasts with the timing of RS arrival, which was much more constant between years. The differences in LS arrival times between years may be due to annually varying ice conditions. The interaction of prevailing ice conditions and the presence of animals is complex. According to Siniff et al. (2008), pack ice seals (Weddell seal, crabeater seal, Ross seal, leopard seal) are generally very sensitive to ice changes, as seals are dependent on the ice to a large extent or at least for certain stages of their lives. Of the four Antarctic pack-ice seals, the LS and the RS are the least affected, both physically and biologically, by variations of ice. However, the ice and its prevailing conditions may have an impact on other marine organisms (e.g. fish, krill, cephalopods) which are essential food sources for the seals. In particular, crabeater seals play a role for the LS, whose pups constitute part of the LS menu. The crabeater seals, on the other hand, are extremely sensitive to changing ice conditions and their behavior can therefore indirectly affect that of the LS (Siniff et al., 2008).
Therefore, arrival times may be affected by the availability of food, which in turn is dependent on certain ice conditions. (Gurarie et al., 2017) Besides krill on which the LS feeds all year round, cephalopods are on the menu in October and November, while crabeater pups are eaten in addition in December and January (Kreiß, 2008). Thus, earlier arrival times as in 2013/2014 and later arrival times like 2018/2019 may be linked to different ice conditions and consequent different prey availability.
In contrast to the different arrival times, the LS remain relatively faithful to their departure time (12 days difference from earliest to latest departure). In the first three years of the analysis, the PS stay took place in the last third of LS presence in the Atka Bay. After the departure of the vessel, the species was always present for at least another 14 days. An exception is 2017/2018 in which the animals have already left before PS arrived. It cannot be assumed that the LS left the area earlier in response to the presence of the PS, since the general departure period for the LS did not deviate from the usual, but rather remained within the same timeframe. In 2018/2019, the LS could be theoretically expected as well to leave the region earlier to avoid the noise of arriving PS. However, this seems not to be the case, the animals rather kept their inner and usual departure time and left almost simultaneously with the vessel.
From the point of view of the presence overlap, the PS presence does not seem to have any effects on the LS. The variation of arrival time and thus the duration of LS acoustic presence, seems to be independent of PS presence over the 5 years of analysis.

5.1.2 Call Activity

When looking at the five graphs, it is noticeable that the number of calls decreased considerably as soon as PS is present. However, calls increased again (2013/2014) after the departure of the ship, and in some cases (i.e. 2010 and 2011) exceeded the levels during the period prior to or during PS was present. The years 2010 and 2011 followed a similar pattern in the beginning, not least because of PS presence for almost the same period of time. The increased call activity in both years after leaving PS suggests that the animals may still be increasing call activity towards a peak of the mating period after the departure of PS. In earlier analyses, December 16 (2006) turned out to be the peak of all LS calls during the mating season at PALAOA (Van Opzeeland et al., 2010). The year 2013/2014 is similar to the previous years in terms of decreasing and increasing call activity with the presence of PS. However, the increase in calls before and after PS is less drastic, which may be due to the fact that the peak calling time and thus the climax of the mating season is already over when PS arrives. The considerable, but not complete decrease in calls 2013/2014 during PS presence is a strong indication that the noise of PS masks the calls of the seals. This is supported by the fact that calls strongly decrease every year during vessel presence, but never completely disappear. The calls remain sporadically and in small numbers visible and audible. If the animals would leave Atka Bay completely, it would be likely that no calls at all should be seen during PS presence. Furthermore, when animals would leave, calling would be unlikely to increase immediately post PS presence. It is more likely that the calling is either reduced during PS presence or calls are masked by the ship noise, leading to the reduced number of calls detected during the analyses.

The year 2018 cannot be evaluated, because the animals had already left the area prior to PS arrival. The seals' calling behavior in 2019 cannot be attributed to the presence of PS, as it is a late arrival of the ship and the LS calling activity has already drastically reduced prior to the arrival of the ship. However, here, too, very few calls were detected immediately after PS had left, suggesting that also late in the season, animals seem not to cease calling due to the presence of the ship.

5.1.3 Call Repertoire

It is not easy to draw clear conclusions about the call type behavior of LS, since of the five years of analysis, only the first three years were ultimately available for complete analysis. Moreover, conspicuous features often do not coincide within these three years.

The most used call over the three years and events is the LDT. The call increased during all three years after the departure of the PS, even if only slightly in some cases. This could indicate that the species used this call type in particular when PS was present to counteract

the noise. However, this is an assumption, since most calls during PS presence are presumably masked and show different developments during the three years of presence. Therefore, this assumption can only refer to the post PS presence.
However, it may also be that the LDT is simply used less during PS because it is less useful for communication during ship presence (main part of noise is on similar/low frequencies). As soon as PS leaves, the LDT is used more often again, as PS no longer interferes with this call type.
Since the HST decreased in 2011 and 2013/2014 during PS presence and increased after departure while the opposite was recorded for the call type MST (call count increased during ship presence and decreased again afterwards), one could conclude that the animals use higher (MST) instead of lower (HST) frequency call types during PS presence. However, this is only true for two of the three years and may also be due to different intensity of masking of PS presence. Furthermore, this assumption is not supported by the use of call type LDST and partly by the LAST. These two call types are also low call types, which increased despite vessel presence and decreased with its departure.
The assumption that certain call types tend to increase or decrease number due to the ship presence is difficult to confirm based on the current data.

The Call Repertoire - Linegraph highlighted the absence of calls on the 18/19 December, during PS presence, and on the 23/24 December during the V&A period of the year 2011 (despite normal functioning of the observatory). Having a look at the Spectrogram Screen Selection of this year (see Appendix B 16 & B 17), it is visible that the ship noise is particularly strong at this time. This may be linked to a greater number of engines in operation, in order to break through the ice on the approach or to be freed from it again after the 6-day stay. After the parking position was reached, one or more of the four engines could possibly be turned off, thus becoming quieter allowed occasional calls of the LS to be heard.

After the data gap on December 22 in 2010, no LS calls are visible for a few hours. This time, at least spectrographically, the ship noise seems to be not as loud as in 2011, however the animals stopped calling during this period, suggesting potential disturbance. While in 2010 and 2011 during ship presence, calls are present at least in small quantities, there are no calls at all during PS presence in 2013/2014. The Spectrogram Screen Selection (see Appendix B 13) reveals that the ship noise is extremely loud this year. The spectrogram is almost black over the whole period, and the calls, if they take occur at all, are likely to be masked completely by the noise.

5.2 Interpretation Ross seals

5.2.1 Presence Overlap

Overall, the RS were highly consistent with respect to their arrival and departure dates as over a five-year period, they arrived in Atka Bay one or two days earlier each year. This may be due to the changing ice conditions. The size of ice floes to give birth or suckle the young and for hauling out during moulting is of critical importance to ice-breeding seal species such as RS (Siniff et al., 2008). The increasingly earlier arrival of the RS could possibly be related to the prevailing conditions of ice floes and their size (Siniff et al., 2008). Further investigation is needed to explore how local ice conditions relate to the timing of acoustic behavior in RS.

The arrival times of the PS show a greater variation of scenarios for the RS than for the LS. The years 2010/2011 and 2011/2012 show an especially interesting detail. The RS arrived in Atka Bay on the same date in the V&A period post PS departure. This is also the latest arrival date within the five years. Although the difference is only a few days (8 days between the earliest and latest dates), the later arrival of the animals after PS has already left could be interpreted as a delaying tactic to avoid the full volume of PS. It is possible that the RS perceive the sounds of PS at some distance and cease calling, remaining in the area in waiting position until the ship leaves Atka Bay and the noise is reduced. Another possibility is that the RS continue to call, but their calls are masked by PS presence. In 2013/2014 the arrival of the PS occurred in the first third of the RS presence in Atka Bay and in 2018/2019 in the last third of the RS presence, to which the duration of acoustic presence, calling activity patterns showed no detectable changes, at least from the point of view of the acoustic presence overlap. In 2017/2018 it could be expected that the RS would leave earlier due to the arrival of PS. However, this was not the case since the animals remained consistent in their departure time and thereby left the area almost simultaneously with PS. This makes it difficult to interpret the RS behavior with the presence of PS. Just as for LS, ice conditions and food availability may have influenced the relatively short stay of the RS as well as their earlier departure in 2010. Further investigation is needed to understand whether or not RS calls are masked or animals are more likely to cease calling. Additional experiments where ship noise is added to pinniped recordings can for example be used to mimic realistic underwater ship noise levels and evaluate if calls can still be detected under different scenarios (e.g. ship in parking position, ship at x-km etc.).

5.2.2 Call Activity

During the five-years period of analysis RS calls declined sharply, but not completely when PS appeared. As soon as the ship left, the call activity increased again, according to the respective phases in which the seals are at that time. While the years 2010 and 2011 were of no use, because the RS only arrived in the period after PS departure and thus a comparison over the events was not possible, the remaining three years of analysis give a good comparison. According to Van Opzeeland's research (2010), the RS have their call peak on January 10 (2007). This date also seems to coincide approximately with these three years of analysis. If we place the graphs in the order 2013/2014, 2019 and 2018, we can see an almost continuous progression in life phases and respectively call behavior. In 2013/2014 the calling activity prior PS arrival was rather low, because the seals arrived only recently in the area. Once arrived though, the call activity increased continuously, which can already be seen in the period post PS departure. The 2019 study period shows PS arrival around the call peak (i.e., max. 160 calls on 8 January 2019, likely peak mating period). The call peak must either have taken place shortly prior to the investigation period or happened during PS presence. Over the entire analysis, call activity decreased minimally on average. However, the calls decreased abruptly upon arrival of the ship and increased again just as quickly after its departure. The same pattern is observed post PS departure in 2013/2014. The year 2019 suggests that there are no long term effects of PS presence, at least in terms of the number of calls, especially during the mating season. This fact is particularly noticeable on 16 January, the day on which PS is absent. Here, the number of calls rises to an average of 115 calls per day, whereas the day before, when the vessel was present, it was still at 15 calls, and on 17 January (when PS returns) it drops again to 65 calls.

Regarding the 17 January, it must be mentioned, however, that the graph shows average daily calls. Therefore, it can be assumed that the number of calls during the half day with PS presence has decreased, but due to the remaining half day without PS and the associated presumed increase in calls due to peak calling time, the daily average is compensated. A further aspect could be that less masking of calls by ship noise may have taken place compared to the first arrival. This can be explained by a different approach direction and angle of the ship (machines are facing (away) from the hydrophones) and/or fewer machines in operation.

At the beginning of the 2018 period, the RS are still relatively active. However, this activity decreases steadily until it is close to zero post PS departure. The low call activity after the departure of PS is connected to the seasonal departure of RS from the area around PALAOA. The peak calling time was most likely prior to the arrival of PS.

5.2.3 Call Repertoire

While the three years that were analyzable for the call repertoire investigation showed in general a stable repertoire composition between the years, there seem to be differences in the proportions of specific call type usage such as in 2013/2014 illustrating an increased amount of L than in other years. Even if the percentage of WTC was generally very low (except 2013/2014 during), in 2018 during and after PS presence this call is completely absent. A reason for this could be the RS (imminent) reduction in calling activity and thereby they also proportionally even further reduced presence of WTC.

The increase in HS in all three years during PS presence could be an indication that RS revert to using higher frequency call types during ship presence, as has also been found to occur in bird species inhabiting noisy habitats (Slabbekoorn & Peet, 2003). After departure of the icebreaker, the proportion of HS calls continues to rise for 2013/2014 and 2019 but not for 2018. The further increase may be due to the fact that the seals are either moving towards the mating season (2013/2014) or are exactly in this season (2019) and the HS is increasingly used for mating.

With regard to the call repertoire, the call composition may not just be affected by the presence of PS, but it can also evolve during the mating season with the increasing number of breeding individuals arriving in the area. Furthermore it could be that certain call types are primarily in use during mating, while after it, communication decreases or is limited again to the general basic communication necessary for survival.

Alternatively, it cannot be excluded that HS calls are less likely masked by ship noise for the analyst (which is mainly dominant in the lower frequencies (see Figure 12)) and therefore easier to detect during analyses compared to other calls (which may have been present in equal proportions as prior to ship arrival). Here too, further dedicated experiments, e.g. overlaying artificial noise to control recordings to see how noise presence affects the analyst call detection, are needed to clarify if there is a difference in detectability of call types in noise.

The decrease of L during PS presence in 2013/2014 and 2018 and the increase thereafter, could, at first glimpse, be explained by the arrival and departure of the vessel. However, this behavior does not apply to 2019, but rather shows the opposite. One could interpret this behavior as animals reacting more sensitively to the ship during their arrival and departure and less during the mating season.

Since the L falls in 2013/2014 and 2018 and the HS rises every three years during PS presence, it can be assumed that the RS as well as the LS use more call types with higher frequencies during this time. The proportions for 2019 between prior, during and post PS are highly similar and the total amount of calls ´n` is comparably high to the other years. As 2019 is the year in which the RS are in their peak calling time, it could indicate that the

repertoire composition evolves or changes during the season along with the life phase (breeding, mating, moulting) reached by the animals at that stage.
Comparing the number of calls during the three events in 2019, the number decreases significantly during ship presence.
The proportions for 2019 between prior, during and post PS are highly similar and the total amount of calls ´n` is comparably high to the other years.
However, whether the repertoire composition changes over the respective call phases (prior, during, after mating) cannot be determined from the available data.
Once again the Call Repertoire Linegraph plays a decisive role in understanding the drastic drop in calls during the first PS presence in 2019. The linegraph highlights the data gap, not shown in the piechart, in the timeframe 4 pm - 12 pm of January 13 -15. Only the non-masked calls of 13 h instead of in total 57 h could be counted (less than one quarter), which is most likely the reason for the significant drop in calls during first PS presence.
Regarding the linegraph, the calls in 2019 all end in the respective horizontal call type lines, which were established to indicate that the calls exceed a defined number (see explanation Methodology 3.5 Raven Pro Analysis of Sighting Data). During V&A between the two docking times, the calls resume and the rest of the half day with PS presence seems to have little effect on call behavior. The number of individual call types prior to PS presence is very similar to that after the ship's departure. Only the M declines something from 19 January onwards. Considering the few remaining hours after the data gap, as well as the call behavior during the short second PS presence, and at the same time considering that the RS are either in or very close to their call peak, one could conclude that the first period without lack of data would be similar or at least show a certain number of calls. If one considers this probability again in comparison to the previous years and their call activity during PS presence, one can rather assume masking is the reason for the decrease in calls during PS presence instead of call ceasing from the RS. This statement is also supported by the overviews of the spectrogram sections in the appendix (see B 12 – B 20 Overview spectrogram screens from 2013/2014 – 2019).

Despite a first impression of no calls during the PS presence in 2013/2014, the data behind the linegraph as well as the piechart reveal that there are indeed some calls at the very first/last hours of the arrival/departure of PS. As already mentioned in the interpretation of the LS linegraph, the year 2013/2014 is a particularly noise-intensive one, which means that the RS calls are either masked or the animals pause/reduce their calls due to the noise (the overall picture rather indicates masking). One reason for the particularly loud ship noise may be all four engines in operation. With the short stay of only two days, it is probably a shelf-ice discharge (“Schelfeisentladung”), in which all engines are usually on to keep the ship in place. In addition (see B 11 - Appendix) the PS may have chosen a parking position near PALAOA due to the presence of heavy ice. The proximity of the ship to the hydrophone could be a reason for the almost completely black coloring of the spectrogram (see B 19 – Appendix).

In 2018, on the other hand, it almost seems as if the animals are hardly disturbed by the ship's noise. Calls are visible during the whole PS presence, even if they are reduced according to the end of the season. The noise emitted by PS this year is spectrographically (see B 16 – Appendix) rather quiet and not nearly as loud as in 2013/2014, which may be due to the prevailing ice conditions (less ice to break through) or to the fact that PS is docked a little further away.

5.3 Summary of interpretation and implications

Generally and independently of the call activity level of both seal species at the time of PS arrival, the call behavior always decreased strongly and abruptly as soon as the vessel arrived to supply NS. After departure of the ship, the call behavior of the seals developed differently and seems to depend mostly on the timing of the event within the breeding period of each species (i.e., early, middle, late). For both species, it can be assumed that the associated sharp decline in calls during PS arrival is mainly due to (partly strong) masking. However, it cannot be excluded that seals at least partially reduced their calls. It seems unlikely that the animals left the area, given that the calls immediately rise again as soon as PS has left. Calls at lower frequencies tended to decrease during ship presence, while calls at higher frequencies were used more often by both species or were more likely to be detected during analysis. Regarding the LS, it seems the animals keep increasing their calling rate post PS in order to compensate for the disturbance. Whether the increase in calls already occurs during the presence of the ship is not evident from the investigation, but could also be true. In the case of the RS, this statement cannot be made so easily, as the fully available years are three different timings in the breeding period of the animals with corresponding calling behavior. The most important time for seals to become vocally active is the mating season. Based on this study, it seems that the animals are generally not deterred by PS. Once they have started their mating calls, they seem to continue regardless of PS presence. The assumption that the presence of PS influences the length of the call period is difficult to interpret within the existing data, as the difference is sometimes only a few days. The range over which animals can reach potential mating partners may be severely reduced during the period that the ship is present. Both species are thought to be solitary species that do not live gregarious lives or occur in groups. Therefore calling represents a crucial behavior for single receptive animals to find each other for mating. The area

over which the ship is acoustically present might cover a large part of the area where animals search and call for potential mating partners. This may affect the likelihood of encountering mates. Furthermore, calls may form an important feature by which individuals select mating partners (both sexes produce calls in both species). It cannot be excluded that the ship noise affects acoustic characteristics of the call that are used for mate selection.
This problem can lead to the selection of less valuable mating partners, located in vicinity and whose calls are therefore more audible. Without the noise there might have been a more qualitative mating partners chosen (from a bigger area). Therefore, there is the danger of lower breeding success (e.g. mothers less caring/attentive to pups) in case of a second choice mating partner. (Read et al., 2013; as retrieved from Halfwerk et al., 2011;). ´Lost opportunities` are not only related to reproductivity, but also to predator risk/avoidance. The costs of higher consumed energy (e.g. moving away, increased calling rates) and stress might be substantial. In addititon, the extent of the disturbance and the life phase in which the animal is affected play a role (e.g. animals during/after migration and fasting are much more vulnerable than in/after the feeding season). (Tyack, 2008)
Ultimately, it is not only a question of whether the animals are masked, stop calling or leave the area (short-term effects), but also the hidden effects, which rather become visible affecting entire populations in the long-term. (Read et al., 2013; Tyack, 2008)

5.4 Compensation mechanisms

The acoustic adaptation hypothesis (Morton, 1975) claims that in order to expand the effectiveness to transmit acoustic signals, marine species can (to a certain extent) adapt acoustically to the soundscape of their habitat. An example among birds are great tits *(Parus major),* increasing their frequency to overcome the masking of city noise (Slabbekoorn & Peet, 2003). Animals can develop different types of compensation mechanisms (Farina, 2017; as retrieved from (Morton, 1975). Potential mechanisms for increasing the detectability of signals include waiting to call until noise decreases, increasing the rate of calling, increasing signal intensity, increasing signal duration, and shifting signal frequency outside of the noise band (Tyack, 2008).

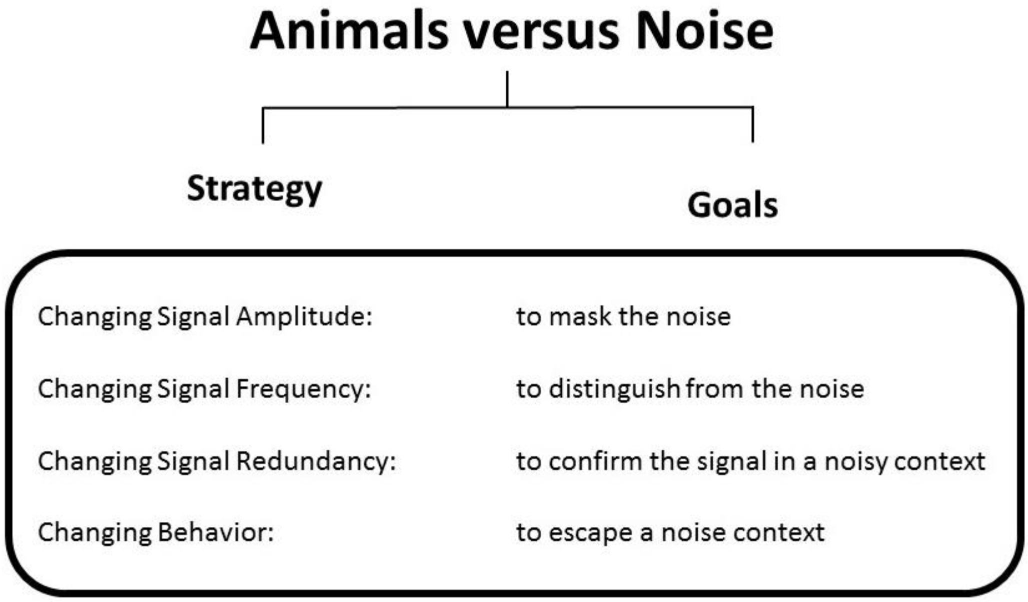


Figure 13 Overview of different adaptation procedures developed from animals to handle noise. *Source: Farina, (2017).*

In order to avoid interference with other signals, timing matters. One of the easiest compensation mechanisms is to wait until the noise stops or decreases at least. Instead of that however, the sending animal could as well and if capable adjust the call structure and stand out more against the interfering noise. (Tyack, 2008)

A further option would be to increase signal redundancy. This means that the acoustic limit resulting of noise in the environment is attempted to be circumvented. The animal affected by that can rise the signal redundancy (Farina, 2017; as retrieved from Wiley, 1994). Furthermore, it was observed on killer whales (*Orcinus orca*) that they lengthen their calls at the increasing presence of ships (Tyack, 2008; as retrieved from Foote et al., 2004). Regarding phocids, Turnbull & Terhune, (1993) found out that harbor seals (*Phoca vitulina*) are capable of sensing instead of a single call, sequences of calls at a minor signal-to-noise ratio (Tyack, 2008; as retrieved from Turnbull & Terhune, 1993).

The Lombard effect (Lombard, 1911) is a suitable example for another compensation mechanism: a change in amplitude respectively signal intensity (Farina, 2017; as retrieved from Lombard, 1911). Killer whales increase their call amplitude by 1 dB when the surrounding noise increases for 1 dB (Farina, 2017; as retrieved from Holt et al., 2009). (Also Beluga whales (*Delphinapterus leucas* – Scheifele et al., 2005) and manatees (*Trichechus manatus* – Miksis-Olds, 2006) are known to rise the source level of their vocalizations when they are surrounded by increasing shipping noise(Tyack, 2008; as retrieved from Holt et al., 2009 and Miksis-Olds, 2006).

Some animals have the capability to change the frequency range of a vocalization which helps them to avoid interfering with signals in the same frequency band. This strategy is called jamming-avoidance response (Tyack, 2008; as retrieved from Ulanovsky et al., 2004), and has also been observed to occur in animals inhabiting areas that are dominated by human-made noise (Slabbekoorn & Peet, 2003).
A change in frequency is also observed in species that live in proximity of natural sources of continuous loud sound. Those animals produce sounds at frequencies much higher in comparison to the ones in an environment with less permanent noise (Tyack, 2008). Weddell seals (*Leptonychotes weddellii*) attempt to avoid jamming by dividing the pitch of their vocalizations (Tyack, 2008; as retrieved from Terhune, 1999). Beluga whales for example rise the frequency of vocalizations when low frequency ship noise is present (Tyack, 2008; as retrieved from Lesage et al., 1999).
Regarding the shift in behavior, irregular occurring noise sources in space and time are very problematic. As a result, individuals/species can show a reduction in overall activity.
An example are Caribbean hermit crabs (*Coenobita clypeatus*). Predators can approach easier when there is boat noise around the crabs (predatory risk due to ambient noise) (Farina, 2017; as retrieved from (Chan et al., 2010).

However, the various forms of acoustic adaptation may come at a cost, for example when it affects communication efficiency or is energetically more costly (e.g. increasing call rates) (Farina, 2017; Read et al., 2013; Tyack, 2008). Furthermore, animals are limited in their plasticity and in many of the current acoustic environments dominated by human-made sound, species cannot easily adapt (Farina, 2017).

It has to be kept in mind that even if marine mammals are now confronted with additional anthropogenic sound sources, the ocean has never been a silent place. Marine mammals were always facing different natural noise sources, which they had to adapt to when communicating through sound (Tyack, 2008). In the polar regions, ice is an additional factor, producing a range of sounds which can dominate the soundscape for extended periods. Some can be very loud and noisy, such as breaking ice or colliding icebergs (Menze et al., 2017). The ability of animals to cope with noise in their environment is thought to depend on the species and their sensitivity and if noise occurs with a certain regularity or is predictable (de Villiers, (2008).

To understand and interpret the results of this study, it is important to be aware of the compensation mechanisms marine mammals have developed, to overcome noise respectively to circumvent negative impacts. Ship noise is a continuous sound source, covering a wide range of frequency bands (see Figure 12) which allows no or few gaps for communication between animals. Given the density and omnipresence of this sound source, ship noise is believed to be one of the most significant human made noise sources affecting various aspects of marine mammal acoustic communication Tyack, (2008). Active adaptation from the human side may therefore be key to significantly improve the quality of underwater acoustic habitats. Marine soundscape planning may form a first step in this process.

5.5 Marine Soundscape Planning

In order to better control the effects of underwater noise in general, Van Opzeeland and Boebel (2018) proposed the concept of "Marine Soundscape Planning" (MSP).

MSP is a general approach to harmonize the sounds of the marine environment, especially the one of aquatic living species and anthropogenic sound in the ocean. If both sources operate at the same time, area and/or at similar frequency ranges, it may result in interference for both sides. For animals this means that their communication channels are disturbed, potentially affecting fitness on individual and population level. For hydroacoustic instruments that rely on good quality signals for measurements interference may result in low quality data. The goal of MSP is to reduce the mutual interference of acoustics between hydroacoustic instruments and marine mammals. (Van Opzeeland & Boebel, 2018) Marine soundscape planning is closely linked to Krause`s (1993) “acoustic niche hypothesis”, which explains that sounds of biological origin are like single pieces of a puzzle (Van Opzeeland & Boebel, 2018; as retrieved from Krause, 1993). When set all together, they form a natural acoustic environment (biophony). In order to coexist, the animals share an acoustic space, split up in time and frequency to avoid overlap. The key word is “acoustic partitioning” of the environment which requires to allocate the resources “time, space, frequency and signal structure”. Signal structure refers to the composition of both spectral and temporal signal features. Through a human-mediated active avoidance of overlap between anthropogenic and animal communication sounds, MSP could offer a strategy to reduce potential acoustic overlap and interference, thereby improving soundscape quality for all users (Van Opzeeland and Boebel, 2018, p. 3). The approach of MSP aims to support the management of sound distribution and to design in an active way the sound contributing to the acoustic environment. Although in the case of ship noise there is no dependence on the acoustic environment for measurements, the MSP concept can likewise be applied to attempt to identify where overlap occurs and if acoustic partitioning can help improve soundscape quality.

5.5.1 MSP in Atka Bay

Van Opzeeland and Boebel (2018) mainly dealt with instruments, emitting discontinuous noise that can be controlled in a targeted manner. In the case of continuous ship noise, some of the possibilities to balance both animal communication and anthropogenic noise are difficult and some MSP strategies cannot be applied. Ships block not only a certain band with their continuous noise, but rather block the whole bandwidth. If seals increased the frequency of their calls or changed the signal structure as an attempt to improve communication, it would not help the signal stand out. For ship noise, only the spatial and temporal possibilities can be exploited to apply the MSP concept.

With respect to the case study of this thesis, the spatial factor is also omitted, since there is no other way to supply the Neumayer research station with sufficient goods once a year. Nearby docking possibilities (B 5 Appendix) are still within the area with high pinniped acoustic activity and therefore are unlikely to contribute to separating the sources.

Therefore, only the time factor remains ultimately applicable. The timeframe for PS is limited to austral summer, when the light and ice conditions allow to reach Atka Bay by ship. In 2010 and 2011, the RS strongly seem to delay their arrival in Atka Bay due to the noise of PS and its presence. However, if the RS arrived prior to the icebreaker, they appear not to be disturbed or affected in their calling behavior by PS. Since the evaluation of the data allows only speculation in this respect, it is not possible to determine exactly what effects the ship noise has (masking) during the mating season, which is particularly important for the animals. Therefore, for both LS and RS it can be recommended that the later (preferably after the mating season) the PS appears in Atka Bay, the better for both species. The best time would be at the end of January, as is the case in 2018, when LS have already left and RS calling activity is already decreasing rapidly.
It is known that the research icebreaker PS is an extremely noisy ship. Expedition cruise ships are comparatively silent. Looking at the spectrograms in the individual years of analysis, a variability in the volume of PS in its parking position can be observed. In order to supply the NS, the PS has two possibilities for unloading goods, which depend on the prevailing ice conditions. One, the sea ice discharge ("Meereisentladung"), is very quiet, and is only possible in combination with a shelf ice discharge ("Schelfeisentladung") which is very loud or a pure shelf ice discharge. During sea ice discharge, the vessel is attached to the ice allowing the machine power to be reduced to a minimum or shut down completely. However, this is not always possible and some goods still requires the shelf ice discharge. During shelf ice unloading, the engines are permanently in operation, keeping the ship against the ice shelf during the unloading period. These discharge options have therefore

an influence on the noise level of the ship during its visit in the bay (Westphal, personal communication, March 21, 2020) Therefore, the sea ice discharge should be carried out whenever possible and the shelf ice discharge should be reduced to a minimum.

5.5.2 MSP in the Western Antarctic Peninsula region

Regarding the Peninsula, which from a touristic point of view is the most visited region in Antarctica, both spatial and temporal factors can be applied. The expedition cruise ships are limited to the austral summer period, which take turns to visit the most popular destinations mainly between November and March (IAATO, 2018).

According to Meister (2017), LS calling around Elephant Island, one of the northernmost islands of the Antarctic Peninsula, occurs from August to January, with peak calling in December (Meister, 2017). With respect to spatial separation of sources, areas that are known to be used during mating by pinnipeds should not be visited during this and a certain period before. The aim is not only to avoid disturbing the animals during their calling period, but also to avoid possible delaying tactics regarding their arrival (as potentially happened to RS with PS 2010 and 2011). From the operator perspective, timing visits during the time that animals are more likely to haul out on the ice would potentially offer an attractive trade. Aquatic mating pinnipeds, such as RS and LS, are mainly in the water during the mating season and are therefore rarely sighted on the ice during this period.

The most promising time for expedition participants to observe seals is either during the breeding season (which precedes the mating season) when the seals raise their pups or during the time of moulting (following the mating season) (see Figure 14 below).

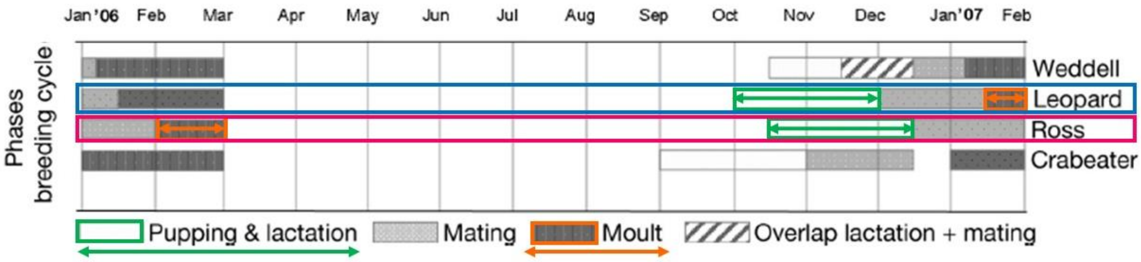


***Figure 14 Recommended visitation time for LS and RS**. The best visitor time to observe both species is during moulting (marked in orange), which occurs for LS between mid-January until mid-February and for RS between February and March. During pupping and lactation (marked in green) the LS are seen hauled-out between October and November and the RS between mid-October until mid-December. However, mother and pups could be disturbed from vessels. Adapted from Van Opzeeland et al., (2010).*

Obviously, the breeding season when dependent pups are present, however, exposes an increased risk of disturbing the seals in their search for food for their young or frightening the young by other activities such as zodiac tours. Therefore, the moulting period seems to be the best time for both animals and their observers. In order to establish further guidelines for the protection of seals, more detailed scientific research is needed, for example on the exact distribution of the animals at certain times of the year and mating sites.

The speed of a ship can be another decisive factor. A clear example is the ship noise humpback whales were exposed to in Glacier Bay National Park, Alaska. There, the vessel noise was measured at different speeds. It turned out that cruise ships are one of the main noise sources there. Ships at higher speeds contributed to a higher noise level than slower moving ships. Cruise ships travelling at 20 knots had noise levels three times higher than those travelling at 13 knots, and further reduction of speed contributed even more to noise reduction (see Figure 15 showing similar results with different speed). (Frankel & Gabriele, 2017) Speed limits for ships, especially in areas often frequented by animals, can therefore be extremely useful and contribute significantly to reducing ship noise. (Frankel & Gabriele, 2017)

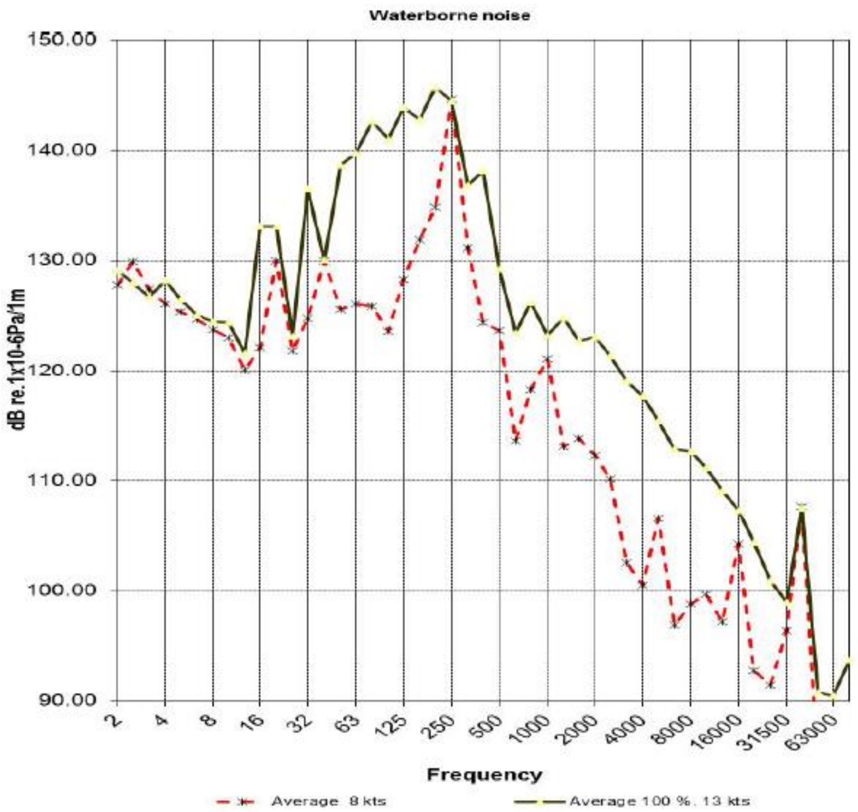


Figure 15 Ship noise emissions at different speed. *While at 8 kt machinery is responsible for most of the noise, it is the propeller tip vortex cavitation at 13 kt. Source: Abrahamsen (2012).*

Disturbance is very unlikely to be completely avoided, but with the approach of MSP it could at least be reduced. To reduce ship noise in general, ship quieting techniques (see elaborated information in Appendix A 2) are another useful tool that should be used. Ultimately, the problem with noise is that it cannot be limited simply by any boundaries (Farina, 2014b).

5.6 Effective regulation of activity

Even if the regulation achievements of ATS and IAATO sound quite convincing, there is criticism as well. Since no single state has sovereignty over Antarctica and can therefore decide on it, the individual parties must find consensus to make decisions and implement them, which is an extremely time consuming process.

Many critics see the biggest problem of the ATS in its vague definitions and the way the rules adopted in the ATCMs are implemented in the field. This means that regulations agreed within the ATS must be converted into national law by the individual member countries in order to be applied. For the Environmental Protocol in particular this took place via the Act Implementing the Protocol on Environmental Protection to the Antarctic Treaty (AIEP) (Erbe et al., 2019).

The procedure entails that these laws are only valid for the citizens of the respective country. In addition, this method of application leaves room for interpretation of the rules, which may vary therefore in stringency from one-member state to another. (Bastmeijer, 2003; UBa, 2013)

In Germany, for example, the "Umweltbundesamt" (Uba) is the responsible authority for German affairs in the Antarctic and belongs to the countries with strictest implementations (Erbe et al., 2019). All activities (research, tourism, etc) in Antarctica emanating from Germany (i.e. under German flag), must first be thoroughly evaluated for possible negative effects before a permit is granted (UBa, 2016a). The ATS implementation procedure leaves (too) much room for interpretation and give individual countries (too) much flexibility for implementation in national legislation. The decisions are therefore unequal and consistency among the countries is lacking (Tin et al., 2014). Moreover, some countries delayed in signing the Protocol and some non-consultative parties still have not signed it at all (e.g. Denmark, Austria, Swiss) (Amelung & Lamers, 2014; ATS, (2020b). Liggett et al. (2017) describes the decision making process of the ATS as “the low-hanging fruit are readily grasped, while tough questions around sovereignty, presence in Antarctica or even climate change may only be touched on during ATCMs without consensus being reached.” (Liggett et al., 2017, p.462) The EIA (Annex I) in the Environmental Protocol is also seen critically, as EIA focuses more on individual activities and is therefore not considered to be sufficient in order to identify the cumulative impacts (= accumulation and in parallel addition of activities, triggered by man and/or nature in an area), which might arise of the many and diverse activities. In general, sensitive areas which are of interest to tour operators are more prone to be damaged than similarly sensitive ones which are more difficult to access and are therefore not (so often) visited. It is basically an interplay of sites of special use and interest for tourists and, at the same time, the natural environment which is particularly sensitive at these sites, making them particularly vulnerable to cumulative effects. An important keyword regarding the EIA is "minor and transitory" (ATS, 1991), which refers to possible impacts of planned activities. They can be less than, no more than or more than "minor and transitory". As the presumed severity of the effects increases, detailed procedures and investigations must be carried out in advance to systematically assess the effects. However, the ATS leaves much room for interpretation as to what is required for assessments. Many impacts that are not yet fully understood or have not been studied/monitored long enough may be misclassified due to this lax terminology or extrapolated to other areas where the ecological situation may be different, as it could be the case for shipping noise. This can have extensive consequences, as can the assessment of a risk that is considered to be very low but then occurs, which cannot be sufficiently analyzed by the EIA. In addition, most EIAs carried out for tourism usually focus on one or a few seasons, but not on the growing tourism sector in general, which will lead to a partly constant flow of visitors for the foreseeable future. (Bastmeijer & Roura, 2004)

In order to detect the impacts resulting from (ship-based) tourism, extensive monitoring programs and long-term studies are necessary, which are not yet in place (Haase et al., 2009; Tin et al., 2009). Due to the relatively recent advances in the availability of affordable remote sensing instruments (such as PAM), the logistic and financial costs of such monitoring programs can be drastically reduced and cover vast areas. In case any changes are detected, long term records will make it possible to analyze if these are a result of a natural fluctuations or potential consequences of human activity (Tin et al., 2009). In addition, predicted impacts are hardly ever investigated further (Bastmeijer & Roura, 2004; Tin et al., 2009).

While the ATS had for certain other issues like fishing or mining very strict regulations in place, the ATCMs have failed to create those for tourism (Amelung & Lamers, 2005). In relation to tourism is the ATS therefore accused to be a “laissez-faire approach” (Verbitsky, 2013, p.281) or a “weak” system” (Amelung & Lamers, 2014, p.134), which is too slow to handle the fast developing tourism industry (Bastmeijer & Roura, 2004).

Verbitsky (2015) points out that even if measures and arrangements have been made with regard to tourism, this “skeletal tourism policy” is not sufficient to manage tourism successfully (Verbitsky, 2015, p. 312). Tourism developments are difficult to undo once they have started, hence time is an important factor and measurements should be taken now. Instead of being proactive, many tourism regulations were discussed and raised only when it was time to act or afterwards. In addition, focus was rather on individual incidents than targeted areas. Furthermore, the regulations made by ATS and their implementation are difficult to control in practice. (Bastmeijer, 2003; Bastmeijer & Roura, 2004)

Moreover, many tourism measures are not legally binding (Haase et al., 2009; Amelung & Lamers, 2014). Critical voices point out clearly that the ATS has lost its leading position in this area due to the disagreement of its Treaty Parties and the rather loose attitude towards

the management of tourism (Liggett et al., 2017). There is also indication that institutions and organizations are increasingly moving towards independence (Liggett et al., 2017).
IAATO has gained a good reputation over the years not only in the industry itself but also within the ATS through its constant proactive behavior in the development of new and the compilation of existing regulations and guidelines for tourism (Amelung & Lamers, 2014; Verbitsky, 2015). Nevertheless, the development of self-regulation is questionable (Amelung & Lamers, 2005) and critics suspect that it can only be continued to a certain extent in the future. At the end, IAATO members are still profit-oriented companies. They are assumed to follow the IAATO guidelines only as long as it is of business benefit (Amelung & Lamers, 2005). For example, the regulation of only one ship per bay helps to maintain the exclusivity of the location, which would get lost, if there were several ships. However, with the growing number of members from various countries and with different ideas, interests are also becoming more and more diverse (Haase et al., 2009). In addition there are recommendations which can be followed on a voluntary basis from both tour operator and visitor site (Verbitsky, 2015). However, with the growing number of members from different countries and with different ideas, interests are also becoming more and more diverse. This raises the question of whether the organization will continue to manage to balance all interests in the future (Amelung & Lamers, 2005).
The International Union for Conversation of Nature (ICUN), for example, called already 1992 for controls and strict monitoring, as commercial activities such as tourism take place on a huge range involving many people, which can cause local disturbance and other impacts (Hall & Saarinen, 2010; as retrieved from IUCN, 1992) . In order to maintain and expand the protection and conservation of Antarctica, scientists need to share their latest findings and work together with responsible decision-makers. This way, any uncertainties can be discussed transparently and thus reduced in order to make effective choices (Hughes 2018). An appropriate example is the impact of anthropogenic noise on marine mammals, which requires targeted research to find practical proposals for its future management (Tin et al., 2009). To date, not all effects of human presence in Antarctica are known, nor have they been studied in detail. Many human impact studies focus on specific locations and/or specific disciplines on a rather small scope. The big picture is relatively difficult to analyze and is therefore rarely performed, making it extremely hard not only to get an overall view of human impacts on Antarctica but also to become aware of the effectiveness of comprehensive approaches. (Tin et al 2009 p.24f) The one and only perfect solution to prevent wildlife disturbance and to bring human activities into a healthy balance with nature does not exist. Whether the disturbance of marine mammals has a lasting negative impact on the animals in the long-term is difficult to answer in a generalized way, since the effects do not only depend on the activity and the location, but can also vary greatly

among the different species. (de Villiers, 2008) A promising approach could be the precautionary principle[1], according to (Bastmeijer & Roura, 2004). Applied to tourism, it aims to improve the application of EIA and the process of cumulative impact assessment before the start of an activity. Instead of trusting that activities will be carried out properly, certain activities should be proactively regulated in time and space according to the respective location. Up to now, Antarctica has been available to tourism almost without limit, except for a few protected areas (Bastmeijer & Roura, 2004). The precautionary principle provides some arguments for the total shutdown of tourism in the Antarctic region. However, the precautionary principle is not intended to be an approach consisting of prohibitions. If so, it would prevent further important research useful to better understand the possible effects of tourism activities. The precautionary principle can be better applied through more targeted methods. This includes for example, a targeted and controlled accumulation of tourists at locations previously used for tourism and particularly suitable for this purpose (controlled monitoring possible, minimum impacts), instead of continued development of new routes to unvisited places invading untouched environment and wildlife. (Bastmeijer & Roura, 2004)

[1] Proactive approach to prevent possible hazards resulting from activities whose effects are uncertain/not yet sufficiently known, before they cause damage. The precautionary principle is not intended to create any absolute bans, but to assess uncertainties (knowledge gaps and risks) and treat them accordingly. (Bastmeijer & Roura, 2004; Fennell & Ebert, 2004)

6. Limitations and future research

The heterogeneity of data in terms of arrival and landing times of PS, and of different life phases of seals offered interesting different scenarios to look at, but at the same time posed major difficulties in interpreting results. A much greater sample size of all scenarios would have helped in drawing more sound conclusions.

In addition, calls were only evaluated if they were both visible and audible, which was not always the case. Especially during PS presence there were calls that were still slightly visible but no longer audible. A less conservative approach could help in understanding seal vocal behavior.

The comparison of the annually varying arrival times of the seals with the local ice conditions and their noise emissions could clarify the questions of premature arrival times of the LS between 2010/2011 and 2013/2014 , the delayed arrival between 2013/2014 and 2018/2019 and why the RS arrive slightly earlier each year. The assumption is that this behavior is an indication of changing ice conditions or food availability. The noise of the ice plays an important role, since much of the natural noise is caused by breaking or friction, which in its volume can affect the communication of the animals. The composition of ice can reduce the transmission of signals (a lot of ice) or ensure their further spread (little ice). Analysis of natural noise were beyond the scope of the bachelor thesis, however future research could include this relevant point as well as the signal-to-noise ratio (SNR) to compare PS noise with seal calls.

Signal-to-noise ratio (SNR)

SNR is the alteration of both signal level (dB) and noise level (dB) (Erbe et al., 2016, p.16)

“ []masking depends on the spectral characteristics of both signal and noise at the receiver. At a low signal-to-noise ratio, the signal might merely be detectable but not recognizable. A higher signal-to-noise ratio is needed for the animal to recognizes or discriminate the signal []”. (Erbe et al., 2018, p. 291)

7. Conclusion

Despite the complexity of the ATS, members should feel more responsible for adopting and implementing regulations for the protection and maintenance of the polar region of Antarctica, jointly and above all uniformly. Even if the interaction between IAATO and ATS has been relatively successful so far, it should ultimately not be based on the voluntary participation of profit-oriented companies. It requires extensive research to determine in detail the effects of human activity in order to take countermeasures. Above all, tourism, which is ultimately nothing more than a leisure activity, should be particularly strongly regulated. As in MSP mentioned, in places with a particularly sensitive environment, it is necessary to extend protected zones with a general ban on visits in order to avoid disturbances. In addition, more time restrictions should be imposed on certain areas, for example important breeding or reproduction sites for animals.

Moreover, (long-term) monitoring plays a very important role. Long-term data collection and analysis of prevailing local ice concentrations is necessary. It can be used to determine direct effects on the behavior of the seals. Also indirect effects, such as the changing distribution of food sources which in turn are dependent on the ice concentration, can be related to the behavior of the seals and thus possible future trends may be derived.

The monitoring of ship noise is necessary on a large scale to gain knowledge over the propagation of noise. (Pavan, 2017) p. 249). Furthermore, there is the need to change shipping routes passing along or cross biologically particularly sensitive areas (breeding and feeding grounds, migratory areas). Expedition tourism in the polar regions is booming, not least due to "last chance" marketing measures. Liggett et al., (2017) expects polar tourism to peak in 2030, followed by a drop in visitor numbers, due to the fact that polar regions are relatively difficult to reinvent[2] (Tourism area life cycle from Butler, (1980)). However, one should not only hope for a natural decline of tourism in the polar regions, but actively introduce regulations to curb the tourism boom in these regions. Especially because there are 41 new expedition cruise ships in delivery between 2019 and 2023 (Monty, 2019). Whether the forecast for 2030 (Liggett et al., 2017) is correct is therefore questionable. One option to counteract this boom would be to limit the number of ships allowed to travel to the polar regions for tourism purposes. In addition, more stringent investigations should be carried out into the possibilities of improving ship noise levels (via ship quietening techniques) and, if these exist, they should be made compulsory. Noisy old ships could thus be made quieter or should be replaced instead of additional new ships. Instead of "last chance tourism",

[2] According to Butler (1980), tourism destinations undergo (7) different phases (Exploration, Involvement, Development, Consolidation, Stagnation, Decline or Rejuvenation). In short: After the destination has been discovered, its visitors increase steady in numbers. The infrastructure develops further among the growing number of visitors. At a certain point the destination reaches its visitor peak and interest in visiting it declines. Fewer and fewer visitors come, unless the destination reinvents itself (e.g. through new attractions).

polar tourism should be marketed based on a sustainable principle. Sustainability is a difficult issue with regard to these remote regions. Above-average CO_2 emissions[3] are already generated during the journey to and from the destination, which are caused by the very long travel times, mostly originating from the northern hemisphere are therefore anything but sustainable.

Therefore, assessing all possible negative effects of a trip should be considered before the booking takes place. On the other hand, obligatory "compensation surcharges", as they are currently known on a voluntary basis when booking a flight, should be imposed. These could, for example, flow into further research in the polar regions. The associated rising costs for the customer should not be an obstacle, as the prices in expedition tourism are already extremely high and this extraordinary travel pleasure is thus almost exclusively taken up by a wealthier upper class. In addition, scientists should be more extensively involved in the sustainability concept on board. Even if there are considerable doubts about the functionality of the principle of ´ambassadorship`(Eijgelaar et al., 2010) and the participants of such an expedition cruise are already comparatively well educated people, sustainability should be a priority during each of these voyages. For this reason, critical lectures should also be offered that shed light on the effects of human presence in Antarctica in all its facets. The customer has an important role to play in the development towards greater sustainability. The more the customer values sustainability and pays for it, the more the suppliers are forced to become even more sustainable. Guests who have already taken part in such a sustainability-oriented voyage and enjoyed the value of such a cruise will recommend this type of product further to family and friends. Ultimately, however, one can only urge people's common sense not to get tempted to go on such a trip. The argument that you can only protect what you have experienced yourself no longer counts nowadays. In our media dominated world, there are abundantly of other opportunities to get to know the polar regions extensively and, above all, in a sustainable way. Not only Antarctica would benefit from this, but our entire environment. Ultimately, Antarctica is a place that is not meant for human existence and should remain largely untouched by human activities.

[3] 6.3 t CO_2 are calculated to be produced per passenger during an Antarctic cruise. In comparison, an average European produces the same amount of CO_2 as a cruise passenger in one year (Eijgelaar et al., 2010; as retrieved from Amelung & Lamers, (2007)) (see *Antarctic cruise tourism: The paradoxes of ambassadorship, "last chance tourism" and greenhouse gas emissions*).

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Appendix

A Background information

A 1 Impacts of Tourism

A 1.1 Non-native species

A major concern is the introduction of non-native species (Tin et al. 2009 ; Kariminia et al. 2013; Woehler et al. 2014; Hughes et al. 2020). Alien species can be transported via aircraft or vessel. Construction equipment, vehicles, food and even clothing can contain dangerous non-indigenous alien species likes plants (e.g. seeds) and animals (e.g. bacteria, vertebrates, etc.) (Tin et al., 2009). Also, ballast water and hull fouling can form significant vectors for the introduction of non-native species into the Antarctic regions (Tin et al. 2014; as retrieved from SCAR 2007). Due to the remoteness of the continent, the appearance of alien species has larger effects, as the local flora and fauna (both terrestrial and marine) is not used to compete with other species (Tin et al., 2009; Woehler et al., 2014).

A 1.2 Habitat destruction

Human activities on shore can destroy or transform habitat through trampling, the use of vehicles or infrastructure construction (e.g. landing stripes for aircrafts). Moreover, certain means of transport (incl. boats) can disturb the animals by their noise emissions (Tin et al., 2009). Especially animals living or breeding in frequently visited areas are exposed to increased human disturbance. This can lead to stress and changes in natural behavior like leaving breeding areas/pups behind (de Villiers, 2008). Transit paths of animals can be interrupted by visitors, leading to prolonged time in finding food and longer waiting times for offspring to get fed. Furthermore, some animals prolong foraging trips to avoid visitors (de Villiers, 2008). This can lead animals to spend more energy and potentially may affect individual and eventually population fitness.

A 1.3 Pollution

A further concern is the contamination of land through garbage, sewage, fuel and oil spills, mostly close to shore. Whalers already started to pollute by leaving their constructions and equipment behind. The construction of research stations also contributed to early pollution of Antarctic areas, when awareness about contamination was little. Nowadays many research stations welcome visitors, leading to additional waste. (Tin et al., 2014).

Cruise ships contribute to all of three impacts listed above.

Cruise vessels produce enormous amounts of litter, black- and grey-water, food waste and so on, which could end up in the water (Kariminia et al., 2013). Moreover, the disposal of chemicals, ship painting, oils and fuel from engine leaks or through thoughtless handling is a matter of concern (Kariminia et al., 2013; as retrieved from Davies & Cahill, 2000). Most detrimental are ship accidents (e.g. sinking of MS Explorer 2007). Especially dangerous are bigger vessels, which could ground, collide with ice or lead to pollution of the water

(Kariminia et al., 2013). A different type of pollution that can affect the lives of marine creatures in many different ways is the underwater noise produced by ships (e.g. Boebel et al., 2018).

A 2 Ship Quieting Technologies

To reduce ship noise and the associated short and long-term effects on the acoustic environment, so-called ship quieting technologies are available. The Marine Environment Protection Committee (MEPC), which is subject to the International Maritime Organization (IMO), has published the non-obligatory "Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life" (IMO, 2014). According to this, the best way to reduce ship noise is to build or plan new ships, but improvements can also be made on existing ships. The main sources of ship noise are: propellers, hull form, onboard machinery, and operational aspects (IMO, 2014). Particularly important for reducing noise is the proper adjustment of hull and propeller. Most of the noise is generated by propeller cavitation (see chapter 2.5 Ship Noise), which causes broadband noise by collapsing cavitation bubbles. Propellers should therefore be designed to reduce cavitation as much as possible, whereby the shape of the propeller plays an important role. Especially for ships that are designed to break through ice, the balance between quieting technologies and technical specifications such as ice-strengthened propellers is not easy. With regard to onboard machinery, measures to reduce vibration (e.g. vibration isolation of hydraulics and pumps), as well as optimized positioning of machines are extremely important. (IMO, 2014)

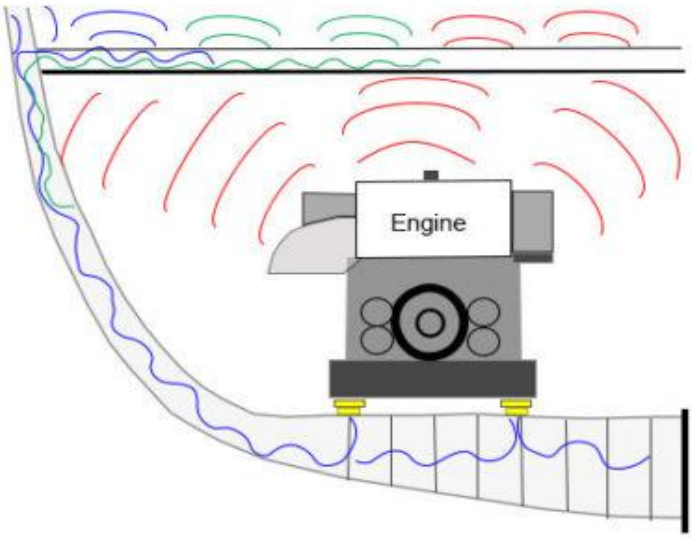

***Figure 16 Propagating noise of ship machinery**. Source: dosits.org (with permission from noise-control.com).*

Furthermore, the diesel-electric drive system has proven to be extremely low-noise (IMO, 2014). Maintenance measures provide a further option for reducing the noise emission of a ship. These include cleaning the propeller and hull to keep out bio-fouling, and hull coatings to reduce drag and turbulence, which in turn have a positive effect on the ship's noise level.

Finally, and most effective, is the reduction of ship speed, as mentioned already in the chapter Marine Soundscape Planning. As the MEPC points out: "Speed reductions or routing decisions to avoid sensitive marine areas including well-known habitats or migratory pathways when in transit will help to reduce adverse impacts on marine life." (IMO, 2014, p.6)

A 3 Passive Acoustic Methods

PAM plays a major role in species monitoring since daylight (austral winter), weather (fog) and accessibility (e.g. heavy ice conditions) have no impact in comparison to visual observations. Additionally, many marine mammals spend most of their time under water, which is a disadvantage for visual observations, but a big advantage and the basis for PAM. Rogers et al., (2005) carried out a joint-visual-acoustic survey on Antarctic pack-ice seals. Regarding Ross and leopard seals, the survey took place during the breeding season when the species are known to be generally highly vocally active. The result was that both species were much more detected acoustically than through visual observation (Cato et al., 2006). Apart from different systems with regard to the installation possibilities, the hydrophones are preferably placed in an array of three in order to better localize potential sources of sound and to cover greater areas. After the data recovery or transmission, spectrograms (e.g. with Raven Cornell Lab) can be established. These allow to differentiate between, and identify species according to sound (individual vocalizations) and a visualization of it (Pensieri & Bozzano, 2017). Time series emerge of which time-frequency analysis can be carried out. This gives in turn an insight about species represented in the monitored area (Pensieri & Bozzano, 2017). PAM creates therefore a better comprehension of marine mammals, their contribution to the marine ecosystem and displays negative impacts such as anthropogenic noise (Mellinger et al., 2007; Pensieri & Bozzano, 2017).

A 4 PALAOA

The autonomous listening station PALAOA (PerenniAL Acoustic Observatory in the Antarctic Ocean) is operated by the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven. This PAM station was built in 2005, at a distance of 15 km from the German Antarctic research station Neumayer, PALAOA is located on the Ekström Ice Shelf (70°31`S 8°13`W), which borders to the eastern Weddell Sea. Initially, PALAOA was set up 1 km away from the ice shelf edge, but because the ice shelf moves, it currently around 200m away from the edge. Holes were drilled through the 100 m thick ice, through which the four hydrophones were lowered into the 160 m deep water beneath. PALAOA was connected to Neumayer via a 13 km wireless connection, which in turn transmitted data in real time via satellite in a compressed data format. From December 2005 to January 2008, this set-up delivered a total of 10,000 recording hours. The overall aim of the recording station is to collect and evaluate acoustic data of biotic (e.g. seals, whales, fish, etc.) and abiotic (e.g. ice) origin, even at times when the area is difficult to access due to heavy ice conditions. In addition, the station serves as a mean to monitor the effect of human activity on the local acoustic environment. (Boebel et al., 2006)

A 5 Ross seal (Ommatophoca rossii)

***Figure 17 Ross seal** with its typical hauled-out posture. Source: Wikimedia Commons/NOAA, n.d..*

The Ross seal is the rarest and smallest Antarctic seal. Females tend to be slightly larger and heavier (1.96 and 2.6 m, ~186 kg) than males (1.65 and 2.08 m, ~ 173 kg). (Shirihai & Jarrett, 2006)

Ross seals are relatively easy to identify with their thick body and compact little head, especially with their typical haul-out posture of an upright neck and head with the small mouth mostly opened. Their coloration is dark brown, partly dark grey from the snout along the back towards the hind-flippers. Along the sides and ventrally the fur turns into a light silver grey. (Shirihai & Jarrett, 2006)
Ross seals are good divers, reaching depths of 200 to 500 m with diving times of up to 15 minutes (Blix and Nordoy, 2007). Blix and Nordoy (2007) measured even a maximal diving depth of 792 m and dive durations until 30 minutes. Typical prey consists of krill, migrating squid and mid-water fish (Blix & Nordøy, 2007; as retrieved from Skinner & Klages, 1994).
Ross seals have a circumpolar distribution in the Southern Ocean of Subantarctic and Antarctic waters until the Southern Antarctic Circumpolar Current Front (Ropert-Coudert et al.,

2014). Usually Ross seals live solitarily or at low densities, with exception of the mating season, which takes place during austral summer (November, December).
Ross seals are also known as the "Singing Seals" (Seibert, 2007; as retrieved from Thomas, 2002). They produce sounds not only underwater, but also on ice (Van Opzeeland, personal communication, May 3, 2020). Ross seals are particularly vocally active during the mating season, which represents their vocal climax (Van Opzeeland et al., 2010). The vocal repertoire is believed to be used in general by both sexes to attract mating partners (Van Opzeeland *et al.*, 2008; as retrieved from Van Parijs, 2003). Their vocalizations – so called “siren calls” (Van Opzeeland *et al.*, 2008) can be heard over long distances (Van Opzeeland et al., 2010).
During breeding time (mid-November until mid-January), the females remain steadily hauled-out for pupping and nursing (Van Opzeeland et al., 2010). When moulting (January and February) (Blix & Nordøy, 2007) takes place, it is assumed that the animals stay mostly hauled out and fast (Blix & Nordøy, 2007; as retrieved from Skinner & Klages, 1994).

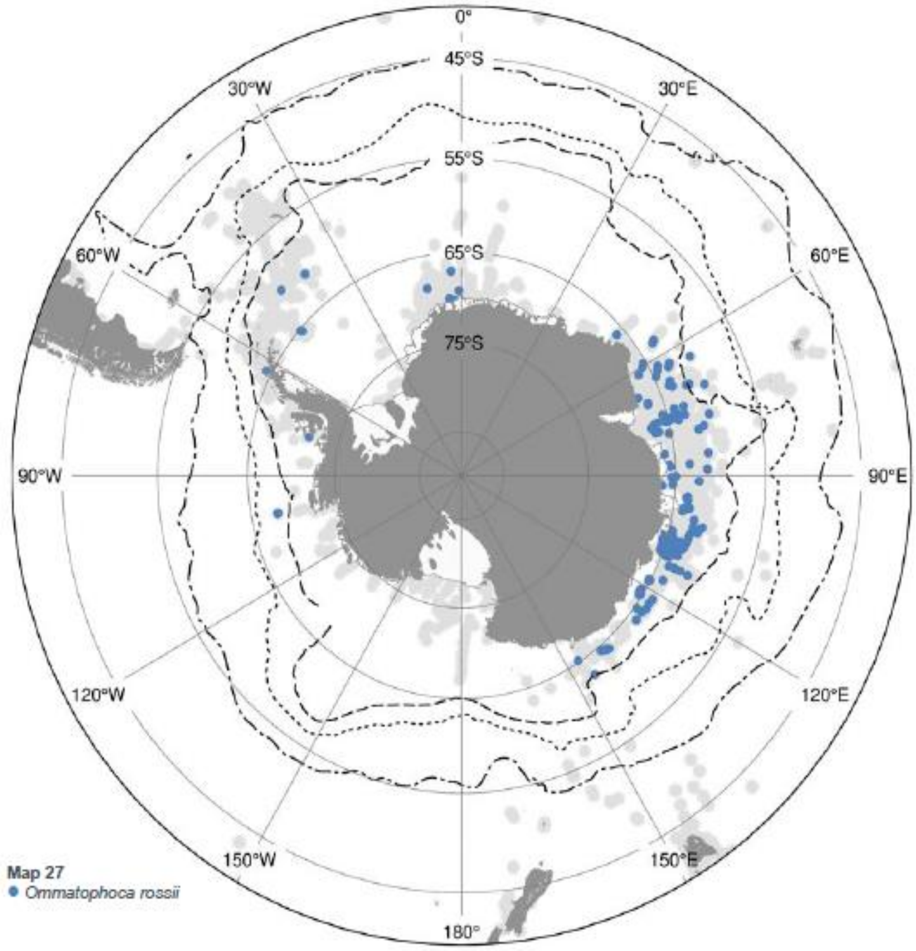

***Figure 18 Ross seal locations (dispersion and habitat) around Antarctica**, gathered particularly during observations, since tracking of this species is both difficult and complex. Following a clockwise direction, in the area between 150°E and 30°E sightings barely exist, although remarkable research attempts were carried out. The reason for the data lack is justified by monitoring techniques and the periods of time during which those observations were executed (Ropert-Coudert et al., 2014). Source: Ropert-Coudert et al. (2014).*

Apart from the summer time, the seals have a pelagic lifestyle, carrying out long foraging trips towards north and staying offshore during March until October (Blix & Nordøy, 2007). Distances up to 2000 km were reported (Blix & Nordøy, 2007) and single animals have even been sighted around some Subantarctic islands such as for example South Georgia Island, Heard and McDonald Islands and McDonald Islands (Hückstädt, 2018).

It is assumed that both killer whales (Orcinus orca) and leopard seals (Hydrurga leptonyx) belong to their predators. This species is less studied in comparison to other Antarctic pinnipeds given their favored haul out place is the pack ice, which is difficult to enter and due to their general low densities (Ropert-Coudert et al., 2014). In case of encounter, Ross seals show no fear of humans, although they show their typical head up posture (Hückstädt, 2018).

A 6 Leopard Seal (Hydrurga leptonyx)

The leopard seal is the second largest Antarctic seal species. Next to the orca, it is one of the top predators in Antarctica. Females can reach a length of 3.8 m and a weight of 500 kg, while males remain slightly smaller with up to 3.3 m and a weight of 300 kg. (Shirihai & Jarrett, 2006)

***Figure 19 Leopard seal** hauled out at the ice, showing its reptilian head. Source: Wikimedia Commons/ Shiva, 2016.*

Typical for the species is a streamlined, elongated body with long fore-flippers. Another very typical feature is the reptile-like head, with a big mouth and powerful jaws. (Rogers, 2018) The coloration of the animals is usually light-silver grey on the ventral side, while the upper back side is colored in shades of dark-blue grey with occasionally some darker points (Shirihai & Jarrett, 2006). LS spend most of their time at haul out places for taking a break, which is followed by poking around and diving for feeding (Kreiß, 2008). Compared to the Ross seals, leopard seals have only very humble diving abilities. Their body can store less oxygen, which shortens their dives to an average time of 2 minutes. Therefore, they prefer shallower waters around 30 meters and less (Rogers, 2018). This apex predator has a diverse food web, hunting on penguins, marine mammals such as smaller seals, fish, and zooplankton (Rogers, 2018).

Leopard seals are highly active in their underwater communication, especially during mating (November to mid-January) (Tracey Rogers, 2018; Shirihai & Jarrett, 2006). Receptive females produce calls when in oestrus to attract potential mating partners (T. L. Rogers et al., 1996). Males also increase their calls during the mating season. In general, young animals have more variable call types, whereas adults have less, but more stereotyped calls. (Tracey Rogers, 2018) Various studies of the leopard seal have come to varying numbers of calls over the years. There are currently 18 identified calls, including near-range calls from animals in captivity. The variability of the calls can be attributed to the different regions and the associated isolation to some extent. In general, there are 5 calls that researchers have frequently encountered in vocal repertoire studies: Low Double Trill (LDT), Hoot with Single Trill (HST), Low DeScending Trill (LDST), Medium Single Trill (MST) and the High Double Trill (HDT). (Kreiß, 2008)

Moulting takes place after the mating season between January and February (Kreiß, 2008).

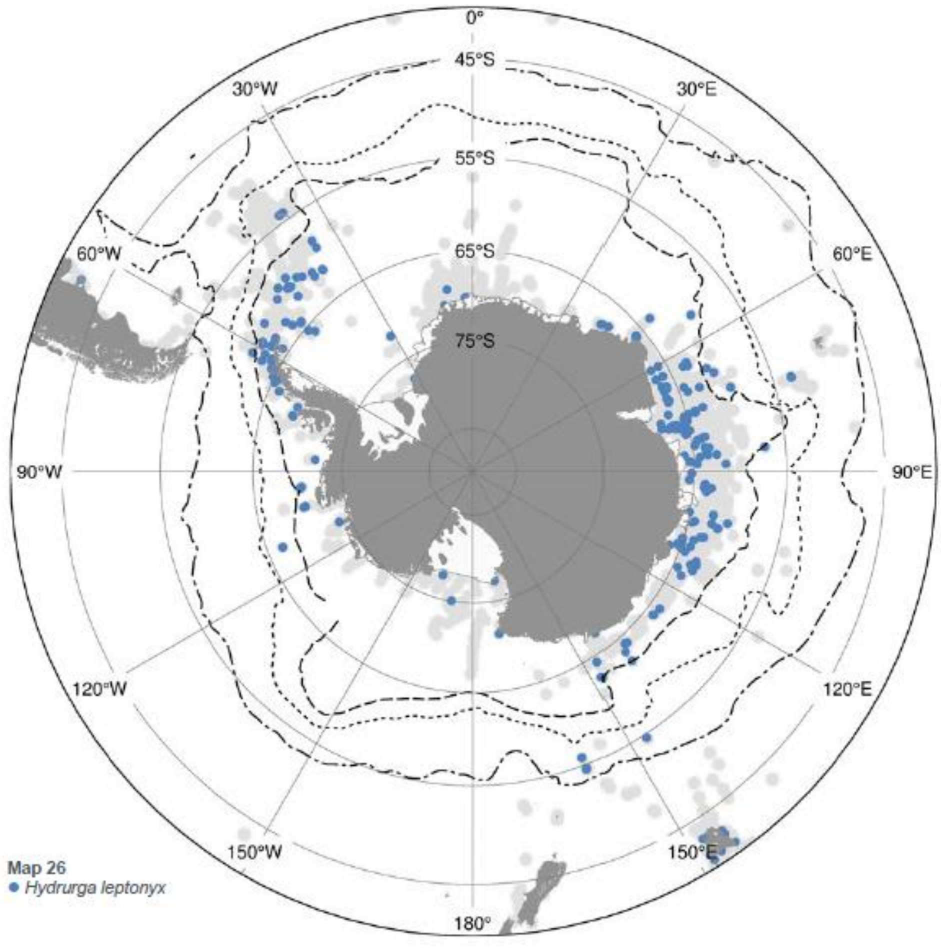

***Figure 20 Leopard seal distribution around Antarctica**. The species is less abundant in both the Weddell and Ross Sea (Ropert-Coudert et al., 2014). The species have been spotted even around Tierra del Fuego, Marion Island, South Georgia and the Kerguelen Islands (Kreiß, 2008; Ropert-Coudert et al., 2014). (Kreis p. 4). Source: Ropert-Coudert et al., (2014).*

Leopard seals live in low densities within the Antarctic polar circle. In the summer, the animals stay usually near the land, where they feed on penguins and fur seals (Ropert-Coudert et al., 2014). While in pack ice, they feed more on smaller marine animals such as fish and squid. Some animals follow the pack ice northwards when the pack ice has its largest extent and return to more southern areas to reproduce.

Leopard seals respond to humans, when hauled-out with targeted slipping movements (Shirihai & Jarrett, 2006), however those encounters are usually good-natured.

B Additional Figures

IAATO Seal Watching Guidelines

General code of conduct for viewing seals on land and ice:

- When viewing seals do not surround or separate them, especially mothers and pups. Stay on the side where they can see you.
- On beaches, avoid getting between seals and the sea, walk 'above' them.
- Suggested minimum distances from seals ashore are at least 5-15 meters/15-45 feet – some species, or behaviors, require a further distance to be kept (see below).

Understanding seal behavior

Seals hauled out on land, rock or ice, are sensitive to boats and human presence. Noises, smells and sights may elicit a reaction.

Be aware of seal behavior that indicates a seal has been disturbed. Such behaviors include, but are not limited to:

- An increase in alert or vigilance,
- Head turning,
- Change in posture from lying to erect,
- Hurriedly moving away from the approaching vessel,
- Open mouth threat displays (e.g., in leopard seals on ice, or elephant seals on land), and/or
- Aggressive displays or bluff charges in your direction.

Viewing seals on land and ice

- Try not to break their horizon or tower over hauled-out seals – stay low.
- Pups are often left alone when the mother is feeding. They are not abandoned and should be left alone and not touched.
- Any seal response other than a raised head should be avoided.
- If an individual or a herd moves towards the water or there is a hurried entry into the water by many individuals, you should retreat slowly and carefully.
- Be aware that fur seals and sea lions are highly mobile on land and might charge (and potentially bite) if approached too closely - keep at least 15 meters/45 feet from them.
- Be aware of animals in tussock grass areas. Ideally, a field guide should lead, carrying walking stick or equivalent.
- Keep a minimum distance from jousting bull elephant seals of 25 meters/75 feet.
- Elephant seal pups (weaners) are often very inquisitive and may approach close to passengers. It is important that the weaner is in control of any interaction at all times.

IAATO Seal Watching Guidelines (2016) www.iaato.org

***B 1 IAATO Seal Watching Guidelines**. It underlines the sensitivity of seals on land to the presence of boats and humans. Source:* (IAATO, 2016b)

IAATO General Information for Wildlife Watching

Introduction

IAATO's General Information for Wildlife Watching and related Guidelines aim to provide guidance to IAATO operators for viewing cetaceans, seals, and birds in their marine environment. These guidelines minimize potential environmental impacts to wildlife and suggest ways to comply with Annex II (Conservation of Antarctic Fauna and Flora) of the Protocol on Environmental Protection to the Antarctic Treaty. The guidelines do not replace any domestic governmental laws, but provide an additional code of conduct to help reduce potential disturbance to the marine environment. Some countries have guidelines or regulations stricter than these, which may override IAATO's guidelines. Violation of national regulations may be punishable by fines, imprisonment and, in extreme cases, seizure of vessel. IAATO operators should be aware that compliance with the IAATO guidelines might be insufficient to prevent violation of, and penalties resulting from, national laws and regulations.

Compliance with the International Regulations for Preventing Collisions at Sea has priority over these guidelines at all times.

Are intended to be used by IAATO members operating:

- Any type of vessel e.g. ship, sailboat, yacht, Zodiac, small boats, kayak, etc. (Note: The use of jet- skis, surfboards or windsurfers should not occur in areas of known wildlife)
- By the officers, crew, expedition staff and visitors involved in navigating in wildlife-rich areas during viewing sessions

The Guidelines Aim to:

- Minimize wildlife disturbance;
- Protect cetaceans, seals and seabirds while ensuring a high quality wildlife-watching experience through responsible observation. (Many passengers are concerned about the welfare of wildlife and expect high standards of conduct by operators);
- Avoid harmful impacts on marine wildlife populations by ensuring that the normal patterns of daily and seasonal activity of the animals are maintained in the short and long term. Competent, careful boat handling avoids harming wildlife and leads to better wildlife watching.

Reduce Possible Impacts from Vessels

Possible negative impacts from vessel operations include physical injury, interference with or disruption of normal behaviour, stress, underwater noise and possibly increased exposure to predators.

In addition, animals could be exposed to increased levels of environmental contaminants such as oil from leaking outboard engines and discharged bilges.

The recommended guidelines will help minimize the level of potential disturbance and should prevent the following from occurring:

- Displacement from important feeding areas;
- Disruption of feeding;
- Disruption of reproductive and other socially important behaviours;
- Changes to regular migratory pathways to avoid human interaction zones;
- Stress from interaction;
- Injury;
- Increased mortality or decreased productivity/ survivorship (and therefore population decline).

Aircraft and Helicopter operations

- Aircraft (including helicopters) should follow the guidelines laid out in Antarctic Treaty Resolution 2 (2004) 'Guidelines for the Operation of Aircraft near Concentrations of Birds in Antarctica.'

Entanglement and strandings

- Any animals entangled in fishing equipment etc., should be assisted where possible. Please only use experienced staff/crew for these situations and take the necessary precautions such as protective clothing – seal bites are particularly prone to disease.
- Photographs of the entanglement should be taken. Please complete a report and send it to IAATO.
- Should you not be able to assist, please record details including geographic position (expressed as coordinates in latitude and longitude), species, and type of entanglement.

Please report the event as soon as possible, so assistance may be sought from other vessels with experienced staff onboard.

- Details of dead (floating) animals and 'strandings' (beached) cetaceans should be recorded and reported to IAATO. Where possible, please take photographs recording the front and side of the head of the animal (for species identification). Please include a scale of measurement (e.g., a ruler or Zodiac paddle) in the photographs. If the state of decomposition of the animal allows, please also take photographs of the fluke (tail) and the dorsal fin (if present) to allow recognition of potentially known individuals (i.e. using photo-identification).

Identification and data collection

Identifying and, in many cases, recording species for the voyage log purposes is part of most onboard naturalists' remit. Logs, which include these records coupled with latitude and longitude of sightings, species identification, and any additional information such as identification photographs, are of immense value. Information on citizen science projects collecting these data can be found through IAATO website or by contactingIdentifying and, in many cases, recording species for the voyage log purposes is part of most onboard naturalists' remit. Logs, which include these records coupled with latitude and longitude of sightings, species identification, and any additional information such as identification photographs, are of immense value. Information on citizen science projects collecting these data can be found through IAATO website or by contacting **iaato@iaato.org**

B 2 IAATO General Information for Wildlife Watching. *It is included to reduce probable impacts from ships, amongst others "interference with or disruption of normal behavior, stress, [and] underwater noise". Source: (IAATO, 2016a)*

Cruise Label	Start Expedition	End Expedition	*Neumayer Arrival*	*Neumayer Departure*	DSHIP Arrival - 70,51	DSHIP Departure - 70,51	Arrival at NS	Stay at NS	1st PS - visbile	last PS - visible
PS117	15.12.2018	07.02.2019	13.01.2019	15.01.2019	13:15*70,51	21:55*70,50	late	intermediate (3/4 days)	12.01.2019_1245	16.01.2019_1300
			17.01.2019	17.01.2019	08:35*70,50	14:45*70,50			16.01.2019_2330	17.01.2019_2300
PS111	19.01.2018	14.03.2018	*28.01.2018*	*30.01.2018*	19:00*-70,54	22:00*-70,54	very late	short (3 days)	28.01.2018_8005	31.01.2018_02:08
PS 82	19.12.2013	05.03.2014	*30.12.2013*	*31.12.2013*	2:00	15:00	intermediate	short (2 days)	30.12.2013_0005	31.12.2014_2105
PS 79	03.12.2011	05.01.2012	*17.12.2011*	*22.12.2011*	21:00	21:00	early	long (6 days)	17.12.2011_1605	24.12.2011_1800
PS 77	28.11.2010	05.02.2011	20.12.2010	22.12.2010	8:00	18:00	early	short (3 days)	19.12.2010_1905	24.12.2010_0305

1st call RS - Arrival	last call RS - Departure	1st cal LS - Arrival	last call LS - Departure
15.12.2019_0505	31.01.2019_2019	21.11.2018_1320	22.01.2019_0604
17.12.2017_1452	04.02.2018_0809	01.11.2017_1237	19.01.2018_0000
18.12.2013_1105	05.02.2014_2305	05.10.2013_0605	14.01.2014_0001
23.12.2011_0305	02.02.2012_0535	14.10.2011_0022	10.01.2012_2329
23.12.2010_0705	21.01.2011_01:05	21.10.2010_0002	13.01.2011_1101

B 3 Primary data collection. *In order to achieve an overview over various data of importance for the thesis, data was gathered in this Excel Table.*

		files		0:00	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
2010		5 min of 1 min													
15. Dez															
16. Dez															
17. Dez															
18. Dez															
19. Dez															
20. Dez					0201_0205	0401_0405	0601_0605	0801_0805	1001_1005	1201_1205	1401_1405	1601_1605	1801_1805	2001_2005	2201_2205
21. Dez															
22. Dez								0804_0808							
23. Dez															
24. Dez													1801_1805		
25. Dez															
26. Dez															
27. Dez															
2011		5 min of 1 min													
12. Dez															
13. Dez															
14. Dez								0739-0743							
15. Dez															
16. Dez											1401_1405				
17. Dez															
18. Dez															
19. Dez															
20. Dez															
21. Dez								0814_0818							
22. Dez								0824_0828							
23. Dez															2319_2323
24. Dez															
25. Dez															
26. Dez															
27. Dez															
2013		1 min													
25. Dez															
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30. Dez															
31. Dez															
2014		5 min of 1 min													
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04. Jan															
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2018		10 min													
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04. Feb															
2019		10 min													
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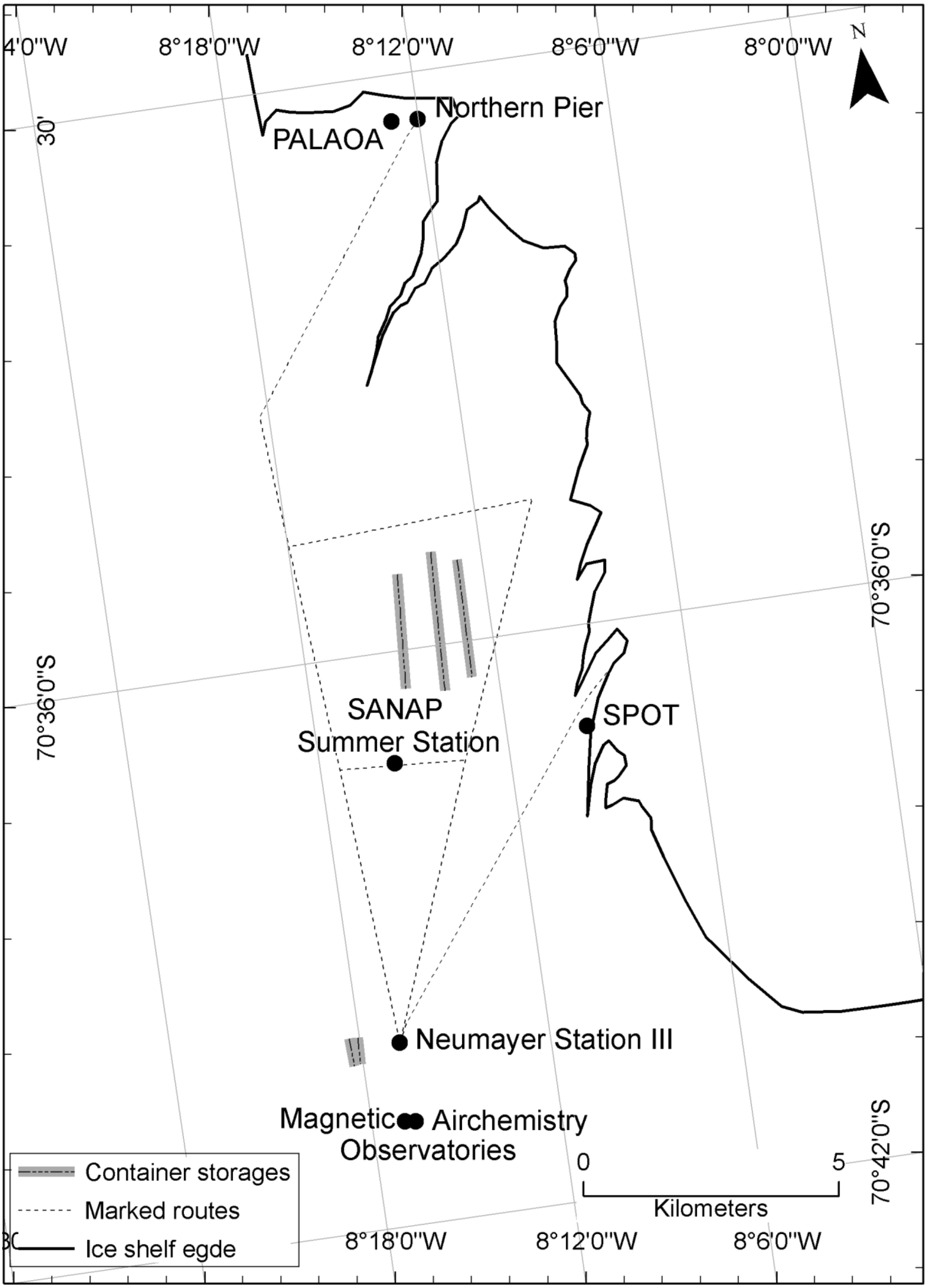
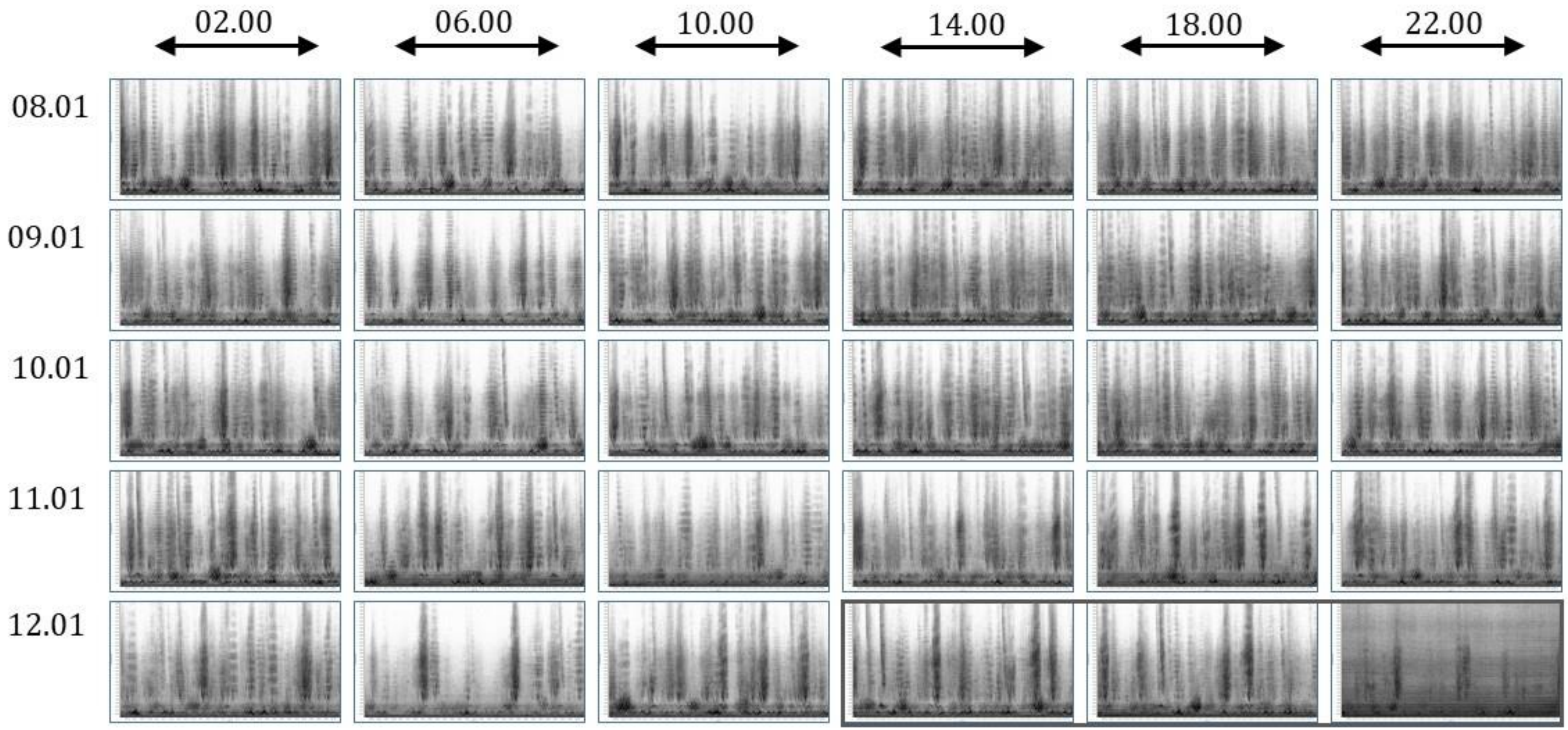
B 4 Data availability. *The table shows the data availability over the 5 years of analysis. Green-marked signifies data is available, grey-marked represents the days of PS presence, red-marked is missing data and the orange-marked ones shows replaced data.*



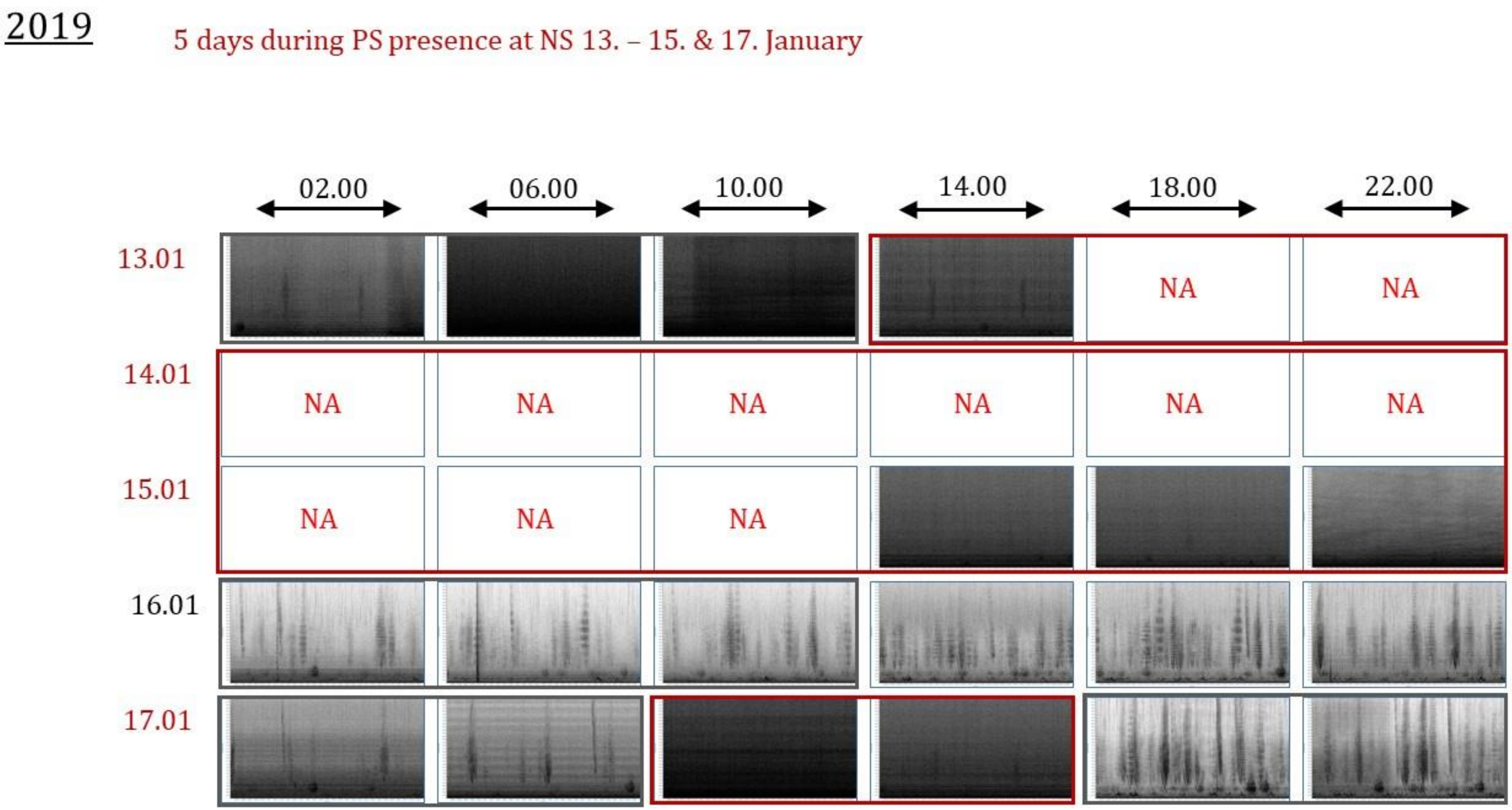
B 5 Map of surrounding of NS*, including piers and parking spots for PS along the shelf ice. Source: AWI/ Wesche C., 2018.*

2019

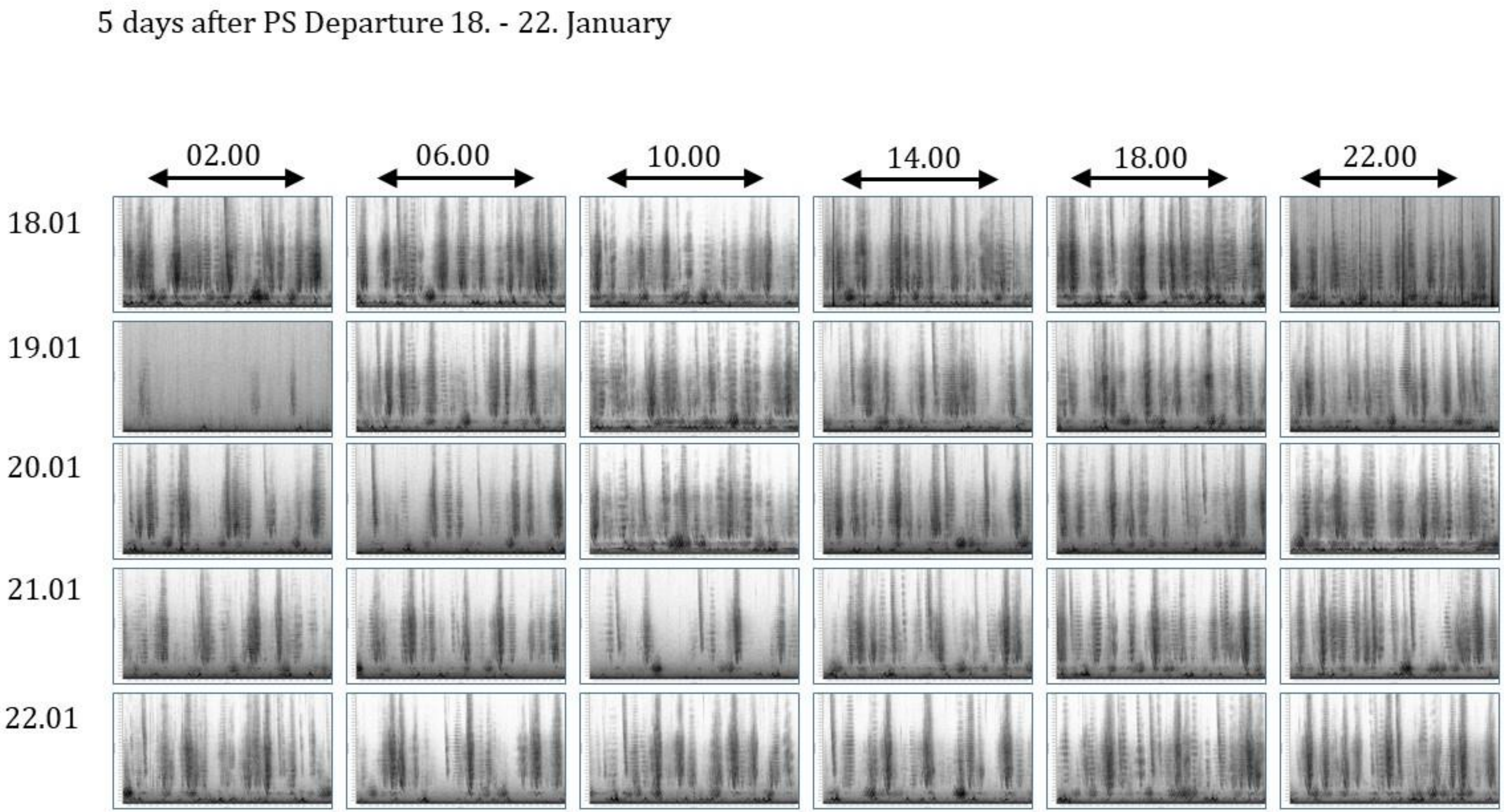
5 days before PS Arrival 08. - 12. January



B 6 Overview of spectrogram screens prior PS arrival 2019.



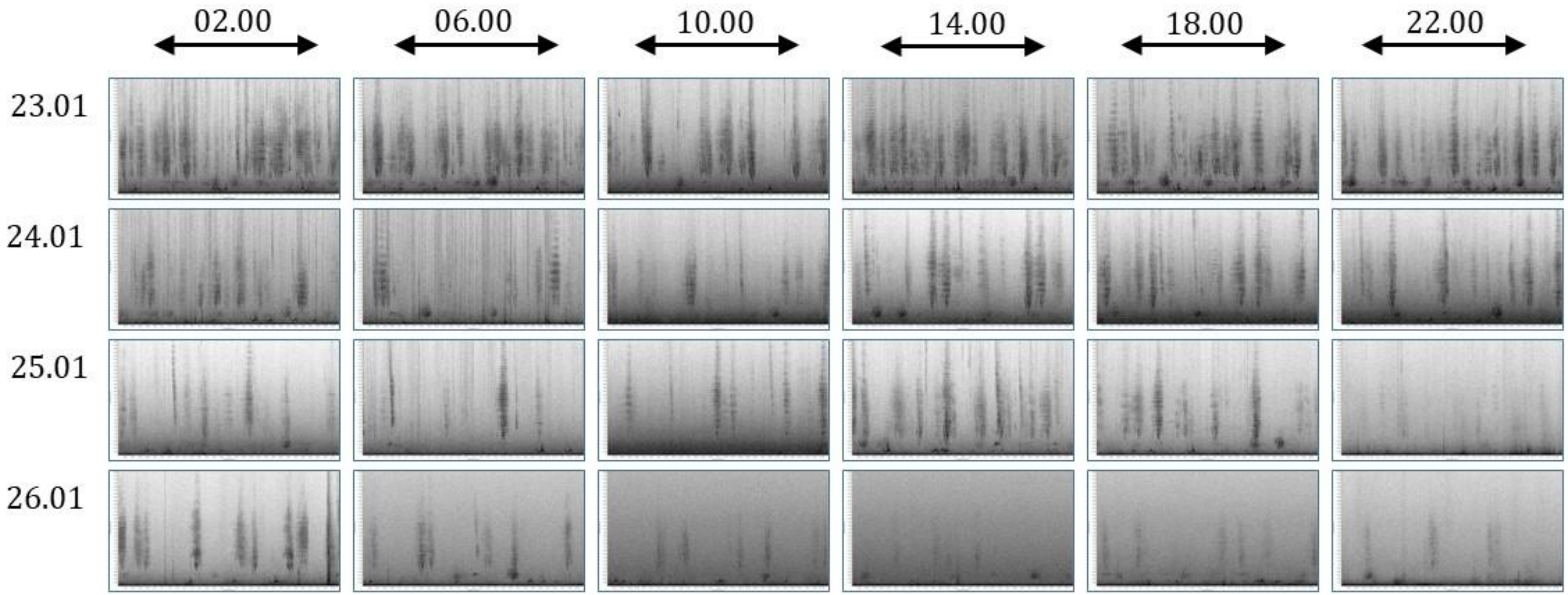
B 7 Overview of spectrogram screens during PS presence 2019.



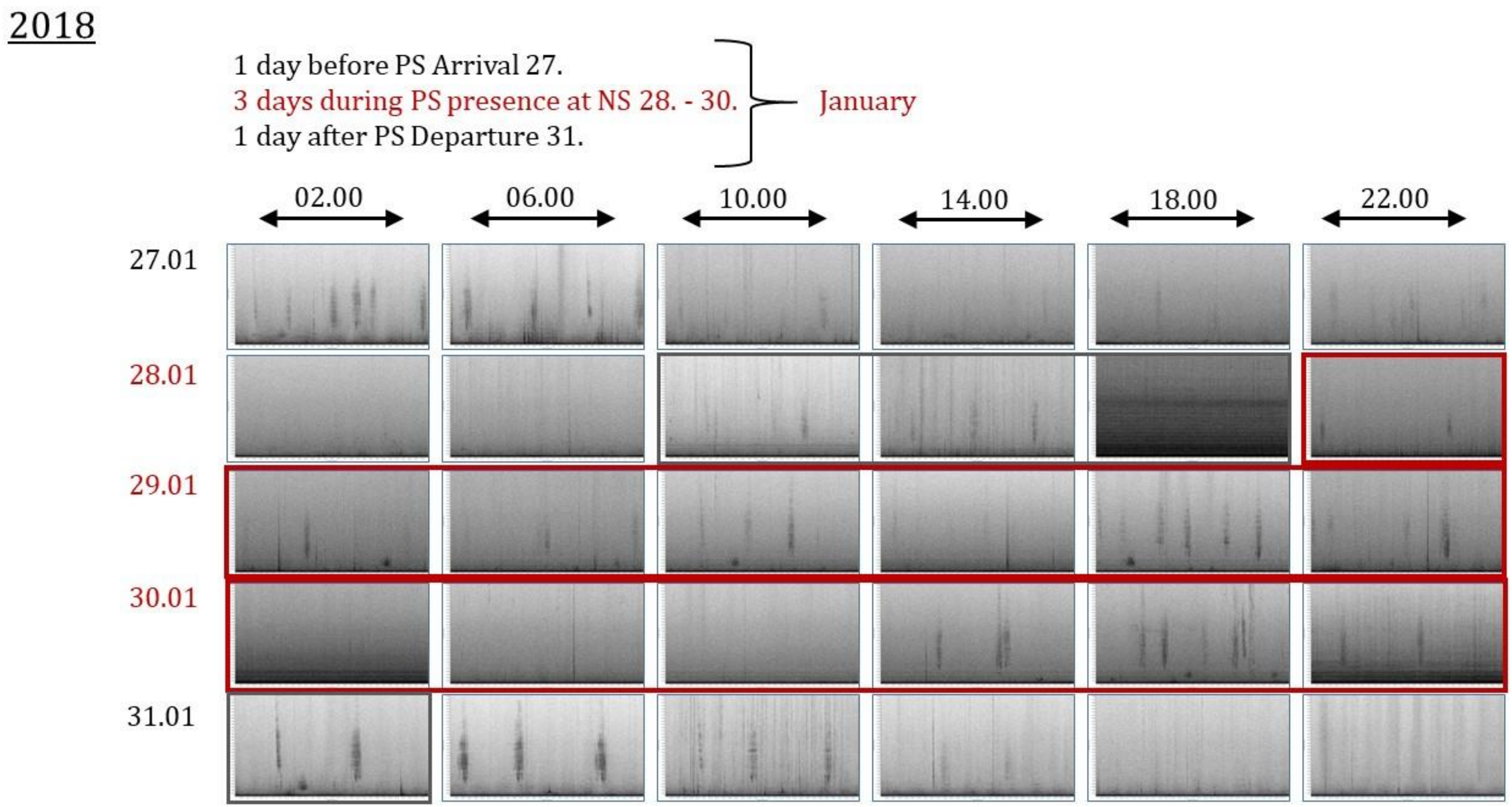
B 8 Overview of spectrogram screens post PS departure 2019.

2018

4 days before PS Arrival 23. - 26. January

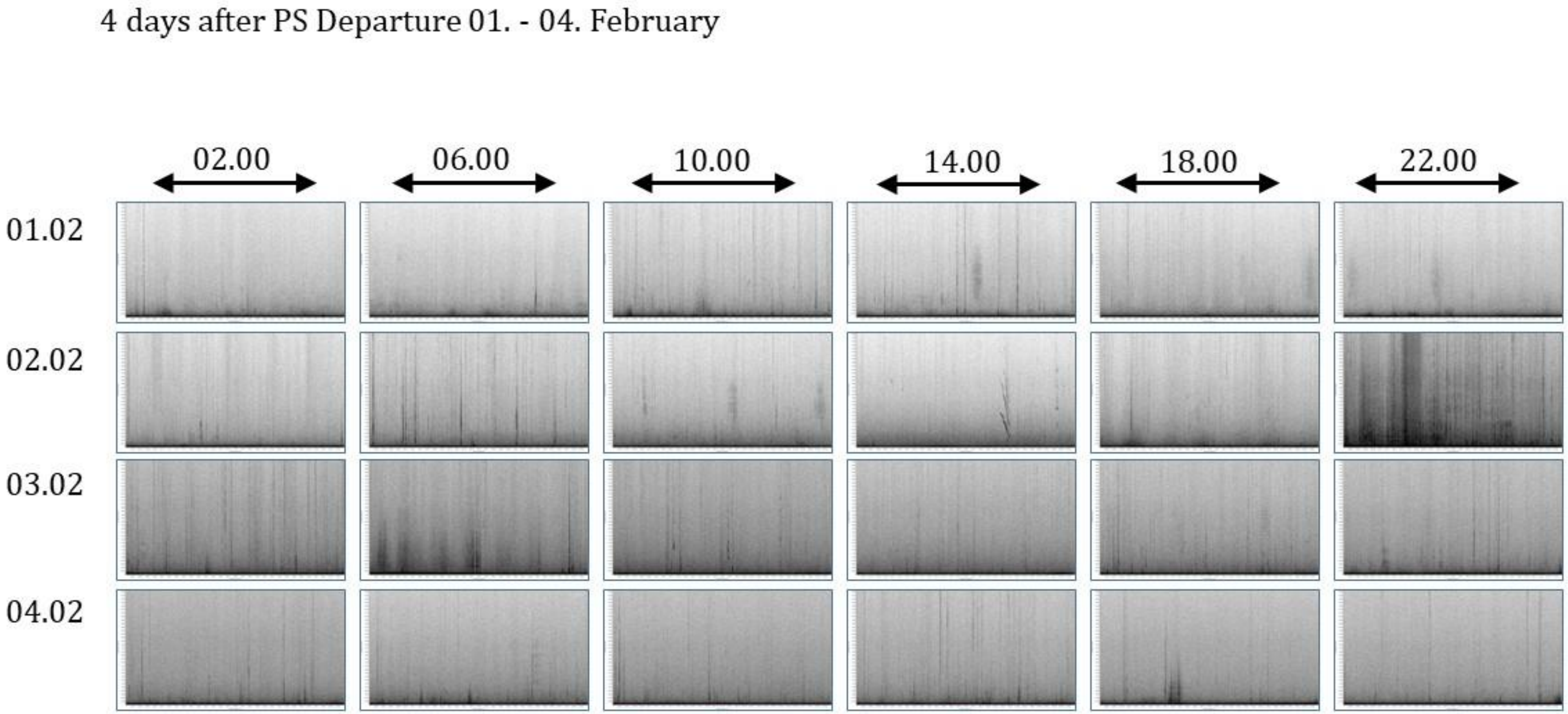


B 9 Overview of spectrogram screens prior PS arrival 2018.



B 10 Overview of spectrogram screens during PS presence 2018.

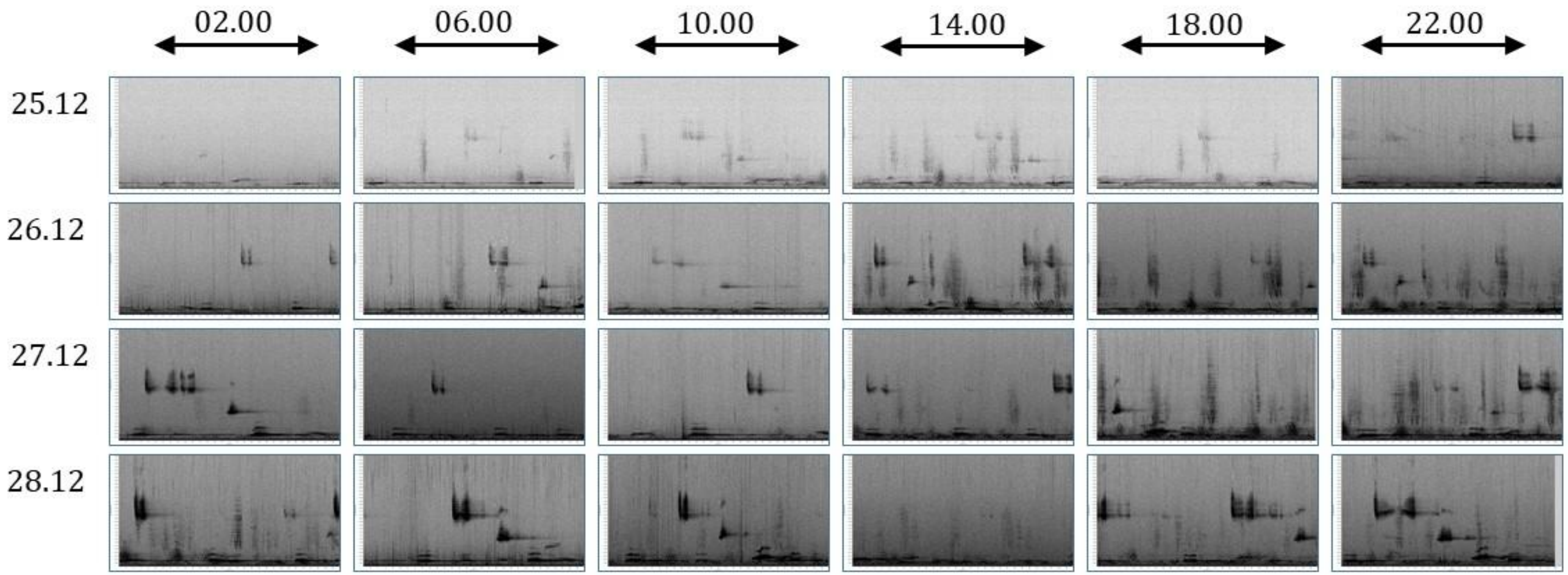
2018



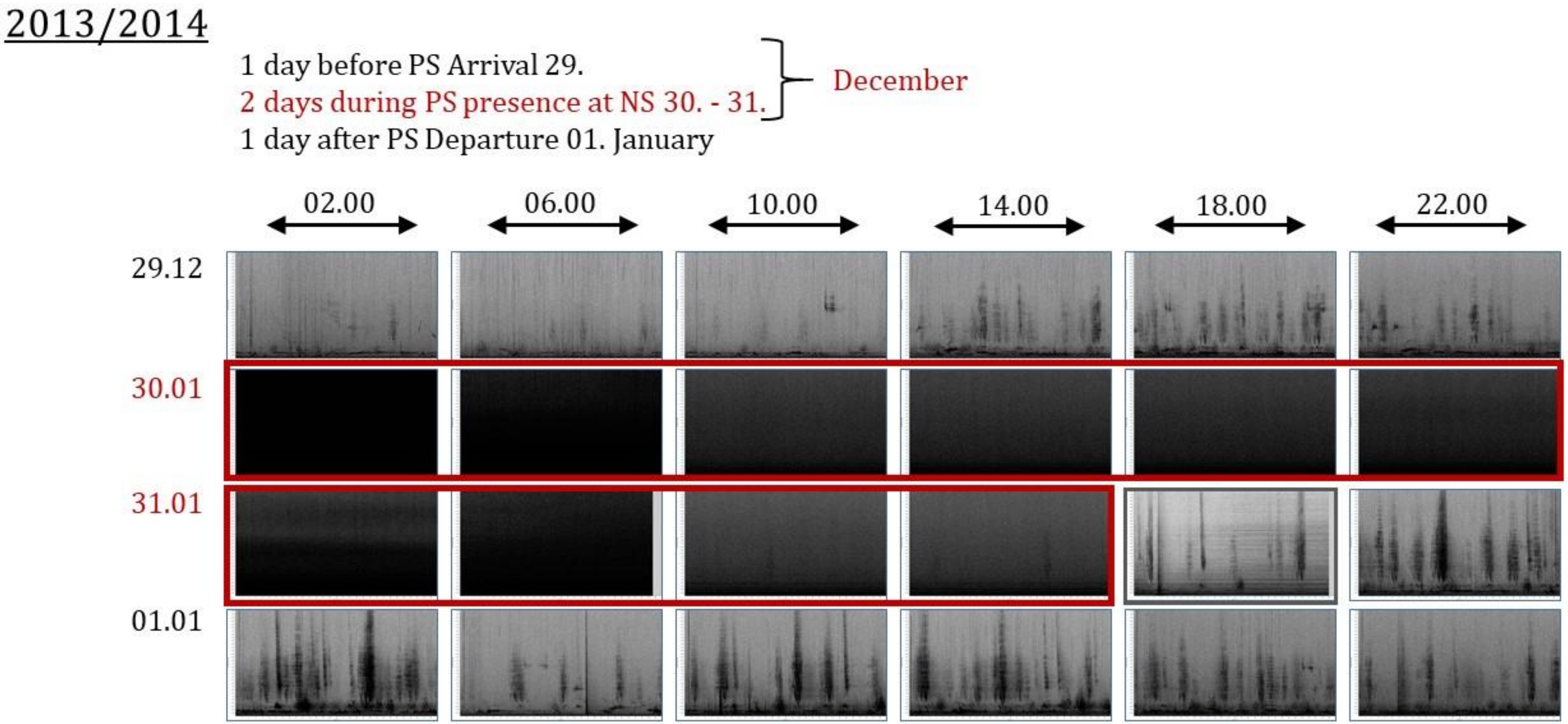
B 11 Overview of spectrogram screens post PS departure 2018.

2013

4 days before PS Arrival 25. – 28. December



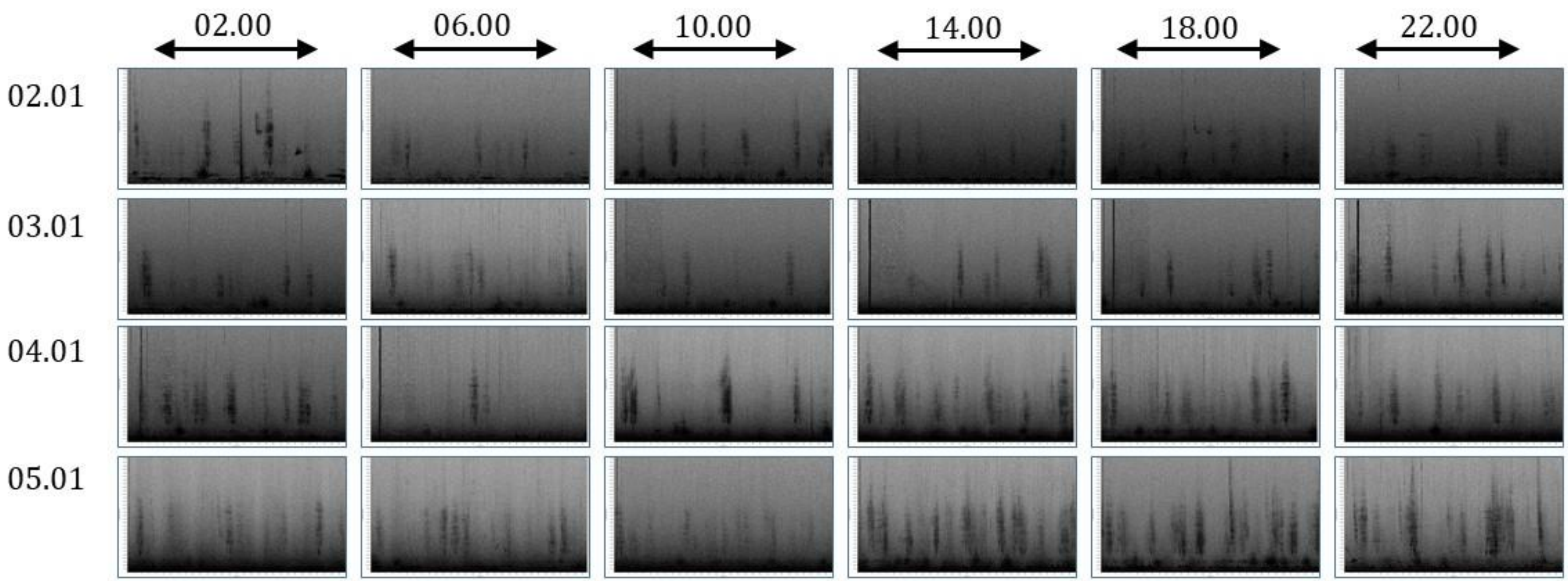
B 12 Overview of spectrogram screens prior PS arrival 2013/2014..



B 13 Overview of spectrogram screens during PS presence 2013/2014.

2014

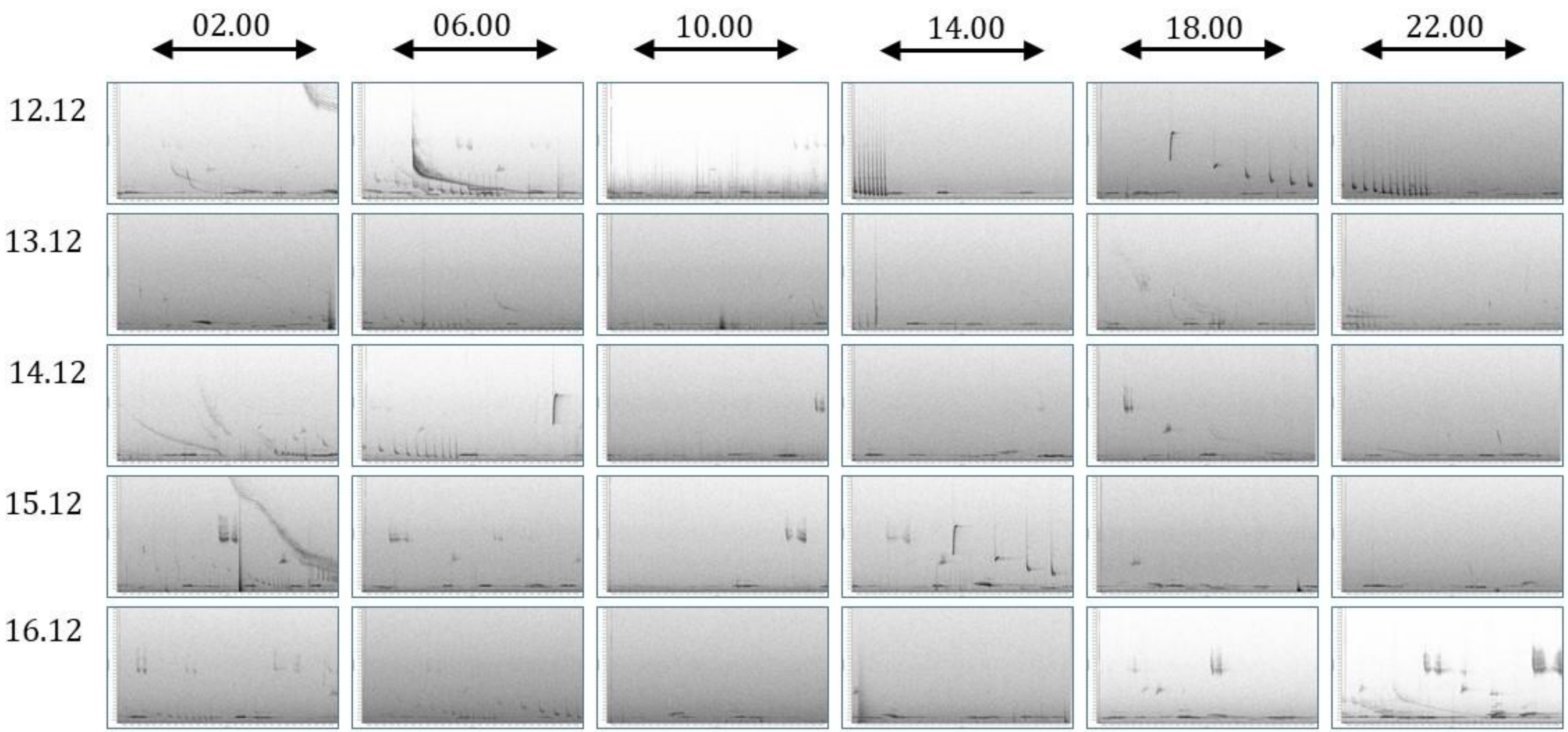
4 days after PS Departure 02. - 05. January



B 14 Overview of spectrogram screens post PS departure 2013/2014.

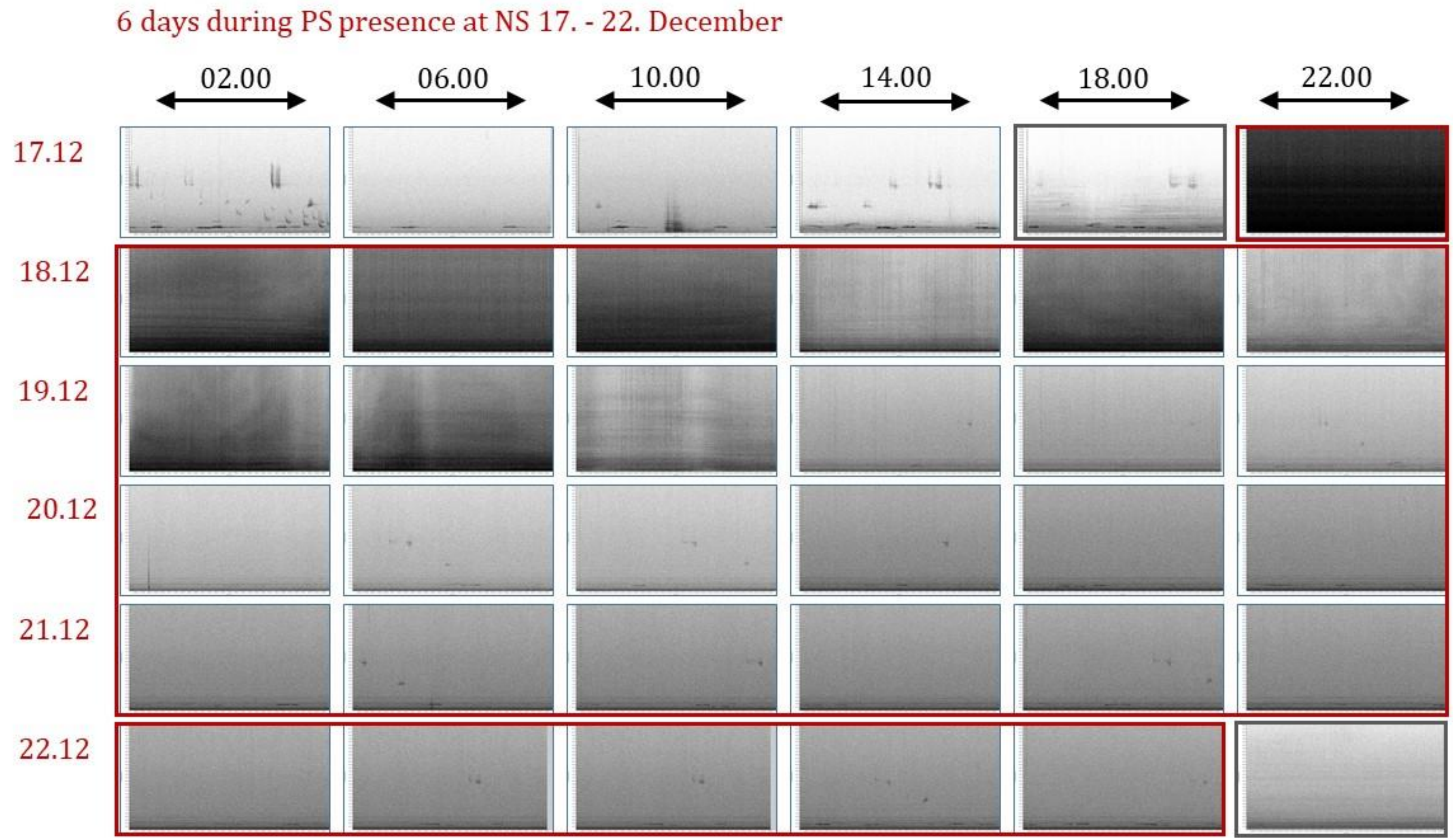
2011

5 days before PS Arrival 12. – 16. December



B 15 Overview of spectrogram screens prior PS arrival 2011.

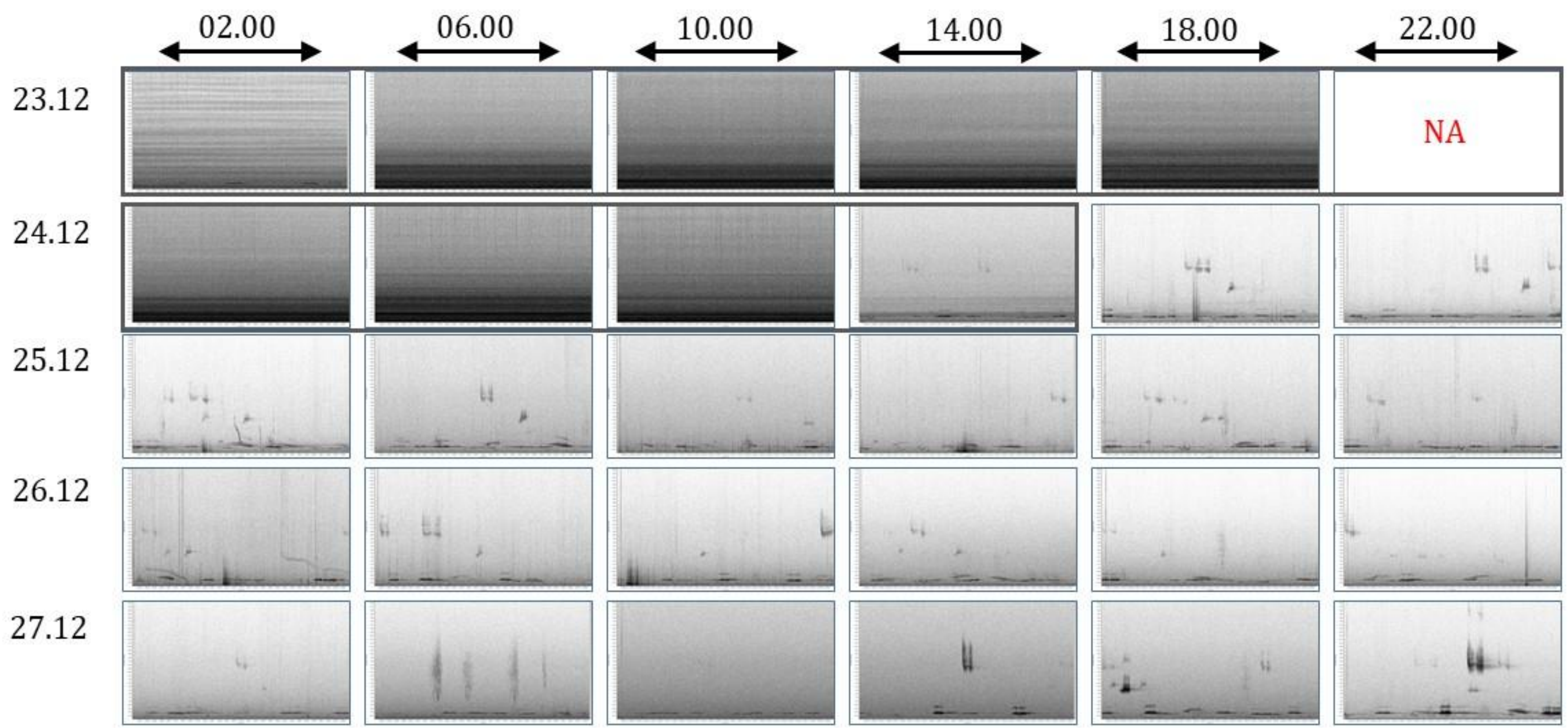
<u>2011</u>



B 16 Overview of spectrogram screens during PS presence 2011.

2011

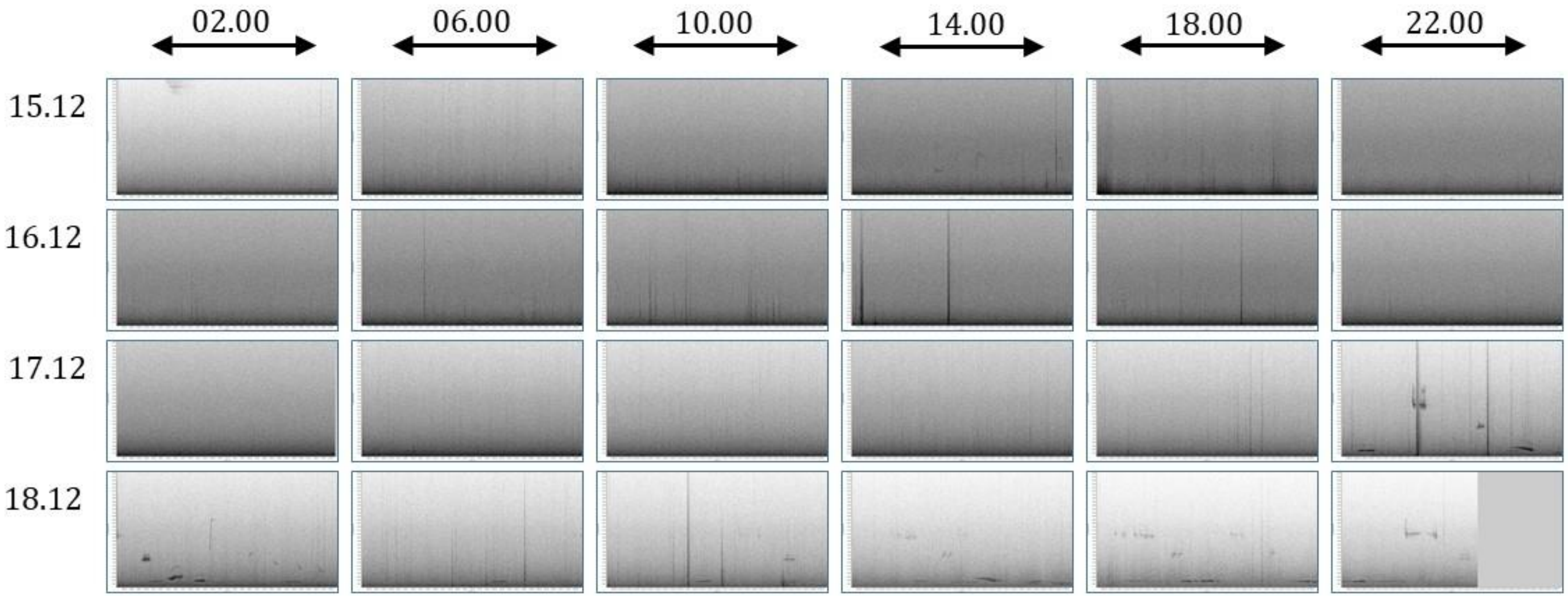
5 days after PS Departure 23. – 27. December



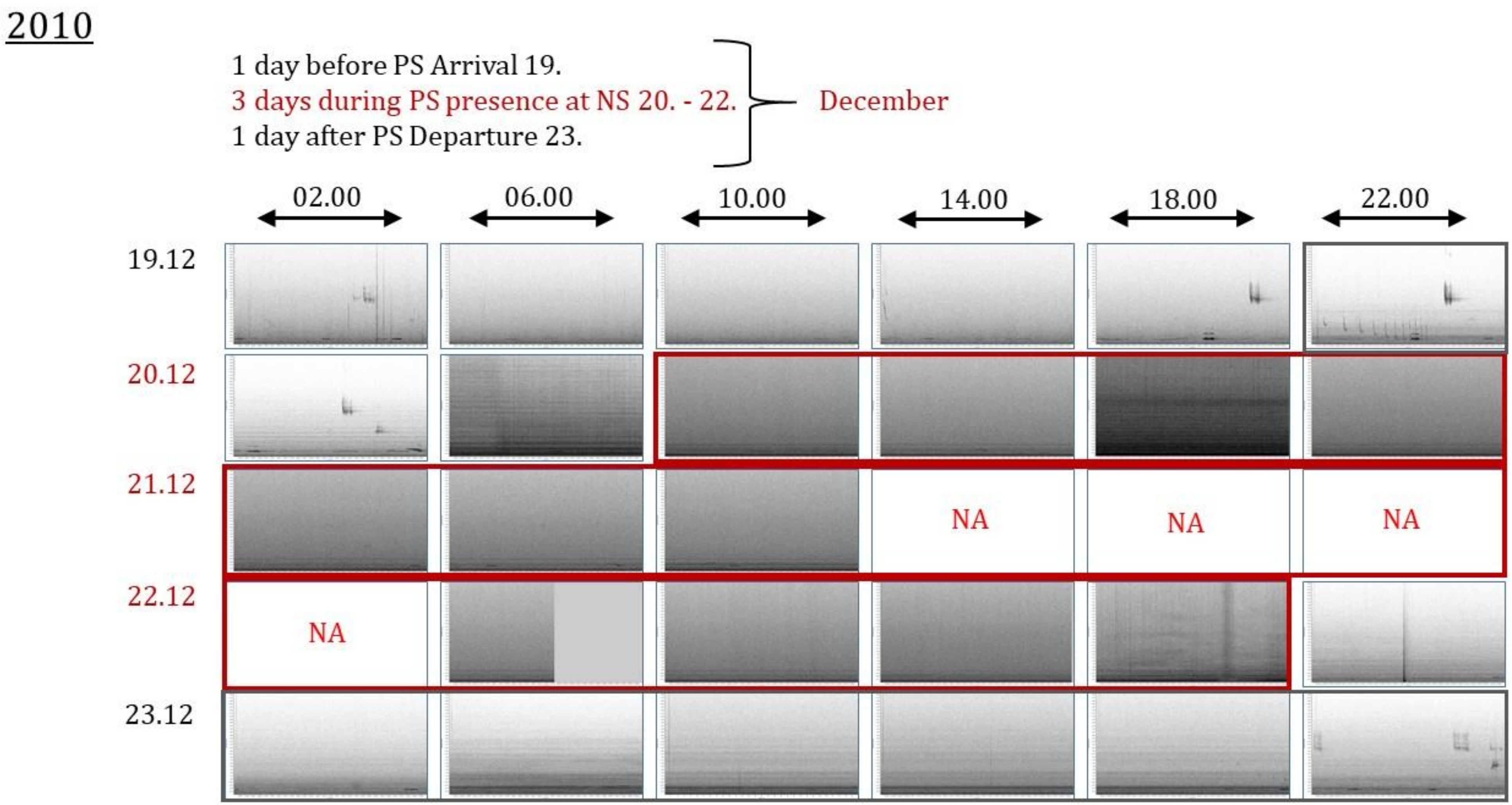
B 17 Overview of spectrogram screens post PS departure 2011.

2010

4 days before PS Arrival 15. – 18. December



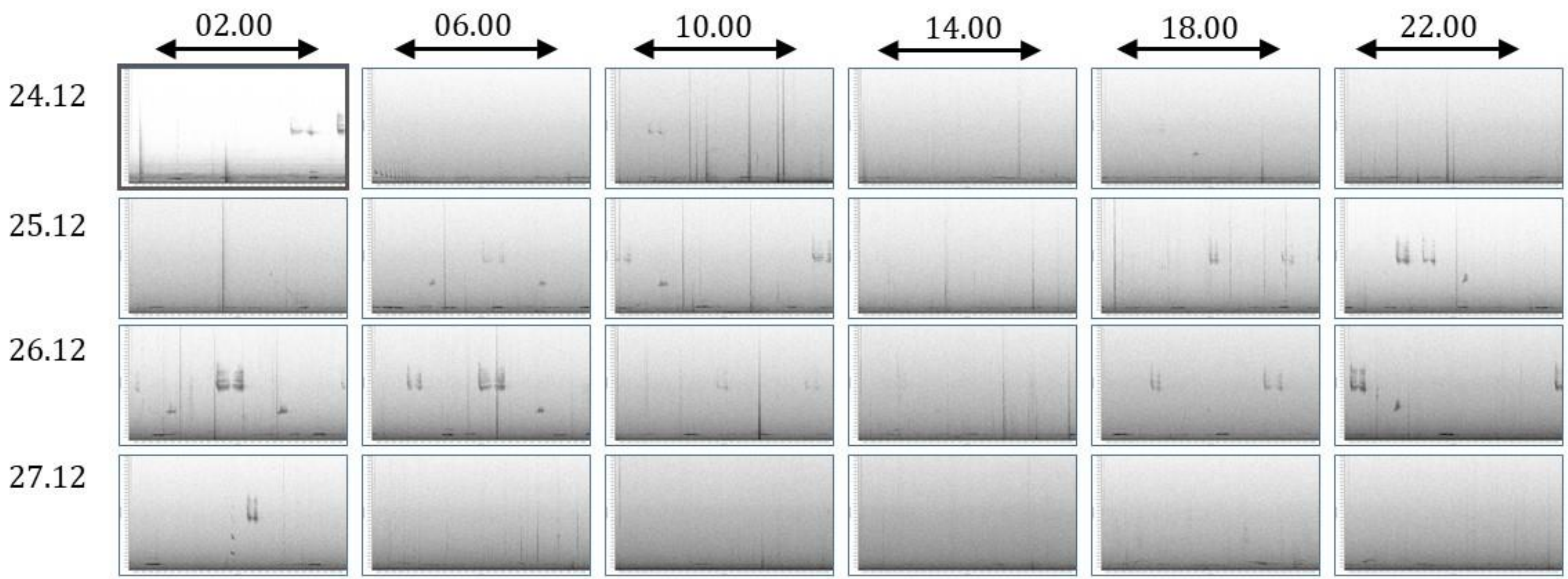
B 18 Overview of spectrogram screens prior PS arrival 2010.



B 19 Overview of spectrogram screens during PS presence 2010.

2010

4 days after PS Departure 24. - 27. December



B 20 Overview of spectrogram screens post PS departure 2010.