LOCAL TO BASIN SCALE ARRAYS FOR PASSIVE ACOUSTIC MONITORING IN THE ATLANTIC SECTOR OF THE SOUTHERN OCEAN

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Abstract: *Passive acoustic data provide a prime source of information on marine mammal distribution and behaviour. Particularly in the Southern Ocean, where ship-based data collection can be severely hampered by weather and ice conditions, passive acoustic monitoring (PAM) of marine mammals forms an important source of year-round information on acoustic presence. Array data can be used to obtain directional information on the species present in the recordings to derive movement patterns. Acoustic arrays furthermore allow spatial comparisons of marine mammal distribution patterns and habitat affinities when the acoustic presence information is linked to local environmental parameters. Here we present two passive acoustic monitoring arrays that have been implemented by the Alfred Wegener Institute's Ocean Acoustic Lab and serve the investigation of marine mammals on different spatial scales. During the austral summer season 2012/2013 a local scale array of sea ice-based time-synchronized passive acoustic recorders was deployed in Atka Bay, Antarctica. The PASATA (PASsive Acoustic Tracking of Antarctic marine mammals) project investigates coastal local habitat usage and communication ranges of marine mammals by integrating positional information from triangulation of calling animals and information from environmental parameters. For studies on marine mammals over larger spatial scales, 23 passive acoustic recorders were deployed in oceanographic moorings in the Southern Ocean, reaching from the Greenwich meridian throughout the Weddell Sea to the Western Antarctic Peninsula. The inter-disciplinary nature of this mooring array allows combining in-situ oceanographic measurements with passive acoustic data on marine mammal occurrence. It furthermore forms the first basin-wide, long term array, at least in the Southern Ocean. Here, we describe both arrays, the recorder types used, and technical and logistic requirements for PAM in a polar environment.*

Keywords: *PAM, passive acoustic monitoring, acoustic array, marine mammals, Antarctic*

Motivation

Marine mammals play an important role in both top-down as well as bottom-up processes in marine ecosystems [1]. Knowledge of distribution patterns of marine mammals therefore provides insights vital to a holistic understanding of ecosystem dynamics and functioning. Furthermore, knowledge of marine mammal habitat usage is of key importance in the context of policy decisions on catch permits and designation of marine protected areas.

Collection of data on marine mammals is complicated by their elusiveness and mobility. In the Southern Ocean, the difficulty of working in a polar environment, as well as most species' massive decline in abundance due to commercial hunting, limits our current knowledge on their distribution patterns. Visual data collection in particular is dependent on weather and ice conditions, generally restricting data collection to the summer season and areas with little ice cover.

By contrast, acoustic recorders are capable of autonomous operation and record data quasi-omnidirectional and independent of light and weather conditions. Marine mammals actively produce sound in many behavioral contexts which can be linked to specific species based on e.g. the spectral characteristics of the sound.

Autonomous, passive acoustic monitoring therefore provides a promising approach to continuously assess marine mammal occurrences over extended spatial and temporal scales. Recent advances in audio and computing technology now allow the acquisition and handling of large acoustic data sets. Networks of time-synchronized acoustic recorders, deployed throughout regions of interest, permit exploring spatial patterns in behavior of vocalizing marine mammals to investigate marine mammal distribution patterns and habitat affinities when the acoustic presence information from each recorder is linked to local environmental parameters.

Here we present two passive acoustic array (PAA) set-ups as implemented by the Alfred Wegener Institute's Ocean Acoustic Laboratory to investigate, on different spatial scales, marine mammal distribution and habitat usage.

Local scale hydrophone array - PASATA

To study small scale distribution and movement patterns of marine mammals in an Antarctic coastal region, the AWI's Ocean Acoustics Laboratory deployed an array of time-synchronized ice-based recorders on the sea ice of Atka Bay, close to the German Antarctic research base Neumayer III during the austral summer season 2012/13. Four ice-breeding Antarctic pinniped species are known to be present in the Atka Bay region: Ross seals (*Ommatophoca rossii*), Weddell seals (*Leptonychotes weddellii*) crabeater seals (*Lobodon carcinophaga)*, and leopard seals (*Hydrurga leptonyx*). These species produce sound during the mating season and are thought to exhibit species-specific sea-ice type preferences [2]. The PASATA (PASsive Acoustic Tracking of Antarctic marine mammals) project investigates coastal local habitat usage, underwater movement patterns and communication ranges of these ice-breeding pinnipeds by deriving positional information from triangulation of the location of calling animals by measuring the time-delay-of-arrival-differences (TDOA) of animal calls as the sound travels across multiple hydrophones.

The PASATA array was subdivided in a small and large array (**Error! Reference source not found.**). The large array consisted of a line-array installed close to the sea-ice edge and focused on recording Ross, leopard and crabeater seals, which are known to occur in the offshore pack ice area. The aim here was to use TDOA of pinniped signals to localize and track calling animals and relate positional information from calling seals to data on environmental conditions to infer species-specific ice habitat preferences.

The small ice based array was installed farther inside of Atka Bay around a Weddell seal breeding colony on the fast ice. In Weddell seals, males are thought to use the stability of their fast ice habitat to maintain underwater territories around or near tide cracks and breathing holes used by females. Underwater vocalizations are thought to be produced by males for the purpose of territorial defence and advertisement. The small hydrophone array aimed at investigating underwater behaviour of vocalizing male and female Weddell seals to provide information on underwater movement patterns in relation to the location of tide cracks and breathing holes.

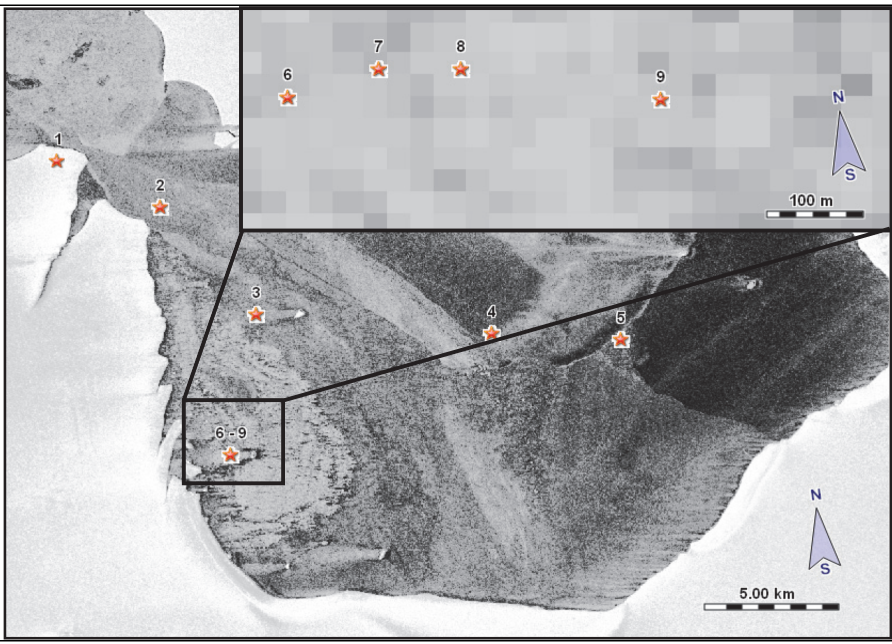

Fig. 1 Map of Atka Bay with positions of the passive acoustic recorders. The large array consists of recorders 1 - 5. Inset image: location and configuration of the small array: recorders 6 - 9

For both sub-arrays, four recorders were installed on the sea-ice of Atka Bay each with a hydrophone deployed through boreholes. Each recorder comprised a Wildlife Acoustics SM2+ acoustic recorder connected to a HTI-96-min hydrophone [sensitivity -165dB re: 1V/μPa]. A GPS antenna was connected to the SM2+ to continuously synchronize system time. The GPS option of the SM2+ allowed scheduling and synchronizing recordings to within one millisecond by inserting or removing samples as needed to maintain synchronization with the GPS clock. Recording occurred continuously at 96 kHz sampling rate in wav format, resulting in a data acquisition rate of 16 GB per recorder per day.

A 33Ah battery pack provided system (SM2+, hydrophone and GPS module) power supply for eleven days, which offered a sufficiently large time window to bridge bad weather periods during which servicing of the recorders was not possible. Recorders were equipped with 2x 128 GB cards, which provided storage capacity for 16 days.

Both the small and the large array recorded under the sea-ice for approximately one month, collecting a total of ~3 TB of acoustic data.

Basin scale array

HAFOS (Hybrid Antarctic Float Observation System), a basin-wide oceanographic observing system including more than 15 deep-sea moorings distributed throughout the Weddell Sea, provides a unique infrastructure for the deployment of passive acoustic recorders. HAFOS' basin-wide implementation allows an unprecedented investigation of the range over which the sounds of the various marine mammal species can be detected. Information on species-specific detection ranges is important for interpretation of call rates in the light of local acoustic abundances. Data from the basin-scale PAA are furthermore used to explore how large scale spatial patterns in marine mammal occurrences relate to environmental characteristics by linking marine mammal acoustic presence to in-situ measured and remote sensed environmental parameters.

Currently 16 deep-sea moorings provide the platform for acoustic recorders in the Weddell Sea and along the Greenwich Meridian south of 59° S. They cover an area from 0° E to 56° W and from 60° S to 72° S. Oceanographic moorings are maintained every second or third year, using the AWI's icebreaking research vessel 'Polarstern'.

In late 2010, a first set of four recorders were recovered and partly redeployed along with additional new recorders, resulting in a total of 10 moored recorders. In 2012, 7 recorders were exchanged and additional units were deployed. Three recorders had to be left in place due to heavy ice conditions preventing access to the mooring location. Now a total number of 24 passive acoustic recorders await their recovery in 2014/2015. **Error! Reference source not found.** shows the acoustic array from 2008 to 2013.

Two types of acoustic recorders are employed: SonoVaults (SV; Develogic GmbH, Hamburg, Germany) and AURAL (AU; Multi-Électronique (MTE) Inc., Quebec, Canada).

From 2008 until 2010 and 2010 until 2012 two AURAL-M2 systems sampled at 32 kHz, 16 bit. The available memory of 160 GB required scheduled, rather than continuous sampling. Recorders were therefore programmed to sample 5 minutes every 4 hours in 2008, and 4.5 minutes every 3 hours in 2010. Since 2012, the increased storage capacity of 640 GB allowed scheduling the recordings at 5 minutes every hour. The design of the AURAL pressure housing limits deployment depth to about 300m [3]. In the Southern Ocean, moorings are generally designed with the top floatation not shallower than 200 to 250 m below sea-surface, to avoid being displaced by passing ice bergs. This requirement leaves little safety margin when moorings are depressed by strong currents which can cause AURALs to exceed their pressure rating.

SonoVault recorders, by contrast, feature a pressure rating of max. 2500m. The currently deployed version of SonoVaults can record continuously for up to 2 years. Recorders were set to a continuous recording mode at 5.3 kHz 24 bit sampling. Limiting factor for recording duration is the storage capacity of 1.1 TB, which can be extended to up to 4.4 TB in future versions. Currently, the power capacity allows continuous recording up to 3 years.

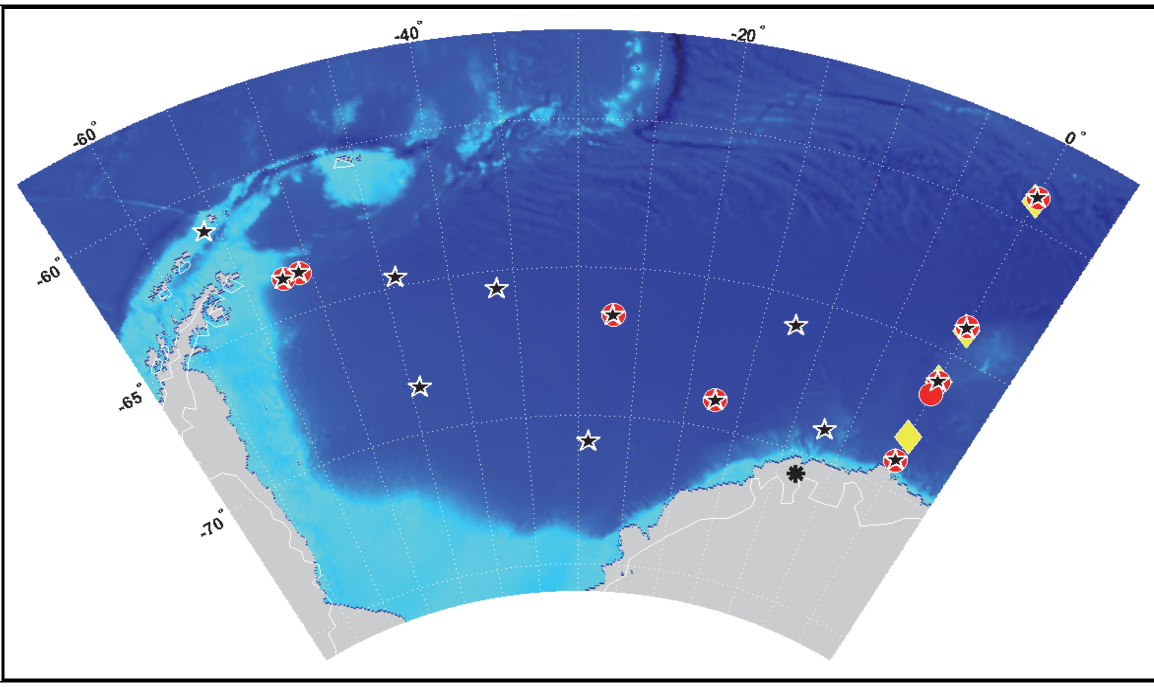

Fig. 2 Oceanographic moorings in the Atlantic Sector of the Southern Ocean containing acoustic recorders. 2008-2010 (yellow diamonds); 2010-2012 (red circles); from 2012 (black stars); German research station Neumayer III (black asterix)

Data from both AURAL recorders were analysed to map the various contributors to the local soundscapes and explore seasonal and inter-annual variation. Long-term spectrograms were computed, forming the exploratory basis for further analysis (**Error! Reference source not found.**).

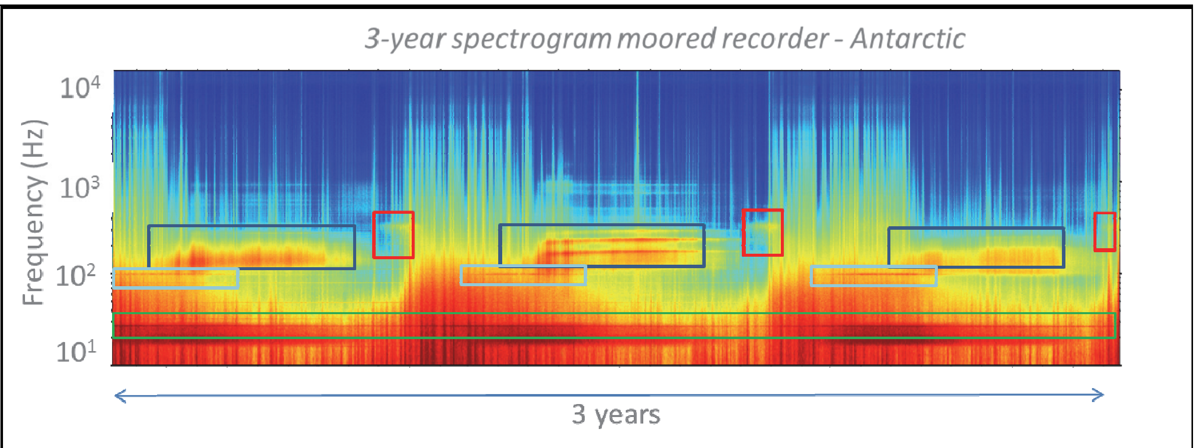

Fig. 3 3-year spectrogram: Grey =fin whales (Balaenoptera physalus), Blue=unknown sound source 'bioduck', Green=Antarctic blue whales (B. musculus intermedia), Red=leopard (Hydrurga leptonyx) and Ross seals (Ommatophoca rossii)

In 2012, data from 6 SonoVaults and 1 AURAL were recovered. Some broadband electronic noise was found in the recordings of the SonoVaults, which is currently investigated. Recording uptime varied strongly between SonoVault recorders ranging from 6 to 21 months while the AURAL was still operational during recovery after 24 months of deployment. Regular drop-outs occurred in the AURAL data when the system stored data from CF memory card to the hard disk.

Technical requirements for deployment in a polar environment

The logistic complexity and high costs of deploying and maintaining scientific measurement instrumentation, such as passive acoustic recorders, in polar oceans are often balanced by relatively long deployment periods. To optimize measurements over the entire deployment period, low power consumption and high power capacity, in conjunction with efficient subsampling schemes are a prerequisite for deployments in polar oceans. In many cases, recording systems will be refurbished and redeployed shortly after recovery. Hence, efficient handling of systems in terms of exchanging batteries, executing firmware updates and expanding storage capacity, greatly enhance the efficiency and reliability of instrument preparation at sea. Reliable and user-friendly on-board calibration possibilities of complete recording systems allow monitoring for e.g. ageing effects of hydrophones after each recovery and can help warrant the quality of the data that are collected during the next deployment. As mentioned previously, the risk of damage from passing ice-bergs in many parts of polar oceans requires deployment depths greater than 300 m. Accordingly, instrumentation housing and sensors should have adequate pressure ratings with a sufficient safety margin.

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