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Towards Collective circum-Antarctic Passive Acoustic Monitoring: The Southern Ocean Hydrophone Network (SOHN)

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The Southern Ocean Research Partnership (SORP)
Antarctic blue and fin whale Acoustic Trends Working Group (ATW)

Summary: The Southern Ocean Research Partnership (SORP) is an international research program initiated within the International Whaling Commission (IWC) in 2009 to promote collaborative cetacean research, develop novel research techniques, and conduct non-lethal research on whales in the Southern Ocean (CHILDERHOUSE 2009). One of the original research projects of the SORP is the Blue and Fin Whale Acoustic Trends Project, which aims to implement a long term passive acoustic research program to examine trends in Antarctic blue (*Balaenoptera musculus intermedia*) and fin whale (*B. physalus*) abundance, distribution, and seasonal presence in the Southern Ocean through the use of a network of passive acoustic recorders: the Southern Ocean Hydrophone Network (SOHN).

Networks of widely spaced passive acoustic recorders can provide insights in spatio-temporal patterns of the presence and properties of whale calls as well as the potential to monitor trends in Antarctic blue and fin whale abundance. The SOHN will consist of a network of autonomous underwater acoustic recording stations surrounding the Antarctic continent with each site remaining active throughout the 10-year duration of the project. In addition to circumpolar coverage, high priority will be given towards achieving simultaneous temporal coverage, especially in the early years of the project. While logistical constraints may prevent uniform distribution of SOHN recording sites around the continent, the Acoustic Trends Working group (ATW) aims to have at least one recording site in each of the six IWC management areas (i.e., one per 60° longitudinal wedge). International collaboration and coordination are imperative to achieve the project goals due to the high cost of Antarctic research as well as the broad spatial and temporal scales over which the SOHN will span. Furthermore, standardization of data is paramount for accurate and efficient analysis and interpretation of SOHN data.

To facilitate international participation in the SOHN, this document provides practical recommendations to guide and support passive acoustic data of project as well as technical and logistic information and recommendations regarding standardization of recording locations is provided here for a diverse collection in Antarctic waters. This whitepaper addresses a wide audience, ranging from scientists from different disciplines with access to instrumenttation and/or infrastructure to collect passive acoustic data in the Southern Ocean, to ship operators or other parties that can provide logistic s*upport to make the SOHN a reality. Background information* and an outline of the scientific aims of project as well as technical and logistic information and recommendations regarding standardization of recording locations is provided here for a diverse audience coming from different backgrounds with widely differing levels of experience with the applications and use of passive acoustic instrumentation. By providing the information relevant for SOHN from the ground up, we aim that this document contributes to increase awareness and participation by a broad range of partner nations and organizations in the SOHN and Acoustic Trends Projects.

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Zusammenfassung: Die „Southern Ocean Research Partnership“ (SORP), initiiert 2009 durch die Internationale Walfang-Kommission (IWC), ist ein internationales Forschungsprogramm zur Förderung der gemeinschaftlichen Walforschung, zur Entwicklung neuer Techniken und zur Durchführung nicht-letaler Forschung an Walen im Südlichen Ozean (CHILDERHOUSE 2009). Eines der ursprünglichen Forschungsprojekte innerhalb von SORP stellt das Projekt „Blue and Fin Whale Acoustic Trends“ dar, welches sich die Implementierung eines langfristigen passiv akustischen Forschungsprogrammes zum Ziel gesetzt hat. Mittels eines Netzwerkes von passiv akustischen Rekordern, dem „Southern Ocean Hydrophone Network (SOHN)“, sollen dabei Trends in der Abundanz, den Verteilungsmustern und dem saisonalen Vorkommen von Antarktischen Blauwalen (*Balaenoptera musculus intermedia*) und Finnwalen (*B. physalus*) erforscht werden. Netzwerke aus großflächig verteilten passiv akustischen Rekordern können Einblicke in raum-zeitliche Muster der Präsenz und Eigenschaften der von Walen produzierten Vokalisationen liefern, sowie mögliche Trends in der Häufigkeit antarktischer Blauwale und Finnwale offenbaren. Im Rahmen von SOHN sollen akustische Rekorder zirkumpolar um die Antarktis verteilt ausgebracht werden, wobei jeder Standort während der gesamten zehnjährigen Projektlaufzeit betrieben werden soll. Zusätzlich zur zirkumpolaren Verteilung wird, besonders in den ersten Projektjahren, hohe Priorität auf eine zeitgleiche Datenerfassung an den vorhandenen Stationen gelegt. Da logistische Einschränkungen eine gleichmäßige Verteilung der SOHN-Aufnahmestationen um den Kontinent möglicherweise erschweren, strebt die „Acoustic Trends Workinggroup“ (ATW) zumindest einen Aufnahmestandort in jedem der sechs IWC-Managementgebiete an (z.B. einen Rekorder pro 60° Längensektor). Der grundsätzlich hohe Aufwand für Forschung in der Antarktis sowie der langfristige Ansatz und die große räumliche Ausdehnung des SOHN-Projektes machen eine internationale Zusammenarbeit und Koordination zum Erreichen der Projektziele unbedingt erforderlich. Darüber hinaus ist eine Standardisierung der Daten von höchster Wichtigkeit für eine akkurate und effiziente Analyse und Interpretation der SOHN-Daten.

Zur Erleichterung einer internationalen Beteiligung am SOHN-Projekt liefert dieser Artikel praktische Empfehlungen für die Erfassung passiv akustischer Daten in antarktischen Gewässern. Dabei wird eine breit gefächerte Zielgruppe adressiert, von Wissenschaftlern verschiedener Disziplinen mit Zugang zu erforderlichen Instrumenten und/oder Infrastruktur für die Erfassung passiv akustischer Daten im Südlichen Ozean, bis hin zu Schiffsbetreibern und anderen potentiellen Partnern, die logistische Unterstützung zur Realisierung des SOHN-Projektes bereitstellen können. Erforderliches Hintergrundwissen und eine Übersicht der wissenschaftlichen Ziele des Projekts, technische und logistische Informationen sowie Empfehlungen bezüglich der Standardisierung von Aufnahmestationen werden im vorliegenden Artikel für eine Vielzahl potentieller Projektpartner, die über unterschiedliche Erfahrungen in der Anwendung und Nutzung von passiv akustischen Gerätschaften verfügen, zusammengefasst. Durch Bereitstellung dieser für SOHN relevanten grundsätzlichen sowie weiterführenden Informationen soll dieser Artikel zur Steigerung von Wahrnehmung und Teilnahme von Partnernationen und Partnerorganisationen an SOHN und dem Acoustic Trends Projekt beitragen.

INTRODUCTION

Understanding baleen whale distribution and abundance in the Antarctic, particularly for Antarctic blue (*Balaenoptera musculus intermedia*, Fig. 1) and fin whales (*B. physalus*, Fig.

2), is complicated by the pelagic distribution of both species, the difficulty of working in the Southern Ocean (SO) and the massive decline of both species due to commercial whaling. After a half-century of protection, little is known about the present-day status of each species. Both blue and fin whales were targets of commercial whaling, particularly from the early 1900's through the 1930's (Tønnessen & Johnsen 1982). Despite heavy depletion of whale stocks during this era, commercial exploitation continued into the mid and late 20th century. Blue whales were protected internationally from whaling in 1966 and fin whales in 1985. At present, both species are listed as endangered by the International Union for Conservation of Nature and there are no reliable population estimates for either species globally.

Population abundance

Sighting surveys are traditionally the means by which cetacean population abundance estimates are obtained. In the Southern Ocean however, these surveys are increasingly few and far between due to the particularly difficult working environment and the costs of surveys, and are also restricted by the inherent limitations of visual surveys (e.g., daylight, weather, sea ice, visual detection range, etc. Branch 2007, Hammond et al. 2013). From 1978 to 2010, the International Whaling Commission (IWC) supported first the International Decade of Cetacean Research (IDCR, 1978-1996) and then the Southern Ocean Whale Ecosystem Research (SOWER, 1996-2010) programs. Auxiliary data from over 30 of these annual sighting surveys (three circumpolar sets of cruises over 27 years from 1978-2004) were used to estimate the abundance of Antarctic blue whales, resulting in an estimate of 2,280 (confidence interval 1,160-4,500) Antarctic blue whales which is less than 1 % of the original population (Branch 2007). Only two of the recent cruises focused on fin whales (*Balaenoptera physalus*, Fig. 2) and did not result in any equivalent abundance estimates (Ensor et al. 2006, 2007). It is unlikely that the circum-Antarctic effort of IDCR/SOWER will be repeated in the near future. Nevertheless, the IWC is interested in monitoring the recovery of Antarctic blue and fin whales and in 2009 initiated an international research program, the Southern Ocean Research Partnership (SORP), to develop novel research techniques for non-lethal research on whales in the Southern Ocean (Childerhouse 2009). Given the distinctive and repetitive nature of certain call types produced by blue

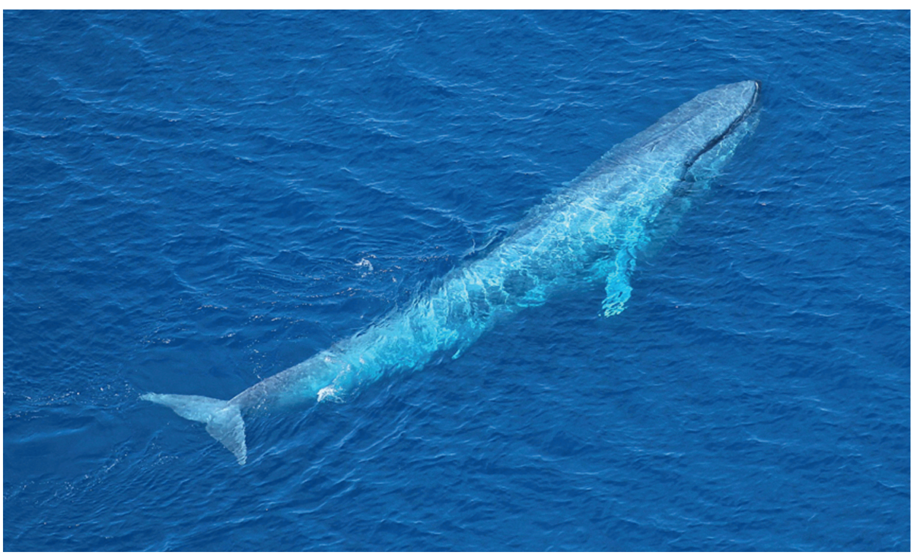

Fig. 1: Dorsal view of an Antarctic blue whale, *Balaenoptera musculus intermedia*, approaching the surface in the Southern Ocean. (Photo: Australian Antarctic Division).

Abb. 1: Antarktischer Blauwal, *Balaenoptera musculus intermedia* (Bild: Australian Antarctic Division).

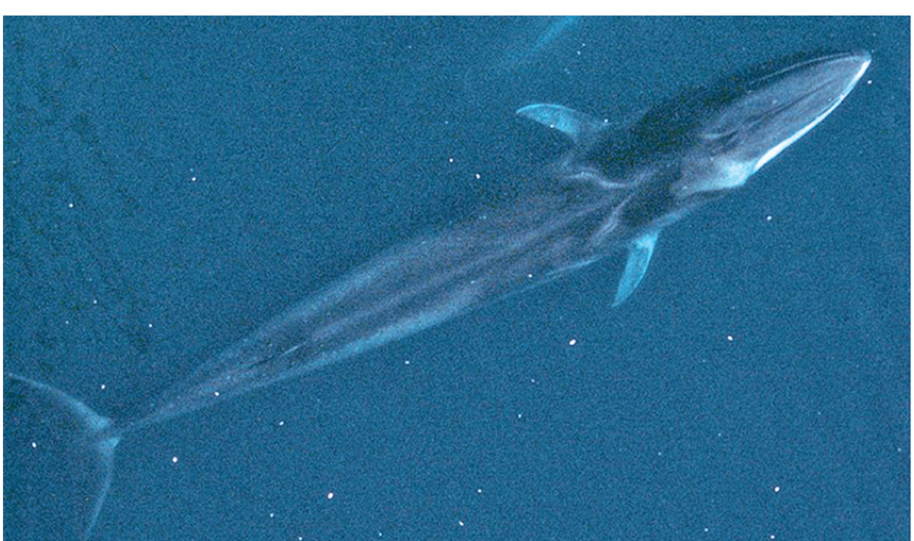

Fig. 2: Ventral view of a fin whale, *Balaenoptera physalus* (Photo: NOAA).

Abb. 2: Ventralansicht eines Finnwals, *Balaenoptera physalus* (Bild: NOAA).

and fin whales as well as the long-range propagation of vocalizations, passive acoustic monitoring offers a robust means to monitor these species over long time periods in remote areas, including the Southern Ocean (Mellinger et al. 2007, Van Opzeeland et al. 2008, Van Parijs et al. 2009, Samaran et al. 2013). The use of passive acoustic recordings of blue and fin whales to examine the geographic and seasonal occurrence of calling whales has become commonplace (Thompson & Friedl 1982, Stafford et al. 1999, 2007, Nieukirk et al. 2004, 2012, Širović et al. 2004). However, using passive acoustic tools for abundance estimation purposes is a relatively recent application of Passive Acoustic Monitoring (PAM, Marques et al. 2013) that is rapidly evolving and may hold promise for elusive species such as Antarctic blue and fin whales.

Passive acoustic monitoring (PAM)

All blue whales produce long, relatively simple, tonal, low frequency calls as part of their acoustic repertoire. Despite these similarities, geographic variation in blue whale calls has been well documented with distinct call types recorded in the Antarctic (Ljungblad et al. 1997, Rankin et al. 2005). In the Antarctic calls are often Z-shaped with a strong tone at 28 Hz that sweeps down to another tone at 19 Hz and lasts roughly 15 s (Fig. 3a) (Ljungblad et al. 1997, Rankin et al. 2005). Additionally, blue whales produce "D" calls, which are variable, higher frequency calls that have been suggested as contact calls or feeding calls (Rankin et al. 2005, Oleson et al. 2007; Fig. 3b).

Fin whales worldwide produce long sequences of pulses between ~15-40 Hz usually referred to as "20 Hz pulses" (Watkins 1981). These are much shorter in duration and generally broader in bandwidth than blue whale Z-calls. There is some evidence for geographic variation in fin whale calls in the duration of the interval between successive pulses (Delarue et al. 2009, Castellote et al. 2011) and in the presence/absence and frequency of a higher frequency pulse concurrent with the 20 Hz pulses. Two different frequency pulses have been noted in the Antarctic, one at 89 Hz from the Antarctic Peninsula region and another, from East Antarctica, at 99 Hz (Fig. 3c; Širović et al. 2009, Gedamke 2009).

Passive acoustic recordings at individual locations or regions provide information about how the presence and properties of whale calls change over time (Širović et al. 2004, Samaran et al. 2010, Gavrilov et al. 2012). At a minimum, passive acoustic data reveal when a species occurs in a region (but only when animals are acoustically active). If additional parameters such as the probability of detecting produced calls in the study area and the average call production rate (including any non-calling proportion of the population) can also be estimated, there is the potential to estimate abundance or density of Antarctic blue and fin whales from acoustic data (Thomas & Marques 2012, Marques et al. 2013). Therefore, temporal trends in Antarctic blue and fin whale abundance could be monitored using long-term acoustic datasets. Furthermore, spatial patterns of calling activity (or abundance, if estimable) can be assessed using networks of widely spaced recorders, potentially providing information about broad-scale movements of animals (Stafford et al. 2004, Morano et al. 2012, Nieukirk et al. 2012, Samaran et al. 2013).

The Southern Ocean Research Partnership (SORP)

One of the original five research projects of the SORP is the Blue and Fin Whale Acoustic Trends Project. The Acoustic Trends Workinggroup (hereinafter referred to as ATW) aims to implement a hydrophone network around the Antarctic that will examine trends in Southern Ocean Antarctic blue and fin whale behaviour, seasonal presence, distribution and abundance through the use of passive acoustic monitoring techniques (Childerhouse 2010). Using a network of passive acoustic instruments to record calls of Antarctic blue and fin whales provides a valuable and cost-efficient method to gather data on trends in abundance in these species (Mellinger et al. 2007). Furthermore, the ATW proposes monitoring of the same areas, simultaneously, over relatively long time scales. Such coordinated spatio-temporal monitoring effort will strengthen the eventual analysis of the data, allowing more robust conclusions to be made about the observed patterns in calling activity.

International collaboration and coordination are central to the SORP and achieving the project goals would be very difficult without it due to the high cost of Antarctic research as well as

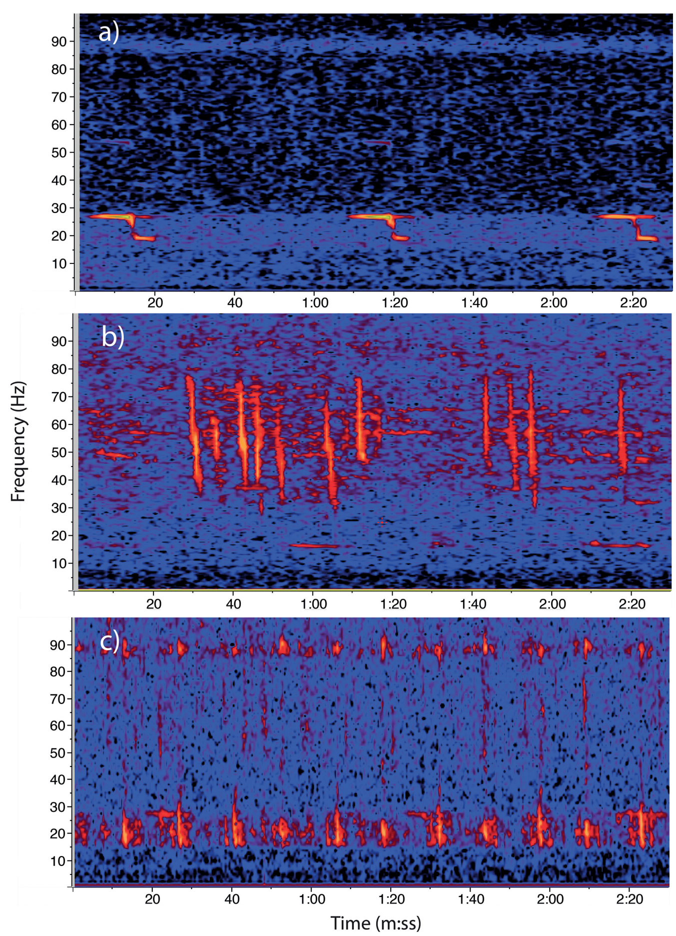

Fig. 3: Spectrograms of Antarctic blue whales (512 pt FFT, 50 % overlap, Hann window). (a) = Antarctic blue whale "Z" calls; (b) = Antarctic blue whale "D" calls; (c) = Antarctic fin whale 20 Hz pulses and 89 Hz high pulses.

Abb. 3: Spektrogramme antarktischer Blauwale (FFT-Fensterlänge = 512 Punkte, 50 % Überlappung, Hann window). (a) = „Z-Vokalisationen" antarktischer Blauwale; (b) = „D-Vokalisationen" antarktischer Blauwale; (c) = 20 Hz und 89 Hz Pulse antarktischer Finnwale.

the broad spatial and temporal scales over which the hydrophone network will span. Just as important is the standardization of data from different areas for accurate and efficient analysis and interpretation of the circum-Antarctic dataset. To facilitate international participation in the project, the ATW aims to provide practical recommendations to guide and support passive acoustic data collection in Antarctic waters with this document. We address a wide audience, ranging from scientists from different disciplines with access to instrumentation and/or infrastructure to collect passive acoustic data in the Southern Ocean, to ship operators or other parties that can provide logistical support to make the hydrophone network a reality. Background information and an outline of the scientific aims of project as well as technical and logistical information and requirements of the SOHN are provided here to inform and encourage a diverse audience (coming from different backgrounds with widely differing levels of knowledge and experience) on the applications and use of passive acoustic instrumentation.

THE SOUTHERN OCEAN HYDROPHONE NETWORK – SOHN-PROJECT

Long-term passive acoustic recorders deployed for up to a year or more were first utilized to study baleen whales in the Southern Ocean (Širović et al. 2004). In 2001, seven Acoustic Recording Packages (ARPs) were deployed for two years off the Antarctic Peninsula to acoustically monitor seasonal movements of large baleen whales (Wiggins 2003, Širović et al. 2004). Although other projects followed to deploy long-term passive acoustic recorders in the Southern Ocean (e.g. Mellinger et al. 2007, Širović et al. 2009), to date long-term PAM is used still relatively sporadically in this region. A review of the available passive acoustic data from the Southern Hemisphere by the ATW (Samaran et al. 2012) illustrated how coverage differs strongly between areas, with some areas being monitored continuously over several years (e.g., at Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) sites, the Perennial Acoustic Observatory in the Antarctic Ocean (PALAOA)), whereas others (e.g., IWC area 1 and 6, see Fig. 4) had no passive acoustic monitoring effort (Samaran et al. 2012). Furthermore, the currently available (long-term) records comprise widely varying time frames, ranging in duration from several months to years (Sirović et al. 2009, Samaran et al. 2012). The fact that these passive acoustic data were collected at changing locations over the past decade with a range of different recording equipment further complicates comparisons among areas and time periods with regards to obtaining information on possible trends in abundance and distribution.

To initiate a long-term structured monitoring program and the gathering of baseline acoustic data, we propose the implementation of a passive acoustic monitoring network consisting of a "necklace" of Passive Acoustic Recorders (PARs) surrounding the Antarctic continent: the Southern Ocean Hydrophone Network (SOHN). One of the core objectives driving the SOHN project is to understand geographic and temporal variation in distribution patterns of animals through their calling behavior. Passive acoustic monitoring therefore needs to occur at a number of fixed locations over the complete duration of the SOHN project. International collaboration and coordination will be essential for the SOHN project to succeed given the scale of effort that is envisioned both in terms of data collection and processing. The low density of shipping in the Southern Ocean combined with limited access to Antarctic-going vessels requires international collaboration among various national research programs and institutes in order to efficiently share logistical assets and minimize the costs of data acquisition.

With this whitepaper, the ATW aims to encourage and guide nations participating in the SOHN project with a set of recommendations to standardize the data that will be collected. We discuss deployment and recovery options for PARs, and investigate tradeoffs among different hardware, software, and mooring systems that comprise available PARs. We then provide recommendations regarding recording locations, hardware, and specifications (e.g., sample rate, duty cycling recordings), as well as recommendations with respect to data formats, calibration, and metadata required by the project. Finally, the ATW proposes that the data acquired by the SOHN PARs are archived in a central data repository, allowing integrative processing of the circum-Antarctic data.

Timeframe

The recommended operational period for the SOHN is ten years as this represents the time span over which the population of Antarctic blue whales should double, assuming a population growth of 7 % (Branch et al. 2004). Furthermore, long-term operation (i.e. collecting continuous acoustic records) of PARs at each site, especially early in the life of the SOHN, is highly recommended in order to facilitate simultaneous coverage, which is required to address questions regarding the spatial distribution of calling whales within a season.

After the initial six years, the need for continuous data collection at each location will be re-evaluated. If non-continuous data collection is deemed sufficient, close temporal coordination between sites will be essential, as it is only through such a coordinated effort that the aims of the SOHN project can be met.

Spatial coverage

To best assess trends in the distribution and possible abundance of blue and fin whales, an understanding of spatio-temporal distribution patterns, including knowledge of where animals are not found, is required. Ideally, the SOHN would therefore have dense circum-Antarctic coverage with equal monitoring effort in all IWC areas. However, logistical limitations make achieving such coverage very difficult. For example, scant shipping routes in the central Pacific sector of the Southern Ocean provide limited cost-effective opportunities for PAR deployments, in contrast to the Atlantic sector of the Southern Ocean which is transited by ships relatively frequently due to ongoing research programs (Fig. 4). Acknowledging these practical concerns, the SOHN project aims to have at least one PAR station in each of the six IWC management areas (Tab. 1). PARs are recommended to be placed within 200 km of the edge of the maximum summer extent of sea ice, to maximize

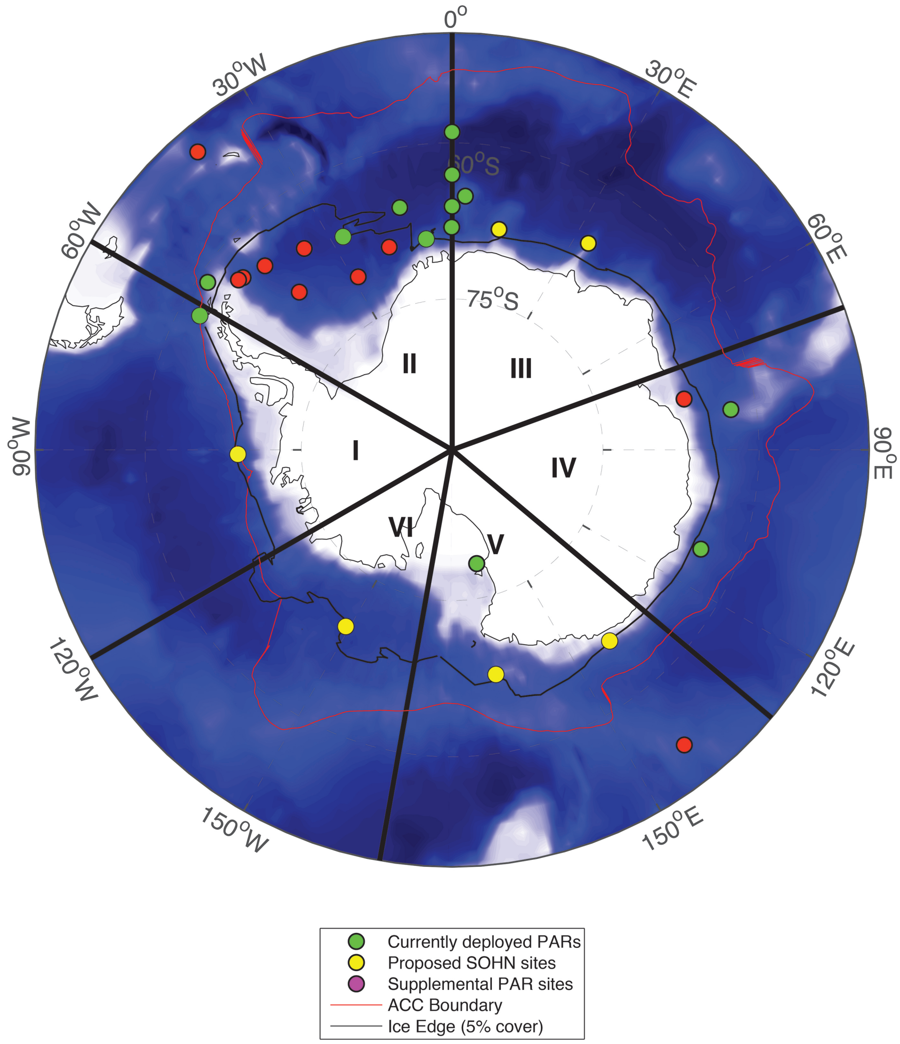

Fig. 4: Locations of current recording sites that may be used as part of SOHN (green circles) and proposed SOHN recording sites (yellow circles). Thick black lines indicate International Whaling Commission (IWC) management areas I-VI. The red line shows the northern boundary of the Antarctic Circumpolar Convergence (Sokolov & Rintoul 2009a). The thin black line is indicative of the edge of the sea ice and corresponds to the monthly average sea-ice cover of 5 % in March from 2000-2012 (Maslanik & Stroeve 1999). Red circles show the location of deployed PARs that do not meet SOHN requirements with regard to the ACC boundary, or Ice edge, but may still provide supplementary data.

Abb. 4: Aktuelle Positionen passiv akustischer Rekorder für eine potentielle Nutzung innerhalb des SOHN-Projektes (grüne Punkte) und vorgeschlagene SOHN-Rekorderstandorte (gelbe Punkte). Dicke schwarze Linien kennzeichnen die Managementgebiete I bis VI der International Whaling Commission (IWC). Die rote Linie zeigt die nördliche Grenze des Antarktischen Zirkumpolarstroms (Sokolov & Rintoul 2009a). Die dünne schwarze Linie zeigt die Meereisgrenze (monatliches Mittel der mindestens 5 % Eisbedeckung im März in den Jahren 2000-2012 (Maslanik & Stroeve 1999). Rote Punkte zeigen die Standorte weiterer passiv akustischer Rekorder an, die aufgrund ihrer Lage nicht die für SOHN erforderlichen Standortbedingungen erfüllen (z.B. hinsichtlich der Grenze des Zirkumpolarstroms oder der Eisgrenze), aber dennoch zusätzliches Datenmaterial liefern können.

the chances that PARs can be retrieved by non-ice breaking vessels. PARs that form part of the SOHN are required to be placed south of the Antarctic Convergence as this zone may act as a barrier in sound propagation. In order to further compare data collected by the SOHN project with historic data sets from the Antarctic, SOHN stations should be established, where practical and appropriate, at the locations of historic recordings (see Tab. 1). Presently, France, Germany, Australia, Argentina and South Africa have deployed, or have plans in the near future to deploy hydrophones in Antarctic waters that may be used as first nodes of the network (green circles, Fig. 4).

Logistical issues

In addition to the limited ship time for Antarctic work, the spatial and temporal coverage of the SOHN project may be further restricted by the cost of PARs. Fixed costs include the cost of purchase of PARs and training of technicians, while ongoing costs of PARs include the cost of servicing, calibration, and the ship time required for deployment and recovery. The cost of electronic components of PARs is likely to decrease with the recent and continuing proliferation of efficient, low-powered purpose-built computers and affordable data storage. Ongoing costs, especially those arising from the ship time required for deployment and recovery, are therefore likely to represent the major costs of PAR stations in the SOHN project. This requires international collaboration among different institutes in order to efficiently share logistical assets and minimize the costs of data acquisition and processing.

Standardization

For this multi-national large-scale passive acoustic monitoring project to achieve the goal of compiling a circum-Antarctic data set spanning ten years, standardization of acoustic and meta-data acquisition methods and data processing is an important prerequisite. The definition of data acquisition and processing standards will allow data from the PARs that compose the SOHN to be merged into a pan-Antarctic database, freely available to participating members, from which large scale patterns in distribution and habitat usage can subsequently be extracted. A blueprint for SOHN passive acoustic data processing will be the focus of a separate document that is currently in preparation by the ATW group.

As emphasized in previous sections, it is paramount that recording efforts are coordinated both spatially and in time,

Instrument name	Depth (m)	Latitude	Longitude	Start date	End date	Instrument type	Initial contact
Drake	350	-60.5	-61	2005-01-01	2006-01-01	HARUphone	Dziak/Park
Bransfield 1	350	-62.9	-59.5	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield 2	350	-62.5	-58.9	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield 3	350	-62.5	-58	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield 4	350	-62.3	-57.9	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield 5	350	-62.2	-57.1	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Bransfield 6	350	-62.9	-60.2	2005-01-01	2007-01-01	HARUphone	Dziak/Park
Scotia1	350	-57.5	-41.4	2007-01-01	2009-01-01	HARUphone	Dziak/Park
Scotia 2	350	-58.9	-37	2007-01-01	2009-01-01	HARUphone	Dziak/Park
Scotia 3	350	-57.4	-36.6	2007-01-01	2009-01-01	HARUphone	Dziak/Park
Scotia 4	350	-56.4	-33.9	2007-01-01	2009-01-01	HARUphone	Dziak/Park
WAP 1	1600	-62.3	-62.2	2001-03-01	2003-02-01	ARP	Širović/Hildebrand
WAP 2	3000	-63.8	-67.1	2001-03-01	2003-02-01	ARP	Širović/Hildebrand
WAP 3	3000	-65	-69.1	2001-03-01	2003-02-01	ARP	Širović/Hildebrand
WAP 4	3000	-66	-71.1	2001-03-01	2003-02-01	ARP	Širović/Hildebrand
WAP 5	3000	-66.6	-72.7	2001-03-01	2003-02-01	ARP	Širović/Hildebrand
WAP 6	3000	-67.1	-74.2	2001-03-01	2003-02-01	ARP	Širović/Hildebrand
WAP 7	450	-65.4	-66.1	2001-03-01	2003-02-01	ARP	Širović/Hildebrand
WAP 9	870	-67.9	-68.4	2001-03-01	2003-02-01	ARP	Širović/Hildebrand
Casey 2004	3000	-63.8	111.8	2004-02-01	2005-01-01	ARP	Gedamke
Prydz 2005	1800	-62.6	81.3	2005-01-01	2006-02-01	ARP	Gedamke
Kerg 2005	2700	-66.2	74.5	2005-02-01	2006-02-01	ARP	Gedamke
Kerg 2006	2680	-66.2	74.5	2006-02-01	2007-03-01	ARP	Gedamke
Prydz 2006	1900	-62.6	81.3	2006-02-01	2007-03-01	ARP	Gedamke
65S.2006	1100	-65.6	140.5	2006-02-01	2007-01-01	Curtin Logger	Gedamke
54S.2006	1600	-53.7	144.8	2005-12-01	2006-10-01	Curtin Logger	Gedamke
54S.2008	2078	-53.7	141.8	2007-12-01	2009-02-01	Curtin Logger	Gedamke
Kerg 2009	587	-56.1	77.8	2009-02-01	2010-01-01	Curtin Logger	Gedamke
Casey 2010	2770	-64.6	108.3	2009-12-01	2010-12-01	Curtin Logger	Gedamke
PALAOA	180	-70.3	-8.1	2005-12-27	ongoing	PALAOA (2 hydrophones)	AWI/van Opzeeland
MARU#1	4798	-59.1	0.0	2008-12-12	2010-12-12	MARU	AWI/van Opzeeland
MARU#2	5144	-64.1	0.1	2008-12-14	not recovered	MARU	AWI/van Opzeeland
AWI 230-6	200	-66.0	0.0	2008-03-08	2010-12-16	aural	AWI/van Opzeeland
AWI 232-9	216	-68.6	0.0	2008-03-11	2010-12-19	aural	AWI/van Opzeeland
AWI 227-11	1007	-59.0	0.1	2010-12-11	2012-12-11	sonovault	AWI/van Opzeeland
AWI 229-9	969	-63.6	0.0	2010-12-15	2012-12-14	sonovault	AWI/van Opzeeland
AWI 230-7	934	-66.0	0.0	2010-12-16	2012-12-15	sonovault	AWI/van Opzeeland
AWI 231-9	1083	-66.3	0.0	2010-12-23	2012-12-16	sonovault	AWI/van Opzeeland
AWI 232-10	987	-69.0	0.0	2010-12-19	left on position (2015)	sonovault	AWI/van Opzeeland
AWI 244-2	1003	-69.0	-7.0	2010-12-27	2012-12-26	sonovault	AWI/van Opzeeland

Instrumen name	Depth (m)	Latitude	Longitude	Start date	End date	Instrument type	Initial contact
AWI 245-2	1051	-69.0	-17.2	2010-12-27	2012-12-28	sonovault	AWI/van Opzeeland
AWI 209-6	207	-66.4	-27.1	2010-12-29	2013-01-01	aural	AWI/van Opzeeland
AWI 207-8	219	-63.4	-50.5	2011-01-06	left on position (2015)	aural	AWI/van Opzeeland
AWI 206-7	909	-63.3	-52.1	2011-01-06	left on position (2015)	sonovault	AWI/van Opzeeland
AWI 227-12	1020	-59.0	0.0	2012-12-11	2015-01	sonovault	AWI/van Opzeeland
AWI 229-10	969	-63	0.0	2012-12-14	2015-01	sonovault	AWI/van Opzeeland
AWI 230-8	949	-66.0	0.0	2012-12-15	2015-01	sonovault	AWI/van Opzeeland
AWI 232-11	958	-68.0	-0.1	2012-12-18	2015-01	sonovault	AWI/van Opzeeland
AWI 244-3	998	-69.0	-7.0	2012-12-25	2015-01	sonovault	AWI/van Opzeeland
AWI 248-1	1081	-65.6	-12.2	2012-12-27	2015-01	sonovault	AWI/van Opzeeland
AWI 245-3	1065	-69.0	-17.2	2012-12-28	2015-01	sonivault	AWI/van Opzeeland
AWI 249-1	1051	-70.5	-28.5	2012-12-30	2015-01	sonovault	AWI/van Opzeeland
AWI 209-7	226, 1007, 2516	-66.4	-27.1	2013-01-01	2015-01	sonovault	AWI/van Opzeeland
AWI 208-7	956	-65.4	-36.3	2013-01-03	2015-01	sonovault	AWI/van Opzeeland
AWI 250-1	1041	-68.3	-44.1	2013-01-05	2015-01	sonovault	AWI/van Opzeeland
AWI 217-5	960	-64.2	-45.5	2013-01-09	2015-01	sonovault	AWI/van Opzeeland
AWI 207-9	219, 1012, 2489	-63.4	-50.5	2013-01-12	2015-01	sonovault	AWI/van Opzeeland
AWI 206-8	277 907	-63.2	-51.5	2013-01-04	2015-01	aural sonovault	AWI/van Opzeeland
AWI-251-1	212 210	-61.0	-55.6	2013-01-06	2015-01	sonovault aural	AWI/van Opzeeland
AWI K02	235	-52.25	-40.5	2013-10-01	2015-01	aural	AWI/van Opzeeland
Davis 2013	2000	-66.2	74.5	2013-01-01	2014-01-01	AAD	AAD
Maud Rise	300	-65	3	2014-01-01	2015-01-01	aural	SABWP
Astrid Ridge	300	-67.75	12	2014-01-01	2015-01-01	aural	SABWP
Dumont Durville	1100	-65.6	140.5	2013-01-01	2015-01-01	Aural	AAD
Casey 2014	2770	-63.7	111.8	2013-12-21	2015-01-01	AAD	AAD
Kerguelen 2014	1800	-62.38	81.82	2014-02-28	2015-01-01	AAD	AAD
Elephant Island 2014		-62	-62	2014-02	2015-02	HARP	Melcon/Hildebrand
Ross Sea 2014		-78	167	2014-02	2015-02		Dziak

Tab. 1: List of known passive acoustic recorder (PAR) deployments in the Southern Ocean.

Tab. 1: Zusammenstellung bisher ausgebrachter Verankerungen mit passiven akustischen Rekordern (PAR) im Südlichen Ozean.

but also ideally with respect to the type of recording equipment that is used, how PARs are programmed (e.g., sample rate, duty cycle) and the type of acoustic data analyses that are used to extract the relevant information. Provided that a proper funding source can be identified, the ATW aims to create and stock a "library" of calibrated instruments that could be checked out by participating partners for deployments either in an extant mooring or as a stand-alone instrument. In the meantime, below we provide details on instruments, moorings and deployments that might be used for opportunistic mooring of instruments that can become part of the SOHN.

Deployment and recovery considerations

Here, we adopt the definition from the recent review on fixed autonomous PAM recorders by Sousa-Lima et al. (2013) that an acoustic recorder (PAR) is defined as *"any electronic recording device or system that acquires and stores acoustic data internally (i.e., without cable or radio links to a fixed platform or receiving station) on its own, without the need of a person to operate it; it is deployed semi-permanently underwater (i.e., usually via a mooring, buoy, or attached to the sea floor); and is archival (i.e., must be retrieved after the deployment period to access the data)."*

We hereby stress that this definition therefore excludes recordings collected with ship-towed arrays, gliders, sonobuoys or cabled observatories. While *in situ* recordings from towed arrays and sonobuoys are likely to be highly complementary to long-term recordings made by PARs, collection and analysis of these short-term recordings are presently outside of the scope of the SOHN project. The same applies to long-term data sets from cabled observatories such as the Comprehensive Test Ban Treaty Organization and PALAOA – these will also provide important complementary data to the SOHN but, based on their location, are not considered direct nodes of the hydrophone network.

In this section we offer recommendations regarding deployment and recovery of PARs. Often tradeoffs must be made between best practices and efficient-practices in order to accommodate logistical constraints and costs. While there is no single "best-practice" for all deployment and recovery scenarios, we attempt to consider the scenarios that are most likely to occur.

Deployment depth

Long-range propagation of underwater sound is highly dependent on the stratification of the water column. Hence reception of Antarctic blue and fin whale calls may display complex depth and distance dependent patterns depending on the relative location of the whale and the receiver. Thus accurate knowledge of the environmental conditions (e.g., depth, salinity, temperature profile) as well as the precise location of the PARs is required in order to maximize the utility of the acoustic data.

The Southern Ocean has a relatively uniform hydrographic regime, at least in the open ocean environment, and stratification is generally stable without strong fluctuations. However, the oceanographic regime can display substantial variation throughout time in areas where circumpolar Antarctic currents have strong interactions with large-scale topography (Sokolov & Rintoul 2009a, b). Most of the energy from sounds produced in shallow waters in the Antarctic are likely to be retained in a surface duct due to a relatively shallow sound-speed minimum and an upward refracting sound-speed profile found in most Antarctic waters (Hall 2005, Miller et al. 2014; Fig. 5). However, logistical, bathymetric, and sea-ice related constraints may prohibit deployment and recovery of PARs in these shallow waters (see below). In order to ensure similar sound-propagation at each of the initial sites comprising the SOHN it is recommended that PARs be deployed deeper than 1000 m.

Ultimately, the relationships between signal strength, background noise contribution, and deployment depth will be re-evaluated based on data from experimental moorings with multiple PARs at different recording depths, which are currently in deployment (Van Opzeeland et al. 2013) to choose a deployment depth that minimizes variability in the detection range and detection probability among sites for Antarctic blue and fin whale acoustic signatures. For deployments where instrument depth might not be known, or may vary (e.g., on an oceanographic mooring), an integrated or external pressure/ depth sensor that is suitable for long-term deployments should be included near the hydrophone.

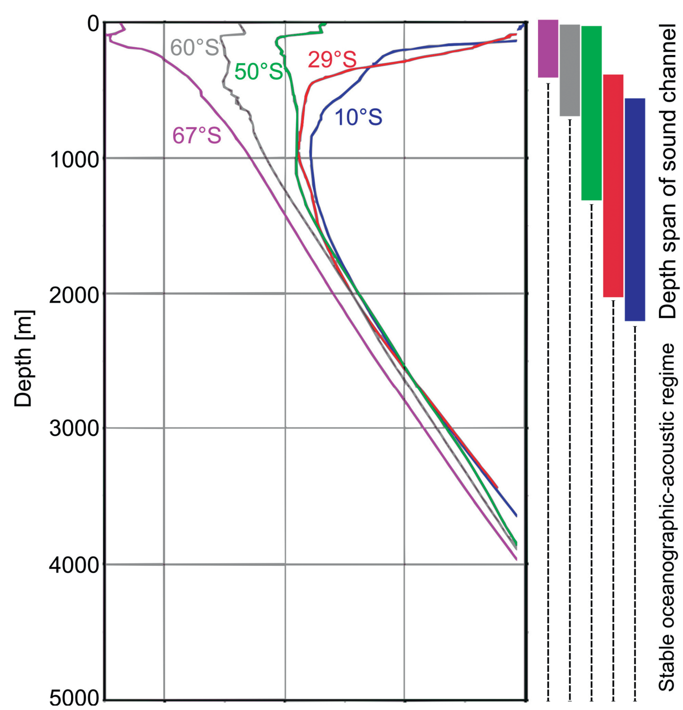

Fig. 5: Sound velocity profiles from hydrographic stations across the Pacific Ocean. An efficient channel for sound propagation is observed around the minimum in the sound-speed-profile. For the 10 °S and 29 °S profiles the axis of the sound channel is around 1000 m. At higher latitudes, the sound-speed minima shift towards the surface creating a surface duct at 50 °S, 60 °S and 67 °S (from Boebel et al. 2009).

Abb. 5: Schallgeschwindigkeitsprofile an pazifischen Hydrografie-Messstationen. Ein geeigneter Schallkanal ist jeweils erkennbar im Bereich der minimalen Schallgeschwindigkeit. In den Profilen bei 10 °S und 29 °S liegt der Schallkanal um etwa 1000 m Tiefe. Weiter südlich (bei 50 °S, 60 °S und 67 °S) erzeugt die zur Oberfläche hin verlagerte minimale Schallgeschwindigkeit einen Oberflächenschallkanal (aus Boebel et al. 2009).

Moorings

PARs can be deployed as part of existing scientific (e.g., oceanographic) moorings, or they may be independently anchored to the sea floor (Fig. 6). In the Southern Ocean, moorings are generally designed with the top flotation not shallower than 200 m below the sea-surface to avoid entrapment and subsequent displacement by passing icebergs. PARs within the SOHN are recommended to be deployed >1000 m to ensure low ambient noise floors and consistent sound propagation among recording sites. Care needs to be taken that PARs are not positioned directly below flotation as these could acoustically shield the PAR and cause turbulence and hence low-frequency noise in the recordings. Hydrophones should be located at least 10 m, ideally 50 m, below floats.

In the frequency band of Antarctic blue and fin whale vocalizations (10-100 Hz), recordings might be heavily affected by strumming noise if the mounting of the hydrophone is too rigid. Strumming noise can be reduced by introducing flexibility in the PAR mounting. PARs can be attached to the mooring line with swivels on both ends so that they can rotate or move along the mooring line with so-called eddy-grips, so as to move with currents. Any combination of metals (e.g. of shackles and mooring frames) needs to be evaluated for compatibility and isolators must be used when necessary to prevent corrosion, which can eventually lead to instrument loss. Taping of shackles or other actions that can introduce O_2-rich or -poor regions should also be avoided to prevent crevice corrosion. Insulated wire or cable ties, rather than tape, have been used successfully to keep shackle bolts held fast. Previous long-term deployments of PARs in the Southern Ocean suggest the prevalence of corrosion and biofouling appears to be relatively low. Galvanized shackles and rings as mooring hardware have proved to work well.

PARs deployed in areas that are known to have some degree of ice cover at the time of retrieval, may need to be designed

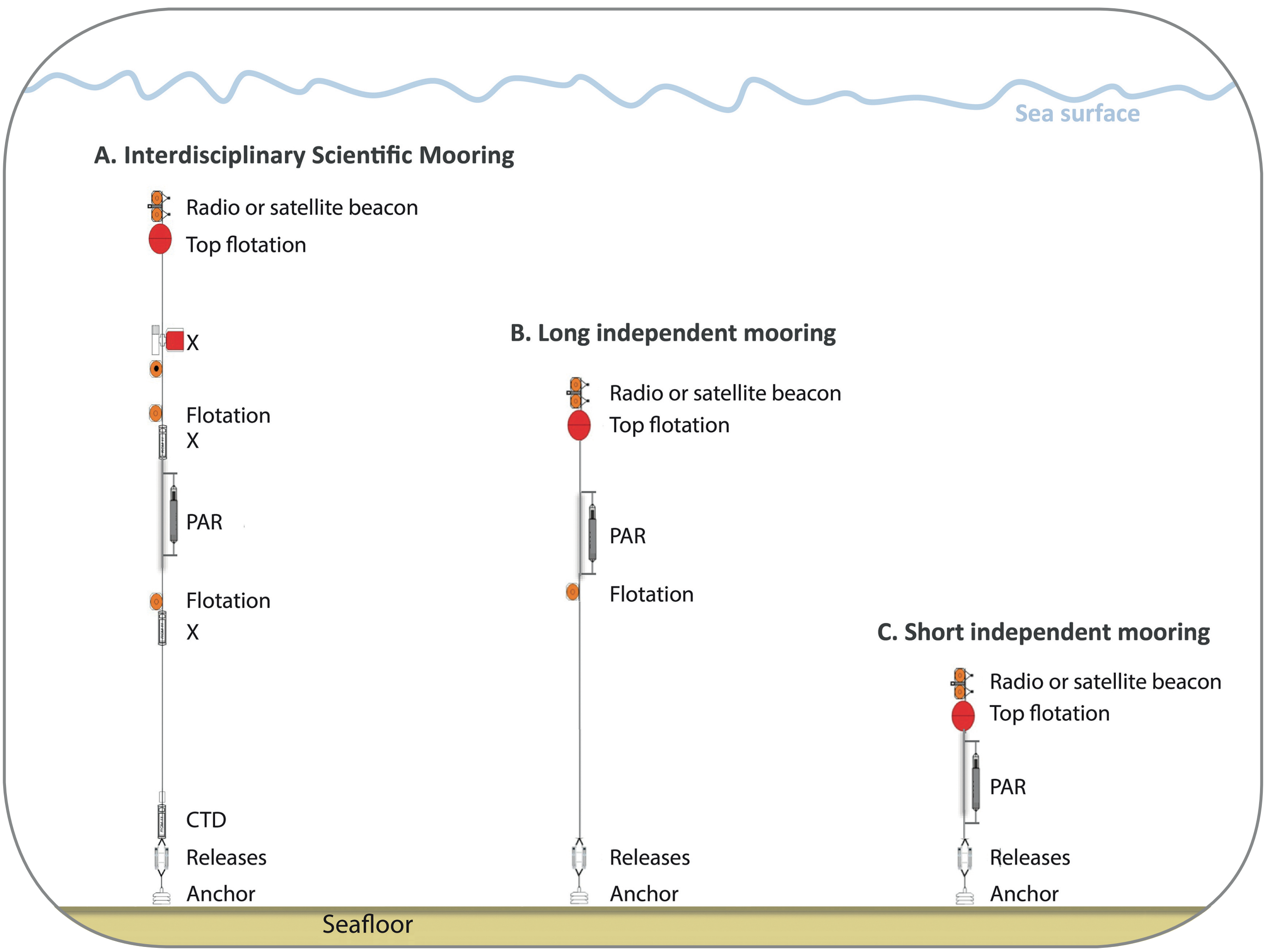

Fig. 6: Example mooring set-up for Passive Acoustic Recorders (PAR) in (A) = interdisciplinary moorings; (B) = long-independent moorings; and (C) = short-independent moorings. X indicates other scientific measurement instruments (e.g., ADCP, current meter, sediment traps). Note that depicted mooring length is not to scale, e.g. short independent moorings may be only 20 to 30 m off the sea floor, whereas long and inter-disciplinary moorings can be 10 or more times as long, depending on their set up and location.

Abb. 6: Exemplarische Verankerungsstruktur für passive akustische Rekorder (PAR) in: (A) = multidisziplinären Verankerungen, (B) = reine lange PAR-Verankerungen und (C) = reine kurze PAR-Verankerungen. X kennzeichnet das Vorhandensein weiterer wissenschaftlicher Messgeräte (z.B. ADCP, Strömungsmesser, Sedimentfallen). Die abgebildeten Verankerungslängen sind nicht maßstabsgetreu, z.B. sind kurze PAR-Verankerungen mit nur 20 bis 30 m Länge möglich, wohingegen lange und multidisziplinäre Verankerungen, abhängig von Aufbau und Lage, die zehnfache Länge (oder mehr) aufweisen können.

with longer mooring lengths as short moorings may not be as readily detected on the surface during retrieval operations. While the mooring length must be balanced with additional costs and operational ease of deployment and recovery, longer moorings are easier to relocate and are recommended in areas with dense ice fields during retrieval. This does not apply in areas with open water, where short moorings can be used with more confidence of a successful relocation. Figure 7 is a flowchart intended to help determine which type of mooring, deployment and recovery strategy is suitable for some common scenarios.

Deployment of PARs in scientific moorings

Using oceanographic mooring infrastructure can help to significantly reduce the cost and logistic effort of deployment and recovery of PARs, particularly in the Southern Ocean. In the context of integrating PARs in oceanographic moorings, it needs to be stressed that PARs do not affect oceanographic measurements, have little hydrodynamic drag and are similar in deployment and recovery operation to standard oceanographic instrumentation such as current meters and acoustic releases. PARs only need a little additional flotation to be added to compensate for their weight (e.g. two additional benthos spheres for a 30 kg PAR). When PARs are deployed with eddy grips, mounting of the PAR occurs out of the mooring line (Fig. 6) and is therefore independent of overall mooring forces. Examples of studies that had PARs included in existing scientific moorings are Miksis-Olds et al. (2010), Royer et al. (2010), Moore et al. (2012), Stafford et al. (2012), and Rettig et al. (2013).

When using existing scientific moorings to deploy PARs, deployment duration will be dependent on the frequency with which the oceanographic moorings are serviced. This projected deployment duration should be factored into decisions on the hardware (e.g., hard drive size, battery life) and software programming (e.g., sample rate) for the instrumentation. Furthermore, deployment locations of PARs are of course dependent on the purpose of the oceanographic measurements.

A further advantage of including PARs in inter-disciplinary moorings is that, in some cases, additional *in situ* environmental information can be obtained from measurement instruments on the same mooring, such as time series data on temperature, currents and local biomass in the water column from ADCPs and sediment traps (e.g., Cisewski et al. 2010). Such auxiliary data may be useful to
(1) assess changes in local sound propagation and therefore changes in the ability of the PAR to detect whales and
(2) derive information on spatio-temporal association patterns of whales with prey as well as other species-specific habitat preferences.

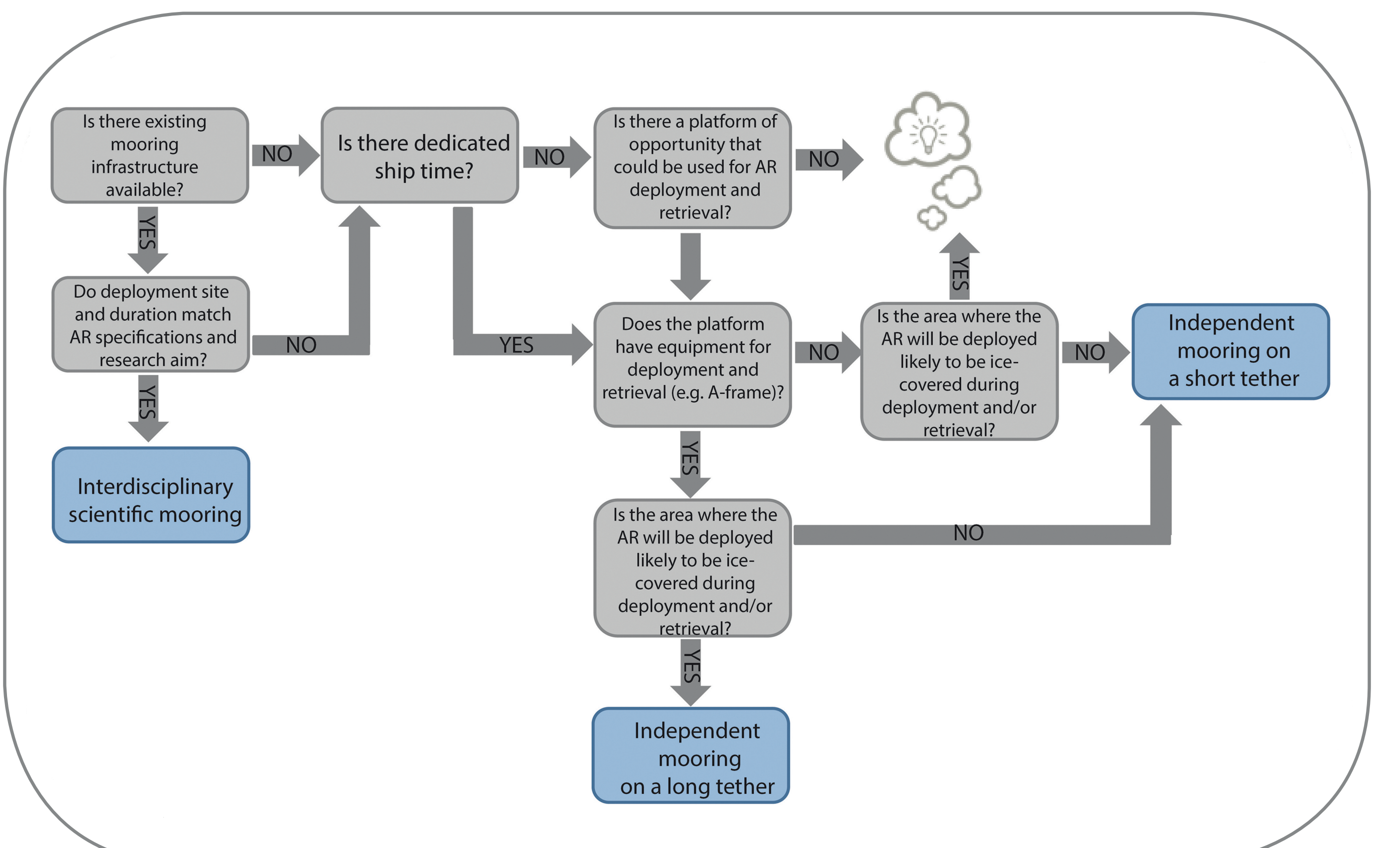

Fig. 7: Flow-chart of different mooring designs to guide decisions on deploying in interdisciplinary moorings, long-independent moorings, and short-independent moorings. The cloud with the light bulb indicates that PAR deployment may be unfeasible or other options to deploy a PAR need to be explored.

Abb. 7: Schematische Darstellung verschiedener Verankerungsdesigns als Leitfaden für den Einsatz von multidisziplinären Verankerungen, reinen langen PAR-Verankerungen und reinen kurzen PAR-Verankerungen. Das Glühbirnen-Symbol deutet darauf hin, dass der Einsatz eines akustischen Rekorders nicht durchführbar ist bzw. alternative Möglichkeiten bezüglich eines Einsatzes sondiert werden müssen.

Independently moored PARs

There are two possible ways to independently moor PARs: as bottom-mounted (i.e., sitting on the sea-floor or on a very short tether) instruments or as part of longer mooring lines that are anchored to the seafloor but extend up into the water column.

Compared to oceanographic moorings, independently moored PARs may provide greater flexibility in terms of deployment location and duration (i.e., frequency of service). However, this flexibility may come with extra costs mainly due to the need for dedicated time for deployment and recovery as well as the need for relatively specialized systems and shipboard equipment to deploy and recover moorings. For moorings with heavy anchors (long moorings, bottom-mounted moorings), a crane or A-frame is generally required to safely lift and deploy the float, instrument and particularly the anchor from on deck. For long moorings, a winch for spooling out line is ideal – however, on deck on- and off-spooling using a simple stand is feasible. Specialized recovery systems are typically comprised of acoustically-activated release mechanisms. These systems are costly, but especially important for moorings anchored in deep waters.

In the sections below, we briefly discuss several ways in which the additional costs that apply to independently moored PARs may be mitigated, explore the tradeoffs between costs of ship charters vs. the costs of moorings, and discuss PAR designs that may exemplify these tradeoffs.

Mitigating the high costs of ship time

Opportunistic deployments

To minimize the amount of dedicated ship time required for independent mooring deployments, mooring locations may be selected along existing supply routes for Antarctic stations (e.g., Gedamke et al. 2007). Apart from reducing the time to reach the deployment location, this also facilitates regular (i.e., often annually in the case of Antarctic station supply ships) servicing of the mooring. However, as is the case when using existing scientific mooring infrastructure, deployments are restricted to locations along supply routes. This should not be problematic so long as the requirements for preferred latitude and concurrent deployment with instruments at other longitudes are met.

When no dedicated ship time is available, some PAR types may allow deployment off platforms of opportunity, such as cruise ships. It is paramount in this case that the dimensions and weight of the PAR unit allow deployment from the platform of opportunity (for example, when no crane and winch are available). Mooring set-up needs to be simple (e.g. have short tethers) and instruments should be prepared for deployment prior to departure. Any consideration of additional instrumentation for *in situ* measurements should also be carefully weighed against increasing the complexity of deployments.

Retrieval of moorings often requires substantial maneuverability of the ship to remain on station, particularly in the case of strong winds and heavy seas. Even for dedicated platforms, it is not unusual for retrieval maneuvers to take more than an hour from first sighting the mooring until it is hauled on deck. It is furthermore recommended that someone with sufficient technical experience and knowledge of PARs is on board the ship to take responsibility for the instrument, e.g., to secure lithium batteries if necessary and provide a time signal for later synchronization of the PAR. Platforms of opportunity such as cruise ships are therefore less suitable for mooring retrieval, but research ships with personnel that have experience with oceanographic instrumentation should be able to opportunistically recover PARs. Attempts to find or communicate with lost or unresponsive instruments may be restricted if there is limited or no dedicated ship time available.

Deployment and recovery efficiency

There are several practical steps that can be taken in order to maximize the efficiency of PAR deployments and minimize the amount of dedicated ship time required. For example, deployments may be optimized by preparing the PAR and mooring on-shore and before arriving on station. In cases when PARs are prepared long before deployment, PAR status checks and clock-synchronization are recommended prior to deployment if feasible. Final checks may be facilitated *by* an externally visible infrared diode that provides an internal clock and life beat (i.e., indicating the device is operational).

Simplifying the mooring design will also reduce the amount of dedicated ship time required, e.g., by using bottom-mounted instruments that require no spooling of cable. For bottom-deployed instruments or PARs moored close to the sea floor, pressure measurements (e.g., by means of additional instruments) can be omitted, provided that the bathymetry at the deployment location is known. A more compact and less complex instrument type has the further advantage that deployments minimize personnel requirements.

Recovery efficiency, in terms of time on station waiting for an instrument to surface, may be increased by maximizing the ascent rate, which can be achieved by increasing buoyancy and minimizing drag forces on the mooring. Where possible, acoustic releases with a “push-off” release mechanism should be used as these are typically more time-efficient than “burn-wire” release mechanisms. To facilitate locating the PAR on the water surface, recovery aids such as strobes to allow recovery in darkness, and increase visibility in daylight, are recommended. A VHF locator can be used for detection of surfacing and bearing to the mooring even when it has not been sighted. Furthermore, satellite telemetry (i.e., short-burst iridium/GPS) is bidirectional and may be considered to efficiently locate the mooring and thereby overcome the cost of a ship-time consuming grid search for instruments. Finally, although these additions increase overall instrument cost, they both reduce ship time for recovery, and reduce the likelihood of instrument loss.

All instruments should have contact information printed on the outside so that lost or detached instruments can be returned in case they are found.

Care should furthermore be taken that, should a permanent loss of instrumentation occur, any impact to the environment is minimized.

Maximizing likelihood of instrument recovery

To minimize the chances of instrument loss due to malfunction of the release mechanism or fouling with the ocean bottom, it is recommended where possible to include redundancy in the release mechanism, either by including dual releases in parallel in case of failure of the primary release and by carrying multiple transponders onboard for activating acoustic releases. This too adds substantially to the cost of the mooring and is therefore not a prerequisite for SOHN PARs as many oceanographic moorings worldwide rely on a single release.

To reduce the chances of instruments on a mooring becoming embedded in soft bottom sediment, it may be advantageous, depending on seabed characteristics (if these are known), to include buffers between weights, acoustic releases, and PAR electronics in bottom-deployed PARs. These buffers function to absorb the motion of in-line instruments upon the impact of the anchors with the sea floor.

Instrument preparation pre-deployment

Given the high cost of time at sea and limited number of berths on many Antarctic voyages, there are many instances in which it may be most cost-effective to perform all servicing of PARs on shore. This trade-off will minimize amount of time and personnel required at-sea, but comes at the cost of efficient use of instruments as instruments will not be redeployed on the same voyage in which they are recovered. Furthermore, depending on how long an instrument will be underway on board a ship, steps should be taken to minimize the time that the instrument is not yet in the water but already recording (e.g. through a scheduled start time for recording when the instrument is expected to be deployed), and to ensure the overall in-water recording duration is sufficient for the project goals. These scenarios are most likely to occur on platforms of opportunity that may have the capability to recover moorings, but lack the technical personnel to fully service and refurbish a PAR. To best facilitate continuous occupation of locations, it is recommended that rather than re-deploying the same instrument that was recently recovered, a pre-programmed, replacement instrument be provided. This will require a larger "library" of instruments but will reduce time on board and the need for a dedicated technician.

DATA AND METADATA STORAGE

Recording capacity

Generally, the logistics complexity and high costs of deploying and maintaining PARs in the Southern Ocean (and polar oceans in general) are often balanced by relatively long deployment periods. Large parts of the Southern Ocean are seasonally ice-covered and hence only allow ships to access these regions to retrieve or deploy PARs during austral summer. Recording capacity with respect to power and data storage therefore needs to cover at least one year for most areas, but preferably two to three years to keep logistics of recovery and deployment as flexible and cost-effective as possible. To meet these capacity requirements, low power consumption and high storage capacity are a prerequisite for long-term deployments in polar oceans. Some of the currently available PARs already allow collection of continuous records up to three years. Moreover, the pace with which developments in acoustic recording technology are progressing promises that PAR recording capacities will soon no longer restrict deployment periods in polar oceans. PARs that form nodes in the SOHN are recommended to collect continuous acoustic records, as currently too little is known about Antarctic blue and fin whale vocal behavior to decide on subsampling schemes that form a reliable basis to e.g., extrapolate hourly call rates (Thomisch et al. pers. comm.).

However, efficiency of data collection should be balanced by minimizing the risk of data loss. In the harsh marine environment that comprises the Southern Ocean there is a very real risk that a PAR might fail to deliver data. Failures can occur due to misconfigured PARs, electronic or mechanical failure within a PAR, or failure to recover a PAR (Dudzinski et al. 2011). Thus, while we recommend the capability for continuous data collection over 2-3 years, we also recommend servicing PARs as frequently as possible in order to minimize potential gaps in data collection that might arise due to PAR failures.

PAR sample frequency

Blue and fin whales produce the lowest frequency sounds of any cetacean, thus sample rates can be low for passive acoustic monitoring, which in-turn relaxes storage capacity requirements for long-term records. In addition, such sample rate requirements also make it possible to explore the possibility of opportunistically including both ocean-bottom seismometers and hydrophones (OBH/OBS) data in the pan-Antarctic data set, in particular for data sparse areas. Assuming that the calls of interest for passive acoustics monitoring are Z-calls for Antarctic blue whales (Fig. 3a) and the 20 Hz fin whale calls that in some cases also have high frequency component (80-100 Hz, Fig. 3c), a sample rate of at least 250 Hz and an appropriate anti-aliasing filter (ensuring clean data up to at least 100 Hz) should be used. This sample rate represents the lower limit of recordings that could contribute towards the SOHN.

PARs that are not bottom-mounted (i.e., in the water column), should be programmed to have a steep high-pass filter (~10 Hz corner-frequency) to attenuate some of the low frequency strumming noise from the mooring. In areas of very high flow, however, where strumming noise can extend into the hundreds of Hz, faired mooring line might be used, or a deeper deployment depth should be considered.

If recording capacity allows, instruments programmed to higher sample rates (e.g., 4 kHz) can capture a much wider range of calls produced by whale and seal species in Antarctic waters (e.g., Gedamke & Robinson 2010, Van Opzeeland 2010). Additionally, higher sampling rates may allow investigation of hypotheses regarding associations and interactions among whale species or large-scale comparisons of acoustic habitats/soundscapes (e.g., Boyd et al. 2011). As mentioned previously, the recent and continued advances in digital storage make power, rather than storage capacity, the limiting factor when considering a sample rate.

Data format

To allow processing with various analytical tools, PARs should, as their primary function, record a lossless encoded waveform of raw acoustic pressure, in addition to any on-board processing providing spectrogram image files or derived data (e.g., event detections). While perceptual-based encoding of data, such as MP3, may allow for increased data storage, encoding schemes based on human perception may yield unpredictable performance when most of the sound energy occurs at frequencies below that which a human listener would likely be able to perceive, as is the case with most Antarctic blue and fin whale sounds.

Pre-processing of data within the recorder may be a viable approach for future studies e.g. triggering recording only when specific acoustic events are detected or saving only the detection information (e.g. event logging). However, for the purpose of the SOHN project, in particular the collection of baseline acoustic information, full, original acoustic records are required. In addition to baseline data on whale vocalizations, full original acoustic records provide important information on the ambient noise spectrum, which, as also addressed earlier, is of interest to evaluate the role of biotic and abiotic contributions to local soundscapes.

Given that WAV (Waveform Audio File) is the most commonly used data format for virtually all sound analysis software, we recommend WAV as the primary user-facing data format for acoustic data from PARs. However, knowledge of sample rate and bit depth can be used to convert almost any lossless encoded data to WAV files prior to data processing. Furthermore, certain recording systems allow storage of metadata (such as instrument serial number, location, time stamps, temperature and depth) throughout the recording in archival file formats (Johnson et al. 2013). Where possible, recording in these formats is desirable, but not a prerequisite, for SOHN PARs.

Calibration of PARs

Periodic (e.g., biennial) calibration of PARs over the full bandwidth of whale sounds is required in order to ensure accurate measurements of the amplitude of the pressure waveform recorded by each PAR. Without full system calibration, it will not be possible to extract some meaningful physical units (e.g., absolute amplitude in Pascals, intensity in dB re 1 μPa) from the recorded data which may prohibit meaningful comparisons among PARs. Calibrations should not be limited to amplitude, but also comprise frequency and absolute time.

Full system calibration can consist of a single frequency-dependent response function and distortion limits for the entire recording chain, or it may be derived from independent calibration factors from each component. A typical recording chain consists of hydrophones, amplifiers, digitizers, and storage. Hydrophones typically function as transducers, converting pressure waveforms into analog voltages. These voltages are then amplified and digitized by the recording chain. Finally, digitized signals are scaled and encoded before being written to digital media. Thus, the frequency-response of the entire recording system (i.e., preamplifiers, anti-aliasing filters, gain of analog-to-digital converters) should also be calibrated periodically. The purpose of a full system calibration is to allow measurement of absolute levels of sound. Additionally, a calibrated system allows for more robust assessment should distortion of sound occur due to overloading of some component of the recording chain.

When possible, the frequency response of hydrophones should be calibrated over the entire recording bandwidth and amplitude range at a dedicated calibration facility. The frequency response of the remainder of the recording chain can be calibrated by connecting a signal generator in place of the hydrophone and allowing the instrument to record several calibrated frequency sweeps (i.e., measured frequency and RMS amplitude). Frequency calibration should cover the entire recording bandwidth. Amplitude calibration should include the noise floor (i.e., zero root-mean-square (RMS) amplitude) up to the amplitude at which clipping/distortion begins to occur.

As an alternative, nations participating in the SOHN project may in the future obtain calibrated instruments through the ATW's "library" of instruments.

Metadata requirements

To archive important metadata to the sound recordings, the ATW recommends that the following information be logged on instrument forms upon deployment and recovery of SOHN PARs. The metadata that can be logged will depend on the platform that deploys/recovers the PAR as platforms of opportunity may not have personnel and expertise to perform more complex tasks e.g., open PARs and measure battery voltage. The Metadata form for platforms of opportunity represents the minimum metadata that are to be logged for SOHN PARs for all deployments, independent of the platform that is used. Research teams responsible for the PAR should make sure that in cases when platforms of opportunity are used, the required metadata can be logged by the ship's crew as efficiently as possible (e.g., provide instrument forms, serial number visible on the outside of the instrument).

Additional metadata to be collected by dedicated platforms provides a more detailed list of important metadata that the ATW recommends be logged when SOHN PARs are deployed from dedicated (research) vessels. These documents will be made available through the SORP website.

Review of PARs for deployments in the Southern Ocean

Sousa-Lima et al. (2013) provided an inventory of fixed autonomous passive acoustic recording devices. Not all recording systems listed in their review meet the requirements of SOHN PARs as listed in previous sections of this document. However, the rapid development of PAR hardware, adaptations and new hardware development are likely to deem any recommendation with respect to specific hardware for the SOHN out of date. The ATW therefore refers to the SORP website where an up-to-date list will be kept on recommended PAR systems currently on the market with links to their manufacturers.

If the PAR "library" comes to fruition, it is anticipated that the instruments will be managed i.e., programmed, calibrated and

Metadata form for platforms of opportunity

- PAR metadata
  - Serial number
  - Start date and time of recording
- Acoustic release (in most cases provided by responsible research team)
  - Type
  - Serial number
  - Operating frequency
  - Activation codes
  - Type of deck box required
- Deployment metadata
  - Deployment time, date, and position (UTC, latitude, longitude)
  - Depth/bathymetry of instrument and sea floor
  - Number and (approximate) location of any whales in the vicinity
- On recovery
  - Date and time of acoustic release
  - Date and time of recovery
  - Any leaks or obvious problems with the PAR?
  - PAR clock offset synchronized (time of signal and type of signal, e.g. could be as simple as banging on a pipe at a known time next to the hydrophone)
  - Number and location of any whales sighted in the
  - Vicinity of the PAR
- Additional information
  - Mooring ID
  - Name of ship
  - Summary of ice conditions at recording location
  - Additional information from recovery aids (e.g., GPS/ Iridium location at surface)

Additional metadata to be collected by dedicated platforms

- PAR metadata
  - Instrument type
  - Data format (e.g., WAV, bin, raw)
  - Sample rate, bit depth, header information
  - Duty cycle used (settings)
  - Hydrophone type, serial number, calibration date
  - Calibration factors (including frequency response)
  - Types of additional data streams
- Deployment metadata
  - PAR clocks initially synchronized to UTC
  - Additional geolocation (post-deployment survey)
  - SSP (sound speed profile if available)
- On Recovery
  - Battery voltage
  - Did the instrument record? # GB recorded
  - Backup the recorded data
- Additional information
  - Instruments on mooring
  - Point of contact

managed by one of the SOHN partners. This is presently under discussion and will also be announced on the SORP website.

Archival and management of the SOHN data base

All acoustic data collected as part of SOHN will be archived so that partner collaborators will have access to the data. Presently, two options are being explored: archiving at PANGAEA, which is managed by the Alfred Wegener Institute (AWI) and the Australian Ocean Data Network AODN. Each of these institutions has experience serving and maintaining large, global databases. We anticipate that if data are collected under the direct aegis of SOHN – (versus current deployments undertaken independently by partners such as South African National Antarctic Programme (SANAP) and the AWI) – the data will be available online after they have been quality checked. Data collected independently by partners that have agreed to be part of SOHN will be embargoed for a mutually agreeable time by those partners before being made available.

As part of the archiving, long-term spectral averages (LTSAs) will be produced and available to provide a rapid assessment of data quality (particularly with regards to noise) and for the seasonal occurrence of blue and fin whales (see Samaran et al. 2012).

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References

AODN website, http://portal.aodn.org.au/aodn/.
eddy-grips http://www.nautilus-gmbh.com/vitrovex-deep-sea-housings/
IUCN International Union for Conservation of Nature: http://www.iucn.org
PANGAEA website: http://www.pangaea.de/about/
SORP website: http://www.marinemammals.gov.au/sorp

Boebel, O., Breitzke, M., Burkhardt, E. & Bornemann, H. (2009): Strategic assessment of the risk posed to marine mammals by the use of airguns in the Antarctic Treaty area.- Information Paper IP 51, Agenda Item: CEP 8c, Antarctic Treaty Consultative Meeting XXXII, Baltimore, USA.

Boyd, I.L., Frisk, G., Urban, E., Tyack, P., Ausubel, J., Seeyave, S., Cato, D., Southall, B., Weise, M., Andrew, R., Akamatsu, T., Dekeling, R., Erbe, C., Farmer, D., Gentry, R., Gross, T., Hawkins, A., Li, F., Metcalf, K., Miller, J.H., Moretti, D., Rodrigo, C. & Shinke, T. (2011): An International Quiet Ocean Experiment.- Oceanography 24(2): 174-181.

Branch, T.A. (2007): Abundance of Antarctic blue whales south of 60° S from three complete circumpolar sets of surveys.- J. Cetacean Res. Managem. 9(3): 253-262.

Branch, T., Matsuoka, K. & Miyashita, T. (2004): Evidence for increases in Antarctic blue whales based on Bayesian modelling.- Marine Mammal Sci. 20: 726-754.

Branch, T.A., Stafford, K.M., Palacios, D.M., Allison, C., Bannister, J.L. et al. (2007): Past and present distribution, densities and movements of blue whales *Balaenoptera* musculus in the Southern Hemisphere and northern Indian Ocean.- Mammal Rev. 37: 116-175.

Childerhouse, S. (2009): Southern Ocean Research Partnership workshop: summary of outcomes. International Whaling Commission. SC/61/O17: 1-6.

Childerhouse, S. (2010): Report of the Southern Ocean Research Partnership Seattle workshop. International Whaling Commission. SC/62/O8: 1-5.

Cisewski, B., Strass, V.H., Rhein, M. & Kraegefsky, S. (2010): Seasonal variation of dial vertical migration of zooplankton from ADCP backscatter time series data in the Lazarev Sea, Antarctica.- Deep-Sea Res. Part I 57: 78-94.

Dudzinski, K.M., Brown, S.J., Lammers, M., Lucke, K., Mann, D., Simard, P. & Wall, C.C. (2011): Trouble-shooting deployment and recovery options for various stationary passive acoustic monitoring devices in both shallow- and deep-water applications.- J. Acoust. Soc. Amer. 129: 436-448.

Ensor, P.H., Komiya, H., Beasley, I., Fukutome, K., Olson, P. & Tsuda, Y. (2007): 2006-2007 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC-SOWER) cruise.- Paper SC/59/IA1, International Whaling Commission (unpubl.).

Ensor, P.H., Komiya, H., Olson, P., Sekiguchi, K. & Stafford, K. (2006): 2005-2006 International Whaling Commission – Southern Ocean Whale and Ecosystem Research (IWC–SOWER) cruise.- Paper SC/58/IA1 presented to the 2006 IWC Scientific Committee (unpubl.) 1-63.

Gavrilov, A.N., Mccauley, R.D. & Gedamke, J. (2012): Steady inter- and intra-annual decrease in the vocalization frequency of Antarctic blue whales. J. Acoust. Soc. Amer. 131: 4476-4480.

Gedamke, J., Gales, N., Hildebrand, J.A. & Wiggins, S. (2007): Seasonal occurrence of low frequency whale vocalisations across eastern Antarctic and southern Australian waters, Feb 2004 to Feb 2007.- International Whaling Commision Vol. SC/59: 1-11.

Gedamke, J. (2009): Geographic Variation in Southern Ocean Fin Whale Song.- International Whaling Commission. SC/61/SH16: 1-8.

Gedamke, J. & Robinson, S.M. (20109. Acoustic survey for marine mammal occurrence and distribution off East Antarctica (30-80 °E) in January-February 2006.- Deep Sea Res. Part II: Topical Studies in Oceanography 57: 968-981.

Hall, M. (2005): Sound propagation through the Antarctic Convergence Zone and comments on three major experiments. Proc. Acoust., Busselton, Western Australia): 475-479.

Hammond, P., Macleod, K., Berggren, P., Borchers, D.L., Burt, L., Cañadas, A., Desportes, G., Donovan, G., Gilles, A., Gillespie, D., Gordon, J., Hiby, L., Kuklik, I., Leaper, R., Lehnert, K., Leopold, M., Lovell, P., Øien, N., Paxton, G, Ridoux, V., Rogan, E., Samarra, F., Scheidat, M., Sequeira, M., Siebert, U., Skov, H., Swift, R., Tasker, M.L., Teilmann, J., Van Canneyt, O. & Vázquez, J.A. (2013): Cetacean abundance and distribution in European Atlantic shelf waters to inform conservation and management.- Biol. Conservation 164 : 107-122.

Johnson, M., Partan, J. & Hurst, T. (2013): Low complexity lossless compression of underwater sound recordings.- J. Acoust. Soc. Amer. 133: 1387-1398.

Kaschner, K., Quick, N.J., Jewell, R., Williams, R. & Harris, C.M. (2012): Global coverage of cetacean line-transect surveys: status quo, data gaps and future challenges.- PLoS ONE 7. e44075.

Maslanik, J. & Stroeve, J. (1999): Updated daily. Near-Real-Time DMSP SSM/I-SSMIS Daily Polar Gridded Sea Ice Concentrations.- 2000-2012. Boulder, Colorado USA: NASA DAAC Nat. Snow and Ice Data Center.

Marques, T.A., Thomas, L., Martin, S., Mellinger, D., Ward, J., Moretti, D., Harris, D. & Tyack, P. (2013): Estimating animal population density using passive acoustics.- Biol. Rev. 88: 287-309.

Mellinger, D.K., Stafford, K.M., Moore, S.E., Dziak, R.P. & Matsumoto, H. (2007): An overview of fixed passive acoustic observation methods for cetaceans.- Oceanography 20: 36-45.

Miksis-Olds, J.L., Nysuen, J.A. & Parks, S.E. (2010): Detecting marine mammals with an adaptive subsampling recorder in the Bering Sea.- Applied Acoust. 71: 1087-1092.

Miller, B.S., Leaper, R., Calderan, S., Collins, K. & Double, M.C. (2014): Source levels of Antarctic blue whale calls measured during the 2013 Antarctic blue whale voyage: preliminary results.- Subm. Sci. Commit. 65b Internat. Whaling Commission. Bled, Slovenia. SC/65b/SH11. 11pp.

Morano, J.L., Salisbury, D.P., Rice, A.N., Conklin, K.L., Falk, K.L. & Clark, C.W. (2012): Seasonal and Geographical Patterns of Fin Whale Song in the Western North Atlantic Ocean. -J. Acoust. Soc. Amer. 132 (2): 1207-1212.

Moore, S.E., Stafford, K.M., Melling, H., Berchok, C., Wiig, Ø., Kovacs, K.M., Lydersen, C. & Richter-Menge, J. (2012): Comparing marine mammal acoustics habitats in Atlantic and Pacific sectors of the High Arctic: year-long records from Fram Strait and the Chukchi Plateau.- Polar Biology 35: 475-480.

Nieukirk, S.L, Mellinger, D.K., Moore, S.E., Klinck, K., Dziak, R.P. & Goslin, J. (2012): Sounds from airguns and fin whales recorded in the mid-Atlantic Ocean, 1999-2009.- J. Acoust. Soc. Amer. 131: 1102-1112.

Rettig, S., Boebel, O., Menze, S., Kindermann, L., Thomisch, K. & Van Opzeeland, I.C. (2013): Local to basin scale arrays for passive acoustic monitoring in the Atlantic sector of the Southern Ocean.- Proc. First Internat. Conf. Underwater Acoustics, 1669-1674.

Royer, J.-Y. (2010): Projet DEFLO-HYDRO- Rapport de missions. Laboratoire des domaines Océaniques.- CNRS, Univ. Bretagne Occidentale Institut Polaire Français Paul Emile Victor, pp. 46.

Samaran, F., Stafford, K.M., Branch, T., Gedamke, J., Royer, J.-Y., Dziak, R.P. & Guinet, C. (2013): Seasonal and geographic variation of southern blue whale subspecies in the Indian Ocean.- PLoS One 8(8): e71561-e71561.

Samaran, F., Adam, O. & Guinet, C. (2010): Detection range modeling of blue whale calls in Southwestern Indian Ocean.- Applied Acoust. 71: 1099-1106.

Samaran, F., Stafford, K., Gedamke, J., Van Opzeeland, I., Miller, B.S., Adam, O., Baumgartner, M., Mussoline, S. & Pressiat, G. (2012): Acoustic trends in abundance, distribution, and seasonal presence of Antarctic blue whales and fin whales in the Southern Ocean.- In: E. BELL (ed), Annual Rep. Southern Ocean Res. Partnership (SORP) 2011/12, Sci. Commit. Internat. Whaling Commission, Panama City, Panama. SC/64/O13.

Širović, A., Hildebrand, J.A., Wiggins, S.M., McDonald, M.A., Moore, S.E. & Thiele, D. (2004): Seasonality of blue and fin whale calls and the influence of sea ice in the Western Antarctic Peninsula.- Deep Sea Res. Part II, 51: 2327-2344.

Širović, A., Hildebrand, J.A., Wiggins, S.M. & Thiele, D. (2009): Blue and fin whale acoustic presence around Antarctica during 2003 and 2004.- Marine Mammal Sci. 25: 125-136.

Sousa-Lima, R.S., Norris, T.F., Oswald, J.N. & Fernandes, D.P. (2013): A review and inventory of fixed autonomous recorders for passive acoustic monitoring of marine mammals.- Aquatic Mammals 39: 23-53.

Sokolov, S. & Rintoul, S.R. (2009a): Circumpolar Structure and Distribution of the Antarctic Circumpolar Current Fronts: 1. Mean Circumpolar Paths.- J. Geophys. Res. 114 (C11): C11018.

Sokolov S. & Rintoul, S.R. (2009b): Circumpolar Structure and Distribution of the Antarctic Circumpolar Current Fronts: 2. Variability and Relationship to Sea Surface Height.- J. Geophys. Res. 114 (C11): C11019. doi:10.1029/2008JC005248.

Stafford, K., Bohnenstiehl, D., Tolstoy, M., Chapp, E., Mellinger, D. & Moore, S. (2004): Antarctic-type blue whale calls recorded at low latitudes in the Indian and Eastern Pacific Oceans.- Deep Sea Res. Part I: 51 (10): 1337-1346.

Stafford, K.M., Moore, S.E., Berchok, C.L., Wiig, Ø., Lydersen, C., Hansen, E., Kalmbach, D. & Kovacs, K.M. (2012): Spitsbergen's endangered bowhead whales sing through the polar night.- Endangered Species Res.18: 95-103.

Thomas, L. & Marques, T. (2012): Passive acoustic monitoring for estimating animal density.- Acoustics Today 8(3):35-44.

Van Opzeeland, I.C. (2010): Acoustic ecology of marine mammals in polar oceans.- PhD Thesis, Univ. Bremen, Rep. Polar & Marine Res. 619: 1-332.

Van Opzeeland, I.C., Kindermann, L., Boebel ,O. & Van Parijs, S.M. (2008): Insights into the acoustic behaviour of polar pinnnipeds: current knowledge and emerging techniques of study.- In: E.A. WEBER & L.H. KRAUSE (ed), Animal Behaviour: New Research, Nova Science Publishers. Hauppage, NY.

Van Opzeeland, I.C., Rettig, S., Thomisch, T., Preis, L., Lefering, I., Menze, S., Zitterbart, D., Monsees, M., Boebel, O. & Kindermann, L. (2013): Ocean Acoustics.- Rep. Polar & Marine Res. 671: 71-81.

Van Parijs, S., Clark, C.W., Sousa-Lima, R.S., Parks, S.E., Rankin, S., Risch, D. & Van Opzeeland, I.C. (2009): Management and research applications of real-time and archival passive acoustic sensors over varying temporal and spatial scales.- Marine Ecol. Progr. Ser. 395: 21-36.

Williams, R., Hedley, S.L. & Hammond, P.S. (2006): Modeling distribution and abundance of Antarctic baleen whales using ships of opportunity.- Ecol. Society 11(1): 1.