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Acoustic Parameters and Hydroacoustic Equipment: Natural Noise, Industrial Exploration and Basic Science

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Summary: In the discussion about the effects of noise on marine mammals it is important to quantify natural and man-made noise sources not only in their intensity but also in their duration and occurrence rates. Marine mammals are subject to natural noise sources such as earthquakes and submarine volcanism. As far as it is known, areas of high seismicity and consequently high intensity events are repeatedly visited by marine mammals. Therefore, it must be assumed that they are adapted to such events, at least for a certain time period. In order to judge the effects of man-made noise to mammals, it is important to consider the duration of the acoustic disturbances within a season as well as the rate at which this disturbance occurs in a particular area over several years. The individual signal length but also the duration of a hydroacoustic survey plays an important role for the level of disturbance.

A comparison of the style of seismic surveys shows that academic research programs carry out mainly line surveys once per area of interest (2-D seismic) with a line spacing of several kilometres, while the exploration industry has moved on to 3-D surveys, which comprise a detailed spatial investigation of the subsurface on seismic profiles a few tens of metres apart. Repeated surveys of a particular area are intended to monitor changes in reservoir fluids, pressures and stresses (4-D seismic). Seismic surveys for academic research in Antarctic waters south of 60 °S serve in most cases a reconnaissance role. The documentation of seismic surveys in Antarctica over the last twenty years shows that there had been not more than one seismic survey in a single survey season (December through April) in a particular region of a few thousand square kilometres. In many cases, seasons have even been skipped. On the average, each seismic survey lasted only a few days.

NATURAL NOISE

Among the most common natural noise sources in the world oceans, earthquakes are the most powerful sources of sound with submarine volcanism, surface waves/breakers as well as mammal communication to follow. Most earthquakes and submarine volcanic eruptions are concentrated along subduction zones and mid-ocean ridges and occur randomly in space and time. In one year, more than 20,000 of such events occur in the oceans. This estimate is conservative because the present seismological network records only the strongest submarine events, and seismological sensors are not evenly spread around the world. Long-term hydrophone observations (e.g. SOSUS) have shown that sound pressure levels of well over 200 dB (re 1 μPa) are generated by earthquakes and submarine volcanic eruptions.

Around Antarctica, the area of the South Sandwich Islands (southwest Atlantic) is tectonically the most active zone as a segment of the South American-Atlantic Plate is being subducted under the Sandwich Plate at the Scotia Sea Trench with an active seafloor spreading ridge just to the west of it (Fig. 1). Although several earthquakes occur per day, population studies (e.g., KNICKMEIER 2002) show that mammals do not avoid this region. Their presence may be explained by excellent feeding grounds in the Antarctic convergence. Another explanation might be that marine mammals are used to such disturbances and tolerate the produced sound levels and/or avoid high seismicity areas after long-lasting activities (earthquake swarms) occurred without harm.

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MAN-MADE NOISE

Anthropogenic noise in the world oceans is generated from a variety of sources but is not evenly spread in terms of space and time (Tab. 1).

Cumulative effects in areas with a continuous acoustic impact, such as along major ship routes, might be more dangerous than in areas with only episodic human activities. High acoustic intensities occur along frequently used ship routes and in particular on continental shelves off major ports as well as in areas of hydrocarbon production (e.g., North Sea, Gulf of Mexico). Low acoustic intensities occur in the deep sea basins of the southern oceans due to limited ship traffic.

Seismic surveys are conducted for industrial hydrocarbon exploration as well as for scientific research. However, intensity and character in terms of line coverage and seismic source power differ enormously (Fig. 2). While industrial exploration is performed with large-volume air-gun arrays along densely spaced lines over several months in one particular region (e.g., North Sea, Gulf of Mexico) as 2-D, 3-D and even 4-D (monitoring) surveys, scientific research projects survey one area normally only once for reconnaissance and use less powered air-gun configurations. Table 2 provides an overview of scientific versus exploration seismic surveys.

SEISMIC ACTIVITIES IN ANTARCTIC WATERS

Seismic surveying in Antarctic waters is only conducted by research organisations with the purpose of obtaining information mainly of the glacial-deglacial and climatic history as the sediments along the continent's margin serve as prime archives of environmental change since the onset of glaciation. A further objective is the investigation of the tectonic history during the break-up of the Gondwana continent, as this caused the opening of ocean seaways responsible for major climate changes in the past.

Seismic profiling around Antarctica is of magnitudes smaller compared to other continental margins and shelf areas in the world. Firstly, the strength of seismic sources used in Antarctica is at the lower limit to achieve the desired results. Se-

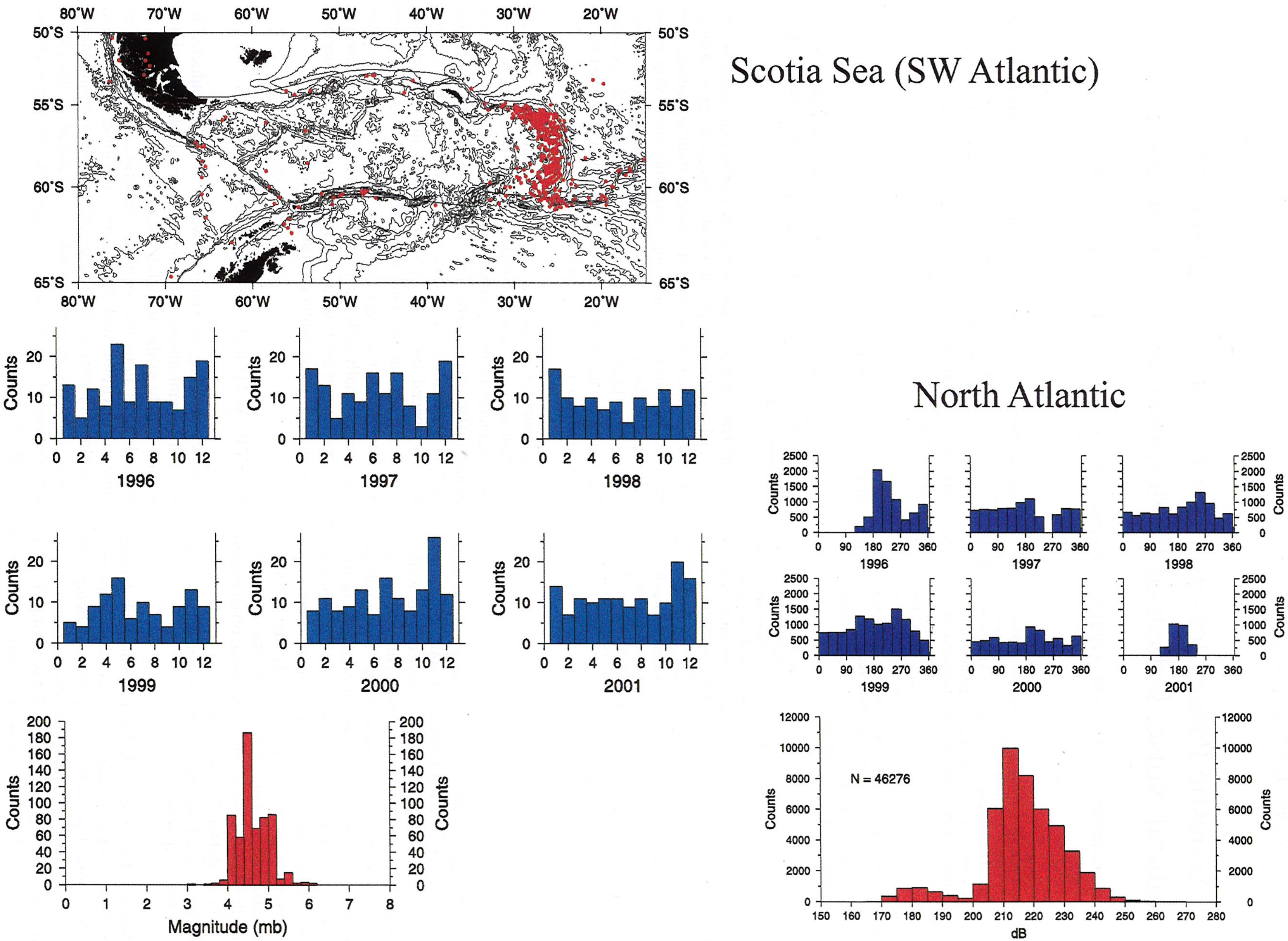

Fig. 1: Left: Frequency of earthquakes in the South Sandwich Island, eastern Scotia Sea region (SW Atlantic). These are only events observed from the global seismological network. Observations from the seismological array at the Antarctic Neumayer Station indicate a ten-fold larger amount of events (Chr. Müller, AWI). Right: Observation of earthquake events in the North Atlantic (data from SMITH et al. 2002). Sound pressure level is in dB (re 1 μPa). Note the large sound pressure level up to 245 dB (re 1 μPa).

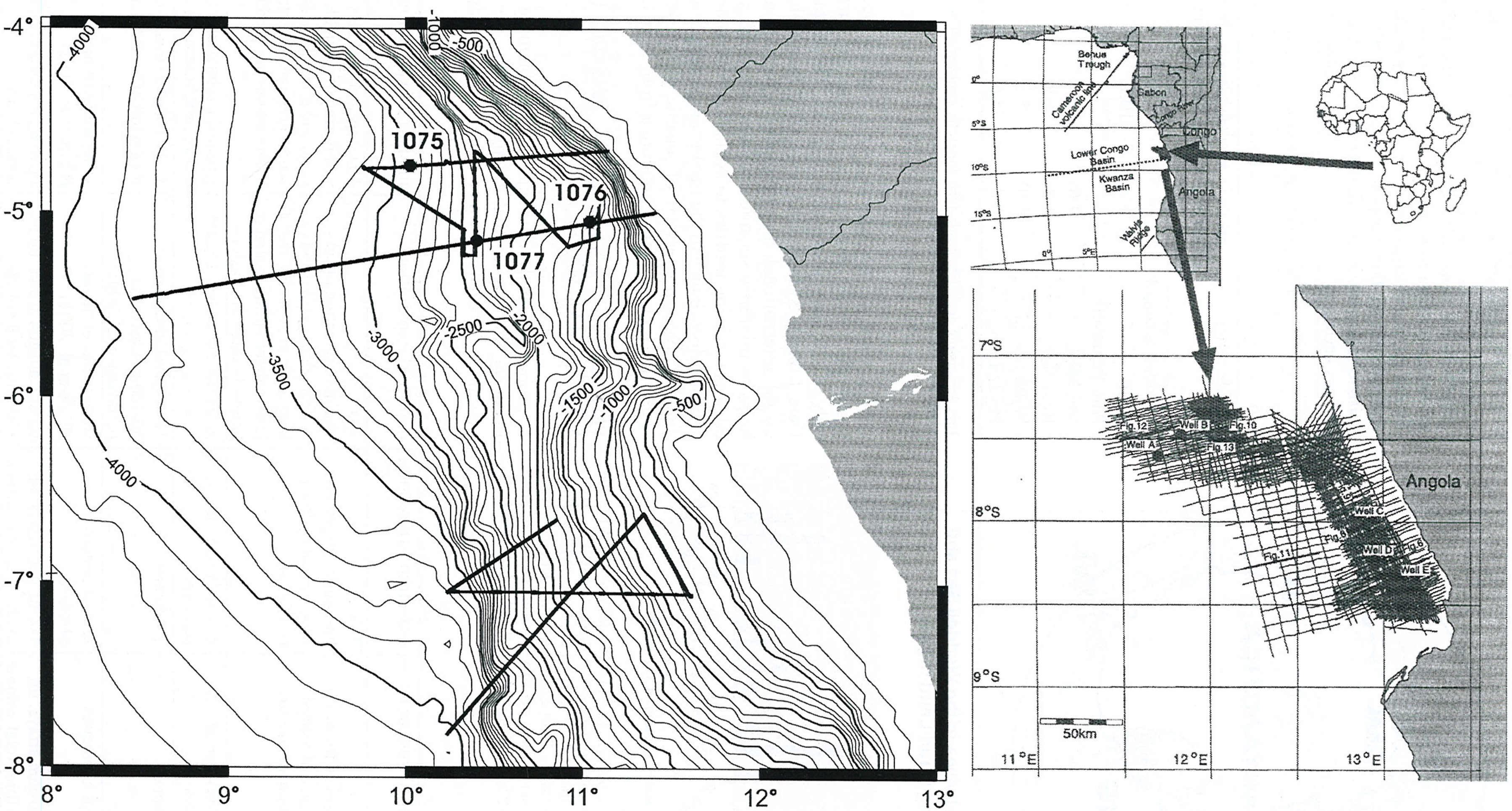

Fig. 2: Left: Seismic profiles of a scientific research project off-shore Congo and northern Angola (UENZELMANN-NEBEN 1998). Right: Grid of seismic industry exploration profile in an oil and gas province off-shore central Angola (VALLE et al. 2001).

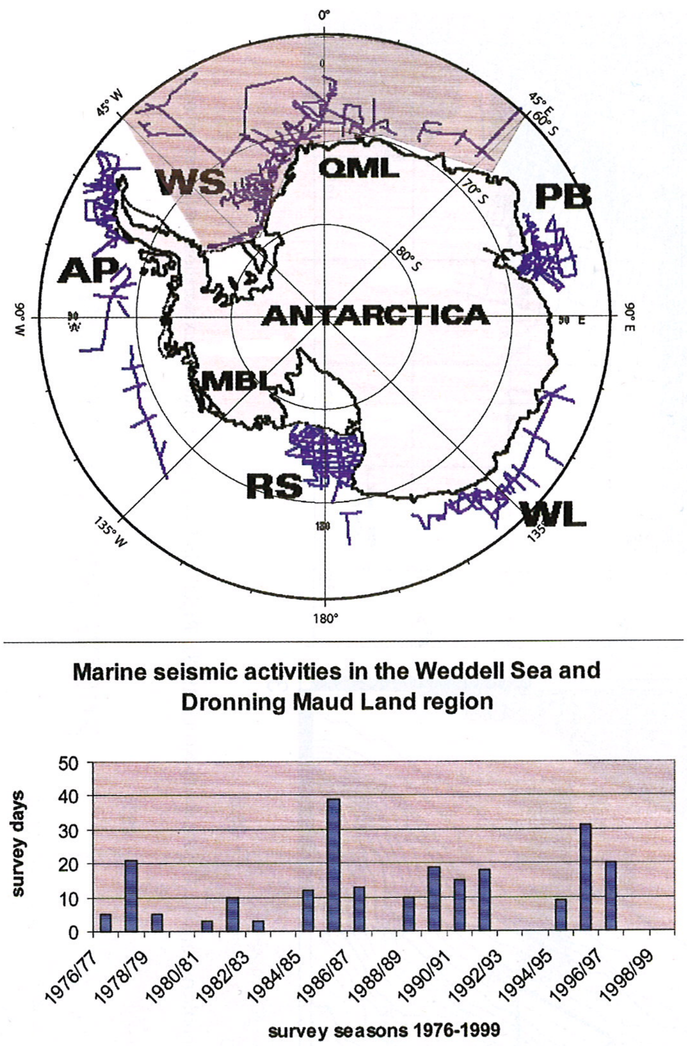

Fig. 3: Top: Coverage of seismic profiles around Anarctica from 1976 to 1999 (Antarctic Seismic Data Library System). Grey box marks Weddell Sea (WS) and Dronning Maud Land sectors (QML); PB = Prydz Bay, WL = Wilkes Land, RS = Ross Sea, MBL = Marie Byrd Land, AP = Antarctic Peninsula. Bottom: Frequency of seismic survey days per survey season (Antarctic summer). The average has been 10 days per season in an area of 5.4 mio km².

human activity	modes
propeller noise from ship traffic	continuous
oil and gas platform operations	regionally continuous
oil and gas seismic exploration	regionally intensive
hydroacoustic sea-floor mapping	episodic
seismic/hydroacoustic scientific research	episodic
military operations	unknown

Tab. 1: Modes of anthropogenic noise

marine sector	area (mio km^2)	average survey days per season	average profile km per season
Weddell Sea and DML	5.4	10.1	2220
Ant. Peninsula and MBL	4.6	15.9	3512
Ross Sea	1.2	8.3	1821
Wilkes Land	1.9	3.3	730
Prydz Bay	0.8	5.6	1221

Tab. 3: Seismic activities around the Antarctic continent. Compiled from Seismic Data Library System (SDLS).

condly, most of the regions (e.g., Weddell Sea region) are repeatedly visited only every 2-4 years for surveys that last only 10-20 days in average (Fig. 3). The Antarctic Seismic Data Library System for Cooperative Research (SDLS) is a useful international archiving and information system that helps to minimize seismic activities. Researchers are informed about existing profiles to avoid duplication and to keep the acoustic disturbance to the marine environment to a minimum. Table 3 gives an overview of seismic survey activities in the respective sectors around Antarctica from 1976 to 1999.

PROBABILITY ANALYSIS OF SEISMIC IMPACT ON MARINE MAMMALS

A probability analysis is one way of obtaining a rough estimate on the impact that seismic surveys have on marine mammals in Antarctic waters. One can make simple assump-

	scientific research	industrial exploration	industrial exploration	industrial exploration
general character and objective	2-D line survey for reconnaissance of tectonic and sedimentary structures	2-D line survey for reconnaissance of hydrocarbon fields	3-D spatial observation of subsurface; dense grid of survey lines over an area with the ob jective determining spatial relations in three dimensions	4-D (repeated 3-D surveys) monitoring of oil fields to help understand and track changes in reservoir fluids, pressures and stresses while hydrocarbons are produced
number of surveys per area	generally one survey per area	generally one survey per area	generally one survey per area	repeated exploration of an area every 3-5 years (Christie et al. 2001)
number of streamers	1 streamer	1 streamer	12-16 parallel streamers, 50-100 m total width (Christie et al. 2001)	12-16 parallel streamers, 50-100 m total width (Christie et al. 2001)
seimic line spacing	several kilometres	several hundreds of metres	some tenths of metres (Elde et al. 2001)	some tenths of metres (Elde et al. 2001)
seismic source	1-2 air-gun arrays; up to 60 litres total volume	1-2 air-gun arrays; up to 60 litres total volume	up to 8 air-gun arrays, up to 120 litres total volume	up to 8 air-gun arrays, up to 100 litres total volume

Tab. 2: Scientific *versus* industrial surveys

tions on the base of known parameters and data. An air-gun array can be treated as an omni-directional source which attenuates its sound level down to 180 dB (re 1 μPa) at about 1 km radius from the source. We call this half-sphere beneath an air-gun array an impact space of radius r = 1 km, thus affecting a volume of about 2.1 km^3. Although an air-gun array acts as a pulsed source which moves with an average ship's speed of 10 km/h and is triggered every 10-15 seconds (every 25-40 m), we treat it here as continuous source being active along the entire lengths of profiles (half-cylinder impact space). Thus, we can calculate the total impact space a seismic survey generates and put this in relation to the total regional volume of the upper 1 km ocean in a particular region. For example, an average annual 2200 km seismic profiling project in the Weddell Sea and Dronning Maud Land (DML) sector will have a total impact volume of 3460 km^3, which means that only 0.06 of the upper 1 km of the regional ocean in this sector is ever affected by seismic profiling in an entire season.

Based on published estimates on whale distribution around Antarctica (e.g., CARSTENS et al. 1999), a simple calculation on the numbers of whales affected by a seismic impact space can be made. One case is a static one in which whales are assumed to remain at their position, but in which the air-gun source is active along a half-cylinder impact space. In the dynamic case, whales move in random direction and the air-gun source moves as a half-sphere through an area (Fig. 4). Using the static case, Table 4 shows the results for the Weddell Sea (WS) and Dronning Maud Land (DML) sector. Therefore, only 0.03 % of a respective whale population could appear within the radius of the impact space per 1000 km seismic profiling.

This probability analysis is still rudimentary with simplified assumptions. More information, in particular on the distribution and migration of marine mammals is needed. However, this exercise demonstrates that seismic surveys in Antarctic waters affect a very minimal area/volume of the circum-Antarctic ocean and that the effect on the population of a particular whale species is probably statistically insignificant.

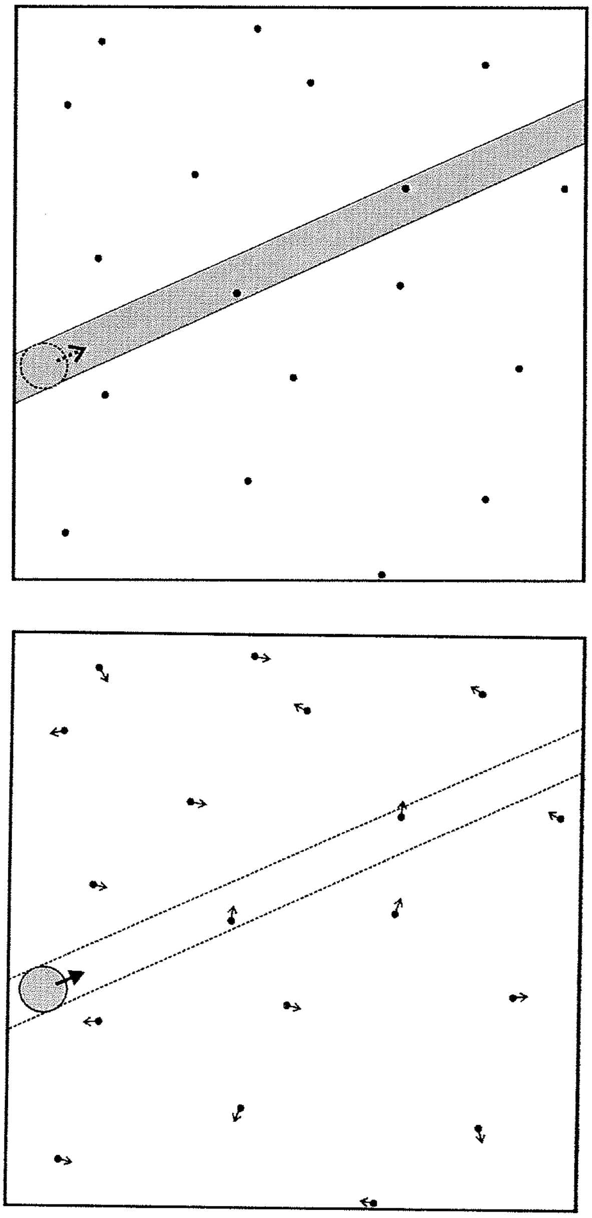

Fig. 4: Simple probability estimate on the numbers of whales affected by an impact space of a seismic survey. Top: Static case; whales are stationary moving half-sphere = stationary half-cylinder. Bottom: Dynamic case: whales move with constant speed in random direction and impact space (half-sphere) moves along line.

CONCLUSIONS

The marine environment is naturally noisy. The natural noise reaches source levels of acoustic/seismic surveys. Hydroacoustic and/or seismic methods in basic research are of magnitudes less intense in space and time than in commercial activities. There are methods in place to minimize total potential acoustic impacts in Antarctica (SDLS and SCAR Working Groups). Hydroacoustic methods are indispensable for desperately needed environmental research.

species	estimated population South of 60 °S (CARSTENS et al. 1999)	estimated population in WS and DML sector and DML sector	average density of whales per km^3 (uppermost 1000 m)	number of whales within impact space per 1000 km seismic profiling
Minke Whale	760,000	160,000	0.03	47
Blue whale	700	230	0.00004	0.07

Tab. 4: Presence of whales (static) and estimated impact by seismic profiling. WS = Weddell Sea, DML = Dronning Maud Land.

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