Chapter 76
Impacts of Underwater Noise on Marine Vertebrates: Project Introduction and First Results

Alexander Liebschner, Henrike Seibel, Jonas Teilmann, Dietrich Wittekind, Eric Parmentier, Michael Dähne, Rune Dietz, Jörg Driver, Cornelis van Elk, Eligius Everaarts, Henning Findeisen, Jacob Kristensen, Kristina Lehnert, Klaus Lucke, Thomas Merck, Sabine Müller, Iwona Pawliczka, Katrin Ronnenberg, Tanja Rosenberger, Andreas Ruser, Jakob Tougaard, Max Schuster, Janne Sundermeyer, Signe Sveegaard, and Ursula Siebert

Abstract The project conducts application-oriented research on impacts of underwater noise on marine vertebrates in the North and Baltic Seas. In distinct subprojects, the hearing sensitivity of harbor porpoises and gray seals as well as the acoustic tolerance limit of harbor porpoises to impulsive noise from pile driving and stress reactions caused by anthropogenic noise is investigated. Animals are equipped with DTAGs capable of recording the actual surrounding noise field of free-swimming harbor porpoises and seals. Acoustic noise mapping including porpoise detectors in the Natura 2000 sites of the North and Baltic Seas will help to fully understand current noise impacts.

Keywords Temporary threshold • Auditory evoked potential • Noise logger • Tagging • Stress

A. Liebschner (✉) • T. Merck
Island of Vilm/Rügen Field Office, Marine and Coastal Nature Conservation Units, German Federal Agency for Nature Conservation (BfN), 18581 Putbus, Rügen, Germany
e-mail: Alexander.liebschner@bfn-vilm.de; Thomas.merck@bfn-vilm.de

H. Seibel • M. Dähne • K. Lehnert • S. Müller • K. Ronnenberg • A. Ruser
J. Sundermeyer • U. Siebert
Institute for Terrestrial and Aquatic Wildlife Research (ITAW),
University of Veterinary Medicine Hannover, Foundation, 25761 Büsum, Germany
e-mail: Henrike.seibel@tiho-hannover.de; michael.daehne@gmx.com;
Kristina.Lehnert@tiho-hannover.de; Sabine.mueller@ftz-west.uni-kiel.de;
Katrin.Ronnenberg@tiho-hannover.de; Andreas.ruser@tiho-hannover.de;
j.sundermeyer@seehundstation-friedrichskoog.de; Ursula.siebert@tiho-hannover.de

A.N. Popper, A. Hawkins (eds.), *The Effects of Noise on Aquatic Life II*, Advances in Experimental Medicine and Biology 875,
DOI 10.1007/978-1-4939-2981-8_76

1 Introduction

The current knowledge about the impact of underwater noise on marine vertebrates in German waters is incomplete. The acoustic impact is therefore one major focus of the German Federal Agency for Nature Conservation (BfN) for sustaining marine and coastal biodiversity. In the framework of different national and international commitments, the BfN organized research on anthropogenic activities in the sea (German Exclusive Economic Zone [EEZ]) in reference to their impact on biodiversity and species conservation. The presented project aims to develop verifiable

J. Teilmann • R. Dietz • J. Tougaard • S. Sveegaard
Department of Bioscience, Aarhus University, 4000 Roskilde, Denmark
e-mail: jte@dmu.dk; rdi@dmu.dk; jat@dmu.dk; sign@dmu.dk

D. Wittekind • H. Findeisen • M. Schuster
DW-ShipConsult GmbH, 24223 Schwentinental, Germany
e-mail: wittekind@dw-sc.de; findeisen@dw-sc.de; schuster@dw-sc.de

E. Parmentier
Functional and Evolutionary Morphology Laboratory, University of Liège,
4000 Liège 1, Belgium
e-mail: e.parmentier@ulg.ac.be

J. Driver
Veterinary Clinic, 25764 Reinsbüttel, Germany
e-mail: info@tierarzt-buesum.de

C. van Elk
Dolfinarium Harderwijk, 3841 AB Harderwijk, The Netherlands
e-mail: Niels.van.Elk@dolfinarium.nl

E. Everaarts
SOS Dolphin Foundation (Stichting SOS Dolfijn), 3840 AG Harderwijk, The Netherlands
e-mail: eligius.everaarts@sosdolfijn.nl

J. Kristensen
Fjord and Bælt, 5300 Kerteminde, Denmark
e-mail: jakob@bionaut.dk

K. Lucke
Institute for Marine Resources and Ecosystem Studies (IMARES), Wageningen UR,
1790 AD Den Burg, The Netherlands
e-mail: klaus.lucke@wur.nl

I. Pawliczka
Hel Marine Station, University of Gdansk, 84150 Hel, Poland
e-mail: iwona.pvp@ug.edu.pl

T. Rosenberger
Seal Centre Friedrichskoog, 25718 Friedrichskoog, Germany
e-mail: t.rosenberger@seehundstation-friedrichskoog.de

norms for the estimation of the impact of underwater noise on marine organisms by conducting applied research on underwater noise measurements and hearing capabilities of cetaceans and pinnipeds. It involves several research institutions in Germany, Denmark, The Netherlands, the United Kingdom, and Belgium. In distinct subprojects, the hearing sensitivity of harbor porpoises (*Phocoena phocoena*) and gray seals (*Halichoerus grypus*) as well as the acoustic, physical, and behavioral tolerance limits of harbor porpoises to impulsive noise equivalent to pile driving and possible stress reactions caused by anthropogenic underwater noise is investigated. Harbor porpoises and harbor seals (*Phoca vitulina*) have been and will be equipped with acoustic data-storage tags (DTAGs). Underwater noise recorders were/are deployed in the Natura 2000 sites of the North and Baltic Seas to estimate actual noise levels at sea with regard to anthropogenic contribution.

2 Effects of Underwater Noise on Harbor Porpoises

In this subproject, the aim is to verify the sound exposure level (SEL) at which a temporary threshold shift (TTS) occurs in harbor porpoises after an impulsive exposure with a sound exposure level (SEL) of 164 dB re 1 $\mu Pa^2 \cdot s$ by an air gun (see Lucke et al. 2009). Results of the first TTS studies led to a maximum permissible value of 160 dB re $\mu Pa^2 \cdot s$ SEL at a distance of 750 m from the sound source, which has now been implemented for German wind farm permissions. One male harbor porpoise held under human care in the Fjord & Bælt Centre in Kerteminde, Denmark, was used by Lucke et al. (2009). For validation, it is necessary to determine the differences between individuals and to be able to differentiate between the effect of impulsive and tonal stimuli using dose-impact relationships.

The TTS after exposure to single and multiple sound stimuli is measured in free-ranging harbor porpoises temporarily kept in Danish pound nets after being accidentally trapped as well as in porpoises in human care using auditory evoked potentials (AEPs). The methodology is based on the existing knowledge on similar auditory measurements in humans and other marine mammals (e.g., Jewett and Williston 1971; Ridgway et al. 1981; Popov and Supin 1990; Bibikov 1992; Szymanski et al. 1999). So far, AEP measurements have been conducted in several free-ranging and human-care harbor porpoises and data analyses are in process. Animals in the wild have been exposed to sound stimuli with an air gun to test whether a TTS occurs at a SEL of 164 dB re $\mu Pa^2 \cdot s$.

For the evaluation of the immune and stress status in harbor porpoises, levels of stress hormones and the mRNA expression of cytokines and acute-phase proteins were investigated in blood samples of harbor porpoises exposed to different levels of stress during handling or in the wild, rehabilitation, or permanent human care. Blood samples were investigated for catecholamines, epinephrine, norepinephrine, and dopamine as well as for adrenocorticotropic hormone (ACTH), cortisol,

metanephrine, and normetanephrine. mRNA expression levels of relevant cell mediators (cytokines interleukin-10 and tumor necrosis factor-α, acute-phase proteins haptoglobin and C-reactive protein, and the heat shock protein HSP70) were measured using real-time polymerase chain reaction. Hormone and cytokine ranges showed correlations to each other and to the health status of investigated harbor porpoises. Hormone concentrations were higher in free-ranging harbor porpoises than in animals in human care (Müller et al. 2013).

To study the influence of anthropogenic noise on harbor porpoises, a high-frequency acoustic data logger (DTAG) has been developed for porpoises (another version will be specially designed for seals). Objectives of this subproject are to study noise levels to which harbor porpoises are exposed and the natural behavior when no ship or other loud sounds are recorded. The results should answer the question about which sounds and at which levels behavioral reactions alternate with baseline behavior. The DTAG will cover a frequency bandwidth of 50 Hz to 160 kHz. The low-frequency response is desirable to record ambient noise but may need to be adjusted upward if excessive flow noise is recorded. It includes triaxial accelerometers and magnetometers and a pressure sensor all sampled at 625 Hz, a programmable release, USB data transfer, VHF and Argos beacons, and memory and battery life for ~2 days (the seal version will record only lower frequencies and will be able to record for several weeks). The device is attached to the porpoise using suction cups. Six deployments on free-ranging porpoises for up to 24 h have been carried out so far.

3 Effects of Underwater Noise on Pinnipeds

Gray seals use acoustic signals for communication purposes both in air and under water (Ralls et al. 1985; Asselin et al. 1993). It can be assumed that the construction of offshore wind turbines or other noise may potentially induce stress, masking, a TTS, or a permanent threshold shift in gray seals. In this subproject, a methodology using earphone inserts was developed and full in-air audiograms for gray seals were collected. The auditory thresholds for gray seals are below 30-dB sound pressure level (SPL) because the results for the frequency range of 4–12 kHz suggest and show strong similarities to in-air behavioral hearing tests of other earless and eared seals above 3 kHz (Ruser et al. 2014).

As described for harbor porpoises in Section 2, a specially designed DTAG for seals will be used to study the influence of anthropogenic noise on harbor seals.

4 Effects of Underwater Noise on Fish

There is growing concern about the effects of human-generated sound on fish. Within this part of the project, a literature review was conducted that included earlier research funded by the BfN (Seibel et al., in preparation). It provided a summary of the

possible damage to fish caused by different sound events and focused on the German and adjacent European waters. In conclusion, little is known about the effects of underwater noise on fish and many studies are only published in gray literature.

5 Noise Mapping in Natura 2000 Sites of the North and Baltic Seas

Underwater noise becomes an issue of increasing concern and is more and more discussed as a parameter that could affect marine wildlife in addition to other known environmental stressors. One expression of this concern is the acoustic descriptors published by the European Union as a metric to judge acoustic environmental conditions that still need to be determined and monitored by the states under the Marine Strategy Framework Directive. Three recorders were tested and noise loggers (JASCO AMAR G3) were deployed in the Fehmarn Belt and six other positions in the German Baltic Sea. A first evaluation showed that the different areas have a high influence of anthropogenic noise at lower frequencies, whereas frequencies above 1 kHz are mostly influenced by natural sounds. Trawl shields to prevent deployment losses due to bottom trawls were tested successfully. The deployment of noise recorders in the German Bight (North Sea) was conducted at the moment (July to September 2013). Ten positions are currently deployed in the Sylt Outer Reef. All recorders will be equipped with trawl shields and configured as in the Baltic Sea while, simultaneously, porpoise detectors will measure porpoise occurrence rates.

Acknowledgments This work was funded by the German Federal Agency for Nature Conservation (BfN). We thank Mark Johnson (Sea Mammal Research Unit, University of St. Andrews, St. Andrews, UK), the German Oceanographic Museum (Stralsund, Germany), and all other people who were involved for their assistance.

References

Asselin S, Hammill MO, Barrette C (1993) Underwater vocalizations of ice breeding grey seals. Can J Zool 71:2211–2219

Bibikov NG (1992) Auditory brainstem responses in the harbour porpoise (*Phocoena phocoena*). In: Thomas JA, Kastelein RA, Supin AY (eds) Marine mammal sensory systems. Plenum, New York, pp 197–211

Jewett DL, Williston JS (1971) Auditory-evoked far fields averaged from the scalp of humans. Brain 94:681–696

Lucke K, Siebert U, Lepper PA, Blanchet MA (2009) Temporary shift in masked hearing thresholds in a harbor porpoise (*Phocoena phocoena*) after exposure to seismic airgun stimuli. J Acoust Soc Am 125:4060–4070

Müller S, Lehnert K, Seibel H, Driver J, Ronnenberg K, Teilmann J, van Elk C, Kristensen J, Everaarts E, Siebert U (2013) Evaluation of immune and stress status in harbour porpoises (*Phocoena phocoena*): can hormones and mRNA expression levels serve as indicators to assess stress? BMC Vet Res 9:145. doi:10.1186/1746-6148-9-145

Popov VV, Supin AY (1990) Auditory brain stem responses in characterization of dolphin hearing. J Comp Physiol A 166:385–393

Ralls K, Forelli P, Gish S (1985) Vocalisation and vocal mimicry in captive harbor seals, *Phoca vitulina*. Can J Zool 63:1050–1056

Ridgway SH, Bullock TH, Carder DA, Seeley RL, Woods D, Galambos R (1981) Auditory brainstem response in dolphins. Proc Natl Acad Sci USA 78:1943–1947

Ruser A, Dähne M, Sundermeyer J, Lucke K, Houser D, Driver J, Kuklik I, Rosenberger T, Siebert U (2014) Evoked potential audiograms of grey seals (*Halichoerus grypus*) from the North and Baltic Seas. PLoS ONE 9:e90824. doi:10.1371/journal.pone.0090824

Szymanski MD, Bain DE, Kiehl K, Pennington S, Wong S, Henry KR (1999) Killer whale (*Orcinus orca*) hearing: auditory brainstem response and behavioral audiograms. J Acoust Soc Am 106:1134–1141