Aria of the Dutch North Sea

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Chapter 5 DISCUSSION AND SUMMARY

The aim of this thesis was to investigate the spatial, temporal and spectral distributions of sound that are generated by anthropogenic and natural sources in the Dutch North Sea. The acoustic insights and mathematical tool box that came out should help policy makers, legislators, biologists and conservationists and may serve in ecological monitoring and impact assessments, guide marine research efforts and may be used to determine potential regions or periods of acoustic conflict between human activities and aquatic life. The process by which I achieved this aim is reflected in the nature of the data chapters that address three distinct steps.

First, I explored, developed and combined mathematical models for specific sound sources and for underwater sound propagation dependent on the environmental conditions (Chapter 2). I was not only able to develop a model which enables fast calculations of propagation of sounds over a large frequeny band, but also applied the detailed comparisons of the model to several test cases from the Weston Memorial Workshop, held in 2010. Another prominent step taken was to adjust the propagation model for shallow water application where we can use the isovelocity approximation. I was able to show that the isovelocity approximation for shallow water waveguides does not lead to large errors.

Second, I used the mathematical models to integrate measurements from the North Sea about anthropogenic and natural sound sources into a variety of maps and visualizations of sound distribution underwater (Chapter 3). I focussed on three antropogenic sources (shipping, underwater explosions and seismic surveys) and one natural source (wind). However, in the future, similar sound mapping techniques can be applied to other sound sources such as pile driving, lightning and rain. The mapping and other visualizations were used to reveal the ranking of the selected sources in terms of their annual contribution of acoustic energy. Most of the sound energy (averaged over two years) in the Dutch North Sea was found to come from ships, followed by airguns and explosives for 100 Hz to 100 kHz frequency band, with most energy at frequencies between 100 Hz and 1 kHz for all three anthropogenic sources. However, I also show that some sources are characterized by brief bursts of very high energy and hence that this needs to be taken into account when assessing the biological impact of energy originating from various sources.

The sound mapping of the Dutch North Sea revealed strong geographical signatures for all anthropogenic sources. Shipping lanes formed fixed acoustic traces like highways on land, while seismic surveys and explosions were clustered in space and time, depending on the human activities of the particular year. Wind was present throughout the Dutch North Sea but the relatively loud high-frequency component was particularly prominent in the northern half due to a combination of higher wind speeds, the absence there of major shipping lanes and the clustering of explosions in the south. As part of this chapter, I also checked and confirmed modelling accuracy with actual sound measurements. The precision of my simulations is inevitably limited by lack of detailed environmental data (time dependent variation of sea surface, seabed properties, sound speed profile etc.), source properties (the number of sources of each type and their geographical distribution, source spectrum and associated source depth), and simplifications in propagation and source models, all of which create uncertainties in the predictions. While I have demonstrated that the effect of the sound speed profile is small, many other uncertainties remain to be quantified, a task that I gratefully leave to a future project.

Third, I participated in a collaborative effort to show the biological relevance of advanced acoustic insights through the integration of acoustic and biological data to assess exposure levels of marine mammals (Chapter 4). Sound exposure levels, locations and event dates of explosions were combined with distribution data and swimming patterns of harbour porpoises to reveal exposure levels at the population level and the impact of animal behaviour on exposure risk at the individual level. The results clearly showed the applied value of sound mapping in combination with biological data and the potential is high for future applications to other marine mammals or fish species. The maps can for example be weighted for species specific swimming depth and hearing range, and thus applied to investigate possible impact on hearing. In order to do this in a meaningful way for fish, the modelling techniques may have to be extended in the future to model particle motion, as all fish are sensitive to particle motion, while just fish with swim bladders have added sensitivity to sound pressure.

In conclusion, the modelling and mapping efforts reported in this thesis reflect both the progress in our understanding of underwater acoustics and the distribution and level of anthropogenic underwater sounds. However, we should not take the brightness in maps for danger or damage. At least not yet at this stage and likely also in many cases not at a later stage. We typically do not know whether artificial elevation of sound levels through noisy human activities really affects aquatic life and whether the effects have detrimental consequences. Aquatic life that may be affected include marine mammals, fish and even invertebrates, which can play a critical role in the food chain or can be important for fisheries (shrimps, lobsters) and the impact may concern masking of critical sounds, distraction, disturbance, deterrence and injury. However, empirical evidence from field studies showing that anthropogenic sound undermines the "Good

Environmental Status" of a particular waterbody is still rare and often non-existing. I hope the acoustic insights and mathematical toolbox coming out of my thesis will raise awareness of these major gaps in our knowledge and stimulate future studies in order to be able to detect, avoid, and mitigate acoustic conflicts due to spatial and temporal overlap in human and animal activities.