Aria of the Dutch North Sea

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Chapter 1 INTRODUCTION

Underwater sound is a critical tool for aquatic animals that communicate acoustically or exploit environmental sounds to find prey, avoid predators, or for orientation [Slabbekoorn et al. 2010; Fay 2009]. The interference of various anthopogenic and natural sound sources can make it difficult to distinguish biologically relevant sounds and can even cause physical damage to these animals. This has given rise to international concern about possible effects of anthropogenic sound sources on marine life due to increasing shipping traffic, exploitation of oil and gas reserves and the development of new offshore energy sources. For instance, the European Union's Marine Strategy Framework Directive (MSFD) [EU 2008] requires EU Member States to achieve or maintain Good Environmental Status (GES) by the year 2020. Specifically, GES Descriptor 11 requires underwater noise to be "at levels that do not adversely affect the marine environment". Calculating the sound distribution and estimating the associated environmental risk requires a multidisciplinary collaboration between acousticians, biologists and decision-makers. Understanding the spatial, spectral and temporal distribution of various sound sources and the characterisation of the acoustic environment are critical components to estimate the possible impact of sound on the marine life.

The MSFD requirement to investigate the potential impact of sound on marine life in the Dutch North Sea provided the background and motivation for a large scale project on "The effects of underwater noise on fish and marine mammals in the North Sea", funded by the NWO-ZKO programme. Within this project, three subprojects dealt with complementary topics including behavioural impact of sound on fish and sound exposure estimates for marine mammals. The aim of my project was to understand the distribution and composition of the sound in the North Sea. This aim is achieved by generating sound maps and calculating total acoustic energies for the various sound sources in the North Sea. The output of this project can serve in the impact assessment of underwater sound on environmental status.

In this thesis, the spatial, temporal and spectral distributions of sound generated by anthropogenic and natural sources in the Dutch North Sea are investigated. In order to achieve this aim, the acoustic propagation is calculated; source characteristics are modelled; and the resulting sound distribution is mapped for each source type. An aria is a piece of music sung by one person, normally as part of a larger performance. The sound maps for each type of source are created by

assuming all other sources are quiet during the activities of the selected source. For example, the sound maps for shipping only contain the voice of ships. The title of my thesis “Aria of the Dutch North Sea” is chosen to indicate that each sound map is for a chosen type of source. In Chapter 2, I start with multi-model propagation loss comparisons to investigate the accuracy of well-known propagation models [Chapter 2.1]. The insight obtained from these comparisons was used for the derivation of a fast and accurate propagation model (SOPRANO) for shallow water test cases based on scenarios specified by the Weston Memorial Workshop, held at the University of Cambridge in 2010 [Chapter 2.2 and 2.3]. This propagation model can calculate propagation loss without requiring a large computational load and complicated algorithms.

Chapter 3 starts with the effect of the sound speed profile on shipping sound maps [Chapter 3.1], compares the shipping sound maps with actual measurements [Chapter 3.2]; and describes the airgun source model AGORA [Chapter 3.3]. Finally, combining source and propagation models as a tool for predicting sound fields, sound maps are generated for the Dutch North Sea and the total acoustic energies are calculated for weekly and yearly periods [Chapter 3.4]. In Chapter 4, some examples of studies are provided to illustrate the use of the simulated sound maps for understanding the biological impact. These maps are used to investigate the potential impact of sound on the marine life. The source models and sound maps which are included in this thesis are listed in Table I. Chapter 5 summarizes the findings and insights from all chapters and involves a general discussion based on the results of my thesis.

Table I. Sound sources, source models and sound maps included in this thesis

Source	***Sound Maps***	***Source Model***
Ship	+	+
Underwater Explosions	+	+
Airguns	+	+
Pile Driving	-	-
Wind	+	+
Rain	-	+
Lightning	-	-
Biological sounds (i.e. marine mammals, fish and invertebrates)	-	-