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Monitoring and Research Shortlist Offshore Wind - Knowledge advancements and follow up

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Title
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Summary
This document describes the recent advancements in knowledge regarding the ecological effects of the construction and presence of offshore windfarms in the Dutch continental shelf of the North Sea. After the Masterplan (Boon et al. 2010), a research and monitoring programme was set up and conducted to increase important knowledge gaps on the ecological effects of offshore wind farms. The results of this programme are compared with the initial goals of the Masterplan, and with the goals described in later documents drafted for the research and monitoring programme, (working) hypotheses are tested, knowledge advancements described and knowledge gaps are identified.

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1 Introduction

1.1 Background

In 2010, a Masterplan (MP) on monitoring and research for the ecological effects of offshore wind farms was published (Boon *et al*., 2010). The MP consisted of the following:

- A description of all possible ecological impacts of the construction, presence and decommissioning of offshore wind farms (OWF).
- An inventory of the knowledge gaps in order to better assess their ecological effects.
- A description and prioritisation of the research that needed to be carried out to increase the knowledge level.

Based on this prioritised list of research plans that needed to be addressed, projects were selected that were given the highest priority for which funds were allocated. These projects have been carried out in 2010 and 2011. This selection, known as the 'shortlist', has been carried out by a consortium of research institutes and was finished in July 2011. The tender for this work was based on the terms of reference (ToR) set up by the Waterdienst, Rijkswaterstaat.

Deltares has been asked by Rijkswaterstaat to do the evaluation of the results of this 'shortlist' work. This means that the results of the various projects that have been carried out are compared to the research goals of the original prioritised list of projects as described in the MP and to the ToR for each project. In other words: do the results of the research projects answer the questions that they were supposed to answer?

This document describes the research goals of the projects described in chronological order, going from the MP, to the ToR, and to the tenders. It then compares the results of the research and monitoring projects to the earlier described research goals in the form of hypotheses. It concludes by describing the knowledge advancements and remaining questions.

1.2 Method

The majority of the work in this report is extracting the general theory, its working hypotheses and the testable hypotheses from the available documents: the MP, the ToR and the tenders for each of the projects. Commonly, research and monitoring plans contain no explicit descriptions of the axioms and hypotheses that are part of the conceptual framework underlying the research.

First, an inventory is given of the projects that have been selected from the MP to be carried out ('shortlist'). Next, a description is given of the terms of reference (ToR) for the projects. These two documents are the main sources for the axioms and hypotheses for the research carried out for the 'shortlist'. Based on these two documents, tenders were written for the specific research projects. The goals described in these tenders are listed. This section gives an overview and comparison of the goals going from the MP to the Tor to the tenders.

Next, the axioms and hypotheses were deduced from the general theories on impact assessments described in the MP. These axioms and hypotheses were compared to the research goals described in the tenders. In most cases, limitations on personnel, material, time and budget are important constraints on performing the research necessary to answer the research questions. When going from a general research question to practical research, decisions need to be taken on which specific questions need to be dealt with first. These are the focal points of knowledge advancement. Hence, the gaps between the research goals described in the MP, the ToR and the tenders need to be made clear.

Lastly, the results of the research and monitoring project are compared to this set of axioms and hypotheses, and a description is given of the knowledge advancements and the remaining question regarding the specific research issues.

1.3 Bookmark

In this report, chapter 2 describes the MP, the ToR, and the tenders for the shortlist projects. From this, an overview is given of the research questions and general set up of research projects and background theory going from the Masterplan to the tenders. For as far as (working) hypotheses were not described in the research plans themselves, they have been deduced from the MP, the ToR and the tenders, which are described in the chapters 3 to 10.

Chapters 3 to 10 each contain a description of the starting points (axioms), the assumptions (propositions) and the hypotheses that form the basis for the research projects which were carried out. The description starts at a rather general level in the Masterplan, and progresses to the more detailed level from the tender. It depicts the various possible research and monitoring pathways per subject, which decisions have been taken in refining the research questions to the tender level, and how these choices determine the progress in knowledge on the discussed subjects. These chapters also contain the results of the nine research and monitoring projects and the hypotheses testing. A description is given of the original questions from the MP that were not well or fully answered (meaning that the hypotheses cannot be rejected or accepted); new questions that have arisen from the studies and the next set of questions to be dealt with to get a better insight into the general questions that were mentioned in the MP.
Hypotheses describing and testing is done per shortlist project in each of these chapters, because this gives the best overview of the line of reasoning without the need of repeating texts.

Chapter 11 gives an overview the evaluation of the results of the various research and monitoring projects from the chapters 3 to 10. It reiterates the research questions, how well these have been answered, if new questions have emerged, and what a next monitoring or research plan might entail.

2 Description of the research projects

2.1 From Masterplan to shortlist

The work in the MP entailed a deduction and prioritisation of the research and monitoring needed to advance the knowledge on the ecological effects of OWFs. Below, a short reiteration of this work is given including the axioms and hypotheses used for this deduction.

2.1.1 Cause-and-effect chains

The main axiom is that OWFs have a negative impact on marine organisms. Birds and marine mammals have been the first of the animals involved in assessments, later on also habitat, benthos, fish and even bats have been added to the list of potentially affected ecological units. Theoretically, also plankton can be influenced by the presence of underwater structures. Effect pathways are diverse, but mostly obvious. Collisions, barrier effects and underwater sound are among the most conspicuous effect pathways. The table below (originally table 3.2 in Boon *et al*. 2010) sums up the possible cause and effect relationships.
Hence, a proposition following from this axiom is that the construction, presence and demolition of offshore wind farms have negative effects on these ecological units as well. It is important to explain the concept 'negative', since this clearly is a human qualification of trends in characteristics of ecological units or processes. As explained in the Masterplan, the use of the terms 'negative', ‘harmful’, ‘advantageous’, etc. as qualifications for the effects of OWFs is partially subjective and sometimes counterintuitive. In general, 'negative' effects mean an increase of mortality, or sub-lethal effects such that individual fitness (chances of survival) decreases. The terminology used is closely connected to our interpretation of the effect or the species level. This interpretation is often associated with notions such as rarity, biodiversity, iconic effect and “naturalness”. However, this interpretation is less straightforward or even sometimes “contra natural”. For example, the breeding population level at which the herring gull and the lesser black-backed gull are protected in the Netherlands is based in part on the high incidence of discarding by fishing cutters. Reducing this human effect will probably lead to an adverse effect on the desired conservation goal for these species. The use of the qualifying terms must be seen in this light. One of the arguments for focusing the proposed research is the judicial protection of species or habitats; it is one of the criteria used for prioritising the research and monitoring projects in the Masterplan.

Less obvious from this table are changes due to effects on ecological processes and food-web effects. Sometimes, not the direct and near-field effects are important, but the indirect and far-field effects. In the case of the effects of piling (underwater noise) on fish larvae, the rationale for the research is the possible effect of decreased numbers of fish juveniles on the fitness of marine birds and mammals, and on the functioning of protected coastal areas as nursery areas for fish. Some effects were not thought to be relevant for the offshore North Sea and have not been listed as research topics, such as the increases of jellyfish that are in some cases thought to be related to increases in hard substrates, and the increase of local fish production due to the increase in invertebrate biomass resulting from the increase in hard substrate surface.

Table 2.1: Overview of main ecological cause-effect relations of offshore wind farms

Phase	Effect pathways	Affected ecological units						
		Habitats	Plankton	Benthos	Birds	Fish & fish larvae	Marine mammals	Bats
Construction phase								
Construction of foundations	Water quality	X	X	X		X	X	
	Noise / vibrations (under & above water)		X	X	X	X	X	
Cable installation	Space taken up	X		X		X		
	Water quality		X	X		X	X	
Navigation	Noise / vibrations					X	X	
Operation phase								
Presence wind turbines	Risk of collision				X			X
	Water quality		X					
	Noise / vibrations					X	X	
	Loss of habitat function and/or space	X			X		X	X
	Hard substrate	X	X	X	X	X		
	Scouring, bottom morphology	X		X		X		
Cable presence	EM radiation			X		X	X	
Navigation for maintenance	Noise / vibrations					X	X	
Navigation prohibition	Noise / vibrations					X	X	
	Fishing prohibition			X	X	X	X	
Decommisioning phase								
Removal foundations	Water quality	X	X	X		X	X	
	Noise / vibrations				X	X	X	
Cable removal	Water quality	X	X	X		X	X	
Navigation	Noise / vibrations					X	X	

2.1.2 Prioritisation and shortlist selection

Based on three sets of criteria (necessity, effectiveness, cost efficiency), a prioritisation of research projects has been made. In the table below (adapted from table in paragraph 4.2 from the Masterplan), an overview is given of the research projects described in the Masterplan, their priority, and which projects have been selected for the shortlist. Additionally, it was important to select projects that were able to deliver results within one year to one year and a half, because funding could only be secured for relatively short-term projects.

Table 2.2: Overview of research and monitoring projects, their priority and other characteristics, with selection for the shortlist.

Research and monitoring projects	Priority 1	Priority 2	Priority 3	Term ST	Term MT	Term LT	Type of information B	Type of information G	Type of information LS	Duration (y)	Shortlist
Underwater noise											
- International consultation	■			■			■			1	*
- Sources	■			■				■		2	*
- Propagation model		■			■				■	2	
- Mitigation review		■			■			■		1	
- Underwater noise map			■			■	■	■		1+	
- Risk analysis tool		■				■		■		2	
Plankton											
- Mixing, primary productivity			■	■				■	■	?	
- Plankton composition			■	■	■			■	■	?	
Benthos											
- Soft substrate species			■		■				■	5	
- Hard substrate species			■		■				■	3	
Fish (larvae)											
- Effect of pile driving	■			■				■		1	*
- Larvae survey	■			■	■			■		1	*
- Expansion of the model, validation of death, autecology of larvae		■			■	■	■	■		4	
- Food web effect			■			■		■		?	
- Effect electromagnetism			■			■		■		1	
- Effect of contaminations			■			■	■	■		1	
Birds											
- Pop. dynamics, tagging lbbg	■			■	■		■			4	*
- Survey at sea (avoidance of sea birds)	■			■			■			5	*
- Radar observations	■				■			■		5	
- Sea bird strandings related to collisions		■				■			■	5	
- Collision measurements		■				■			■	?	
- Ring counting desk			■	■			■			?	
- Ring counting field			■			■	■			?	
- Use of habitat by sea birds			■		■		■	■		?	
Bats											
- Bat detection coast & sea			■							?	
- Data of catches at sea			■							?	
- Behaviour at wind farms			■							?	
Marine mammals											
- TTS por	■			■	■			■		3	*
- Other hearing parameters por		■		■			■				
- Threshold values por		■		■			■				
- North Sea survey por	■			■			■			5	*
- Wind farm survey por		■		■	■			■	■	2	
- Behaviour por as a result of pile driving		■			■			■		?	
- TTS com sl	■			■				■		1	*

- Audiogram gr sl				1	
- Critical ratio com sl				1	
- Other hearing parameters sl					
- Threshold values sl					
- Distribution of sl at sea				3	
- Analysis of the noise effects				1	
- Countings				5	
- Use of habitat por				?	
- Use of habitat sl				?	
- Behaviour of por & sl at OWF				?	

Abbreviations: lbbg: lesser black-backed gull; por: porpoise; com sl: common seal; gr sl: grey seal.

2.2 Shortlist project descriptions and goals

2.2.1 Masterplan

From the above, it follows that nine research and monitoring projects have been selected on the shortlist. This shortlist has been accepted for government funding. The description of the shortlist of projects is (copied from the Masterplan, Boon *et al*. 2010[1]):

1. Standardisation of methods to measure underwater noise at sea. Assessment of the noise, which will be animal species specific (comparable to the dB(A) assessment for atmospheric noise for humans) will have to be discussed in more detail on an international level. Without this synchronisation, the usefulness (= comparability) of the measurements is limited. In that case, it may turn out that national measurements cannot be used internationally, and vice versa.
2. Proper description and validation of the noise sources is necessary. This means that measurements must be taken and models must be made of various sources, primarily the noise of driving piles (of turbine foundations) and of manoeuvring ships. Such measurements are possible in the short term, when the piles are driven for the Belgian wind farm for example, or when measuring masts are installed on the Dutch Continental Shelf (DCS). The result is a calculation model for the prognosis of underwater noise because of the various activities.
3. Data on lethal and sub-lethal effects on fish and fish larvae as a direct consequence of driving piles of foundations for wind farms are required for better assessment of effects. Experimental studies in the field are necessary for this. If the first wind farm in Belgium is constructed (including pile driving), this will be the first option to measure the direct effects. This may be linked to the pile driving activities for the measuring masts, which, as we understand it, will be done this year. It is relevant in that case to know if these pile-driving activities are comparable to those for foundations of wind turbines. Concrete plans for driving piles of wind farms abroad can also be examined (including the Baltic).
4. Distribution of fish larvae on the DCS. Apart from the larvae of a few commercially interesting species, knowledge on the spatiotemporal distribution of fish larvae is not available. For the sake of possible mitigating measures and improvement of the models used for the dynamics of fish larvae distribution, it is important to study possible locations and periods for less harmful pile driving than those currently mentioned in the permit regulations for the second round of offshore wind farms.

[1] *Please note that the projects have been carried out differently from the MP description.*

5. For breeding birds, and especially the lesser black-backed gull, data on population dynamics are chiefly required for better assessment of the effects on protected breeding colonies. This primarily concerns data on survival (ringing and recounting), the share of floaters (study of breeding colonies) and patterns of flying away from the colony tagging breeding specimens; see the observations on the selection of transmitter types above). Such data should be linked to data of the fish larvae, commercial fishing activity and the position of natural food areas, so that a connection can be established between survival at the population level and the food situation in the coastal and offshore waters. Such studies also produce the requisite information on loss of foraging area, barrier effects and change in foraging behaviour for breeding birds. In addition, tags could supply important information on migration pathways and behaviour when the breeding season is over. Also, non-breeding birds could be tagged to this end.
6. Large-scale offshore distribution data are required for avoidance and/or barrier effects (local sea birds and migrating birds), while smaller scale data are required at the site of the plan locations (including changes in foraging behaviour) for OWFs. Aircraft surveys are especially suitable for the larger scale counting of sea birds; ship surveys are required for location-specific counting combined with behavioural observations and measuring flying altitudes.
7. Experiments are required to measure the noise level that causes temporary hearing damage in porpoises, TTS (*Temporary Threshold Shift*). The hearing of porpoises is essential for foraging, and deterioration in the function of hearing will certainly result in a reduced fitness of the animal. This level must therefore be prevented from being reached and can be used as a criterion for porpoises. Such experiments can be carried out in pools (Note: experiments to determine changes in behaviour are required as the follow-up step).
8. Basic data are required on the distribution of the porpoise populations, and dolphin populations if applicable, in space and time in the (southern) North Sea. How porpoises migrate through the southern North Sea is practically unknown, for example whether there different populations and (sub)migrations, etc. A regular survey by aircraft appears to be the most appropriate method for this. Such DCS-wide flights are currently taking place (under orders of the Ministry of Economic affairs, Agriculture and Innovation); continuation of this survey is important for arriving at a proper T_0. Comparable to the porpoise, the TTS can also be an important limit value for the foraging options of common seals.

2.2.2 Terms of Reference

Following on the selection of research and monitoring projects, terms of reference were described for tendering on these projects. These terms of reference give a more detailed description of the criteria for the quality level and set up of these projects. An important part of the ToR is about how the research and monitoring needs to be carried out, but also about the goals and expected results of the projects. More details regarding the expected results mean a stronger focus on the research questions, and a narrowing down of propositions and hypotheses.

Below, an overview is given of the goals and expected results per subject and per project as described in the ToR for the 'Imares' projects. The selection of text from the ToR focuses on the parts that explicitly describe the goals of the project. This expresses best the interpretation of the Masterplan text by the Waterdienst. Note that the original Dutch text has been translated to English by the author.

3 Effect underwater noise on fish and fish larvae
In this study, a pilot experiment will be done in terms of a dose-response relationship in larval fish. In theory, experiments can be performed both in the field and in the lab. The tender will present alternatives, describing advantages and disadvantages of the methods, limitations and uncertainties, risks and costs. Also, a proposal to investigate noises (which focuses on single and multiple exposures) will be delivered. The advisory group will make a choice of the pilot experiment in consultation with the institutions. This experiment must demonstrate in the first stage the feasibility of the method; in the second phase, an initial determination is to be performed of the sound level at which mortality occurs.

4 Distribution fish larvae DCS
The goal of this project is to monitor the spatial distribution and seasonal patterns in the occurrence of fish eggs and larvae on the DCS. This will require a year-round survey conducted where the entire DCS-plus will be sampled. We will also be looking into possible cross-border monitoring points and the usefulness and necessity for monitoring them.

5 Breeding birds
Gaining insight into survival, the proportion of floaters and the flight patterns should result in more detail in the current assumptions (*of the collision models in the appropriate assessments for the Round 2 Offshore Wind Farms, Arjen Boon*). If there is more certainty about the assumptions to date, a better result (fewer casualties) will leave more room to build offshore wind farms. This probably clarifies how offshore space can be used without significant effects in the Natura2000 areas ‘Krammer Volkerak’ and ‘Lage Land van Texel’. More accurate numbers in the model calculations and better assumptions when doing risk assessments will be decisive for the visualisation of the ecological effects of offshore wind farms on the lesser black-backed gull.

6 Distribution seagoing birds
Aerial surveys
Collecting recent distribution of (sea) birds on the DCS. Besides the focus on the entire DCS, the Round 2 and Round 3 areas should be examined in detail.
Shipboard surveys
Site-specific counts of seabirds combined with behavioural observations and any measures of altitudes. Because of the location-specific and more detailed way of observation from a ship, it is possible to try to understand the factors that help determine the observed distribution patterns.
This study is aimed at (sea) birds. As usual with ESAS seabird observations, counts are combined with observations of the presence and behaviour of marine mammals.

Note that the original goals of the surveys as mentioned in the Masterplan (Boon *et al*. 2010), assessing bird distribution and movements for seabirds and migrating birds was not included.

8 Distribution porpoises and dolphins DCS
Aerial surveys
For management and administrative questions, the estimated number of porpoises in the DCS needs to be accurately determined. It is desirable to understand the spatial and temporal distribution patterns on the DCS during all seasons relevant to porpoises. Besides the focus on the entire DCS, Round 2 and Round 3 areas should be examined in detail. The State has the need for understanding factors that determine the dispersal of the porpoise and

for the areas for porpoises that serve as foraging, resting and breeding habitat in relation to the Round 2 and Round 3 areas.
Shipboard surveys
DCS wide counts of porpoises combined with behavioural observations. To be combined with observations of presence and behaviour of seabirds.

7/9 TTS marine mammals (porpoise and seal)
Expected result:
Noise level at which TTS occurs during multiple exposures to "piling noise" for both common seals and porpoises. Noise levels where "piling noise" is heard by harbour seals and porpoises. Results of TTS (as an estimator of PTS) and audibility converted into an effect range for both species on DCS.

2.3 Tender

Below, the goals of the research projects as described on the tender from IMARES are given. The selected text is taken from under the heading 'Aims' or the like.

3 Effects noise on fish and fish larvae
The broader aim of this research line is to obtain a better understanding of the effects of noise on fish. The specific goal of the current project is to carry out pilot experiments on the effect of piling noise on the survival of fish larvae (n*ote author: in tender both lab and field experiments were planned*).

4 Fish larvae distribution
The purpose of this project is to monitor the spatial distribution and seasonal patterns in the appearance of fish eggs and larvae on the NCP. To this end, a year-round survey will be carried out during which ichthyoplankton samples will be taken from the entire NCP and from the adjacent area south and west of the NCP.

5 Breeding birds
Aims of the project are three-fold (*note author: and focus on the lesser black-backed gull*):

- Estimates of (annual) survival.
- Assessment of the number of floaters (and/or recruitment into the population).
- Patterns of flight and foraging distribution (in particular a quantification of the presence and activities of gulls within established wind farm sites and in areas planned to be designated as offshore wind farms) of lesser black-backed gulls breeding in the Natura 2000 areas “Lage land van Texel” and “Krammer-Volkerak”.

6 Distribution of seagoing birds DCS
Shipboard surveys
Given the geographic scale of the problem, data are required on seabird distribution and behaviour, including feeding, migration and flying heights across the DCS, year-round, for all species deemed important in relation to offshore wind parks. Two methods will be used to achieve this: aerial surveys and ship-based surveys. Either method has its strong points and weaknesses. The aerial surveys are an excellent tool for assessing distributions across the entire DCS in a short time-frame, but have problems with identifying certain seabird species-to-species level, and cannot generate data on behaviour or flying heights. As ships are much slower than airplanes, they cover less ground in the same time, but from boats, all species encountered can be identified, behaviour can be recorded and flying heights estimated. In the set-up proposed (see below) data will be collected from a ship that is working the DCS 24h per day. This is cost-effective, but at the same time will result in incomplete coverage as no

data can be collected during darkness (while the ship sails on). This problem is greater in mid-winter, when days are short and nights are long. The boat surveys therefore will result in partial coverage of the DCS, but at a higher level of observational detail, while the aerial surveys will cover the entire DCS, but with less observational details. Hence, both survey-types are complementary to one another and thereby will generate the whole picture. Another aim of the project is, to gather data for re-evaluating the long time series of aerial survey data of Rijkswaterstaat, by crosschecking aerial survey data with boat survey data, collected synoptically and at the appropriate geographical scale, i.e. for the entire DCS.

Aerial surveys
The main aim of the project is to gather detailed information on densities and distribution of seabirds in the search area for round 2 and 3 wind farms in the Dutch part of the North Sea. Given the geographic scale of the problem, data are required on seabird distribution, seabirds' behaviour, including feeding, migration and flying heights especially in the search areas for round 2 and 3 wind farms, year-round, for all species deemed important in relation to offshore wind power. Two methods will be used to achieve this: aerial surveys and ship surveys. Either method has its strong points and weaknesses. Compared to ship-based surveys, aerial surveys are an excellent tool for assessing distributions in large areas within a relatively short period, but have problems with specific identifications of certain seabird species, generate limited data on behaviour and flying heights. However, the combination of ship-based and aerial data will generate the whole picture, as the ship-based survey data will calibrate the aerial survey data on species identification, recorded densities, behaviour and altitudes. Another aim of the project is, to develop a tool for re-evaluating the long time series of aerial survey data of Rijkswaterstaat Waterdienst/Ministry of Infrastructure and Environment, by crosschecking these aerial survey data also with the ship-based survey data, collected synoptically and at the geographical appropriate scale. However, the same can be done as calibration with the aerial survey data collected in this project, as these data are gathered at a lower altitude, with better observation windows, a lower speed and densities are calculated taking into account detection loss.

<u>8 Harbour porpoise distribution DCS</u>
Aerial surveys
The main aim of this study is to estimate the abundance of harbour porpoises in Dutch waters (DCS). The estimate will be provided with confidence limits and coefficients of variation which will allow their use in management and conservation (e.g. by estimating by-catch rates or potential biological removals). The “racetrack” method will be applied throughout the flights to assess and if necessary re-evaluate the currently used g(0) values. These values are used to correct for ‘missed’ porpoises during the surveys.
The results will be used to provide insight into spatial and seasonal changes in distribution of porpoises in Dutch waters for the survey period. The collected data will be presented in maps showing the density of porpoises on the DCS. The results will also provide a baseline database to allow the future assessment of anthropogenic impacts (e.g. offshore construction, noise) on the distribution. The data will also include information on the presence of calves as well as behaviour of porpoise and presence of vessels and net debris.
The priority in this project is conducting three complete surveys in as short a time as possible (less than 4 weeks). Additional survey effort will be concentrated on the planned areas for future offshore wind farm construction. This information will provide more detailed information on porpoise small scale distribution in these areas. Additional “ad hoc” survey flights will be conducted if specific areas are suspected to be of particular interest, e.g. because of a high calf presence.

During all surveys all marine mammals will be recorded and distribution maps will also be provided for those species (e.g. seals, white-beaked dolphins, minke whales). If a sufficient number of sightings will be made abundance estimates will be made. Additional information will be collected on the presence of vessels (e.g. fishery, freighters, tourist vessels) and the location of set-net gear, as well as floating debris associated with fishing activities (e.g. floating nets).

7/9 TTS harbour porpoise and harbour seal

Harbour porpoise

(*Note: only the work mentioned under phase 1 is selected*)

Overall goal: determine the relationship between sound level, type, and exposure duration on temporary threshold hearing shift (TTS) in harbour porpoises. With the information from the entire study (3 phases) the government can set safe sound exposure criteria for harbour porpoises around pile driving sites at sea.

This proposal is the first part (year) of a three year research project on TTS in harbour porpoises. The proposed study will attempt to answer the following questions for harbour porpoises:

Phase 1 (Tests with noise bands: this proposal, 1 year)

1. What exposure level-duration combinations of noise bands cause TTS onset?
2. What is the relationship between the exposure level and duration on the degree of threshold shift?
3. What is the recovery rate of hearing after TTS?
4. Does TTS extend to frequencies higher than the frequency of the exposure noise? (This aspect is given limited attention due to limited available budget and time for the project).

Harbour seal

Overall goal: determine the relationship between sound level, type, and exposure duration on temporary threshold hearing shift (TTS) in harbour seals. With the information from this study, the government can set safe sound exposure criteria for harbour seals around pile driving sites at sea.

The proposed study will attempt to answer the following questions for harbour seals:

Phase 1 (The exploratory phase with narrow noise bands as fatiguing noise)

1. What exposure level-duration combinations of narrow-band noise cause TTS onset.
2. Does TTS extend to frequencies higher than the frequency of the exposure noise? (This aspect is given limited attention due to restricted available time for the project).
3. What is the recovery rate of hearing after TTS?
4. What is the relationship between the exposure level and duration on the degree of threshold shift?

Phase 2 (The actual test phase with impulse sounds as fatiguing noise)

1. What exposure level-duration (number of impulses) combinations of impulse sounds (such as in case of pile driving) cause TTS onset?
2. What is the recovery rate of hearing after TTS caused by impulse sounds?
3. What is the relationship between the exposure level and duration (number of impulses) on the degree of threshold shift?

Application of TTS results

1. Calculation of the distance from a pile-driving site in the North Sea at which TTS will start to occur in harbour seals (example for one location at the Dutch part of the Continental Shelf).
2. Compare the TTS results of this proposed study with TTS distances and detection ranges mentioned in the appropriate assessments?

3 Underwater noise: methodological standardisation

3.1 Research questions

The project was carried out by TNO, and focused in general at "*the development of standards for the measurement and reporting of underwater sound, with a primary focus on acoustic monitoring in relation to the environmental impact of offshore wind farms*" (TNO 2011). Reporting of the project was done in two different parts; one report treats the generic properties of underwater sound and the standardisation of units. The scope of this report is to provide an agreed terminology and conceptual definitions for use in the measurement procedure. The practical implementation of these definitions, the procedures for measuring underwater sound in connection with offshore wind farm licensing, is addressed in an accompanying report (De Jong *et al*. 2011).

The measurement of and the use of quantities and units for underwater sound until now has not been standardised as is the case for sound in air. A variety of units is being used, partly to express the various properties of underwater sound. Concurrently (but not explicitly related), the measurement of underwater sound is being conducted in various ways, related to the techniques as well as the methodology. In order to solve this issue, international meetings were held with acoustic experts, one in 2010 in Southampton, United Kingdom, and one in The Hague, the Netherlands in 2011. As a result of these meeting, agreement was reached on a number of important issues, and a new set of (definitions of) quantities and units is being proposed as a national standard, which is being supported by a large number of acoustic experts from Germany, Norway, the UK and Spain.

3.2 Hypotheses

The goal of this project was to come to a set of internationally accepted properties and units of sound that will be used in future studies, and standardised measurement and monitoring requirements for offshore wind farm constructions. Since there is no experiment or measurement, there are no hypotheses.

3.3 Results

The issues dealt with in this project are diverse and very specific, and mostly difficult to express in non-professional terms without going into detail. Therefore, only a relatively superficial treatment of the most important issues, which were discussed in the meeting, is presented here.

3.3.1 Definitions and units

A table is presented in chapter 2 of TNO (2011) with (mathematical) definitions of general acoustical terms, except those relating to decibels. The reason for this is that a decibel is commonly a log expression of a normalised or weighted other acoustical term. Since there is a lot of discussion about this weighting or normalisation, these terms are presented in another chapter. Chapter 3 in TNO (2011) treats the definitions of terms and quantities, which are expressed in decibels. The reason for this chapter is to facilitate cross-referencing between definitions expressed in decibels and in other units. Here, expressions are presented that are commonly found in reports regarding the underwater sound measurements on the construction of offshore wind farms, such as SPL (Sound Pressure Level) and SEL (Sound Exposure Level). A separate paragraph is dedicated to the treatment of the terms "source level" and "propagation loss", since together they provide a quantitative description of the

sound field at a receiver in the far field of the sound source, which is the standard research question in relating OWF piling sound to effects on fish or marine mammals.
For various reasons, there is a difference in point of view on how to express sound between what is called the "purists" (don't use decibels), and the rest (dBs are ok). This specifically plays a role in expressing peak pressures; a relation between power and peak pressures is only possible through a standardised conversion formula. Two suggestions are given for such a conversion in paragraph 3.3 in TNO (2011). A further list of definitions for which additional conversion might be needed is given in a final table in chapter 3 in TNO (2011).
In chapter 4 in TNO (2011), a syntax is proposed to express under water sound properties in dBs alongside SI units. Since the dB is no SI unit, but a quite commonly used unit in underwater sound studies, propositions for a language is presented that combines the use of dB with SI units. Here, examples are worked out for Sound Exposure Level, but these apply to SPL, Peak level and RMS alike. How this language needs to be operationalised is expressed in paragraph 4.3 in TNO (2011). The report goes into detail on issues such as stating clearly the physical quantity (standard terms, bandwidth, averaging time, weighting etc.), the reference value, and using SI units.
Chapter 5 in TNO (2011) treats the "remainder": the definitions of non-SI units and measurements of scales, and defines (translates) them as well as possible in SI units, although some cannot be expressed as such, e.g. "sea state".

3.3.2 Measurements and monitoring offshore wind farms

De Jong *et al*. (2011) describe standards for monitoring of underwater sound with a primary focus on acoustic monitoring in relation to the environmental impact of offshore wind farms. The approach adopted in their report is to compare existing monitoring approaches and to propose a minimum requirement for monitoring procedures that fulfils the common requirements.
First, De Jong *et al*. (2011) start out developing standards for the use of a common language of the relevant metrics that have been used in the assessment of wind farm related under water noise, so-called noise indicators. As such, it is closely comparable to, and an application of the work on metrics standardisation done in TNO (2011). They begin with describing the relevant "types" of sound: single pulse, multiple pulse and non-pulses. However, the distinction between a pulse and a non-pulse is intuitive, but hard to express concretely, namely in the duration and the characteristics of the sound. Based on these two criteria, De Jong *et al*. propose a classification (based on Southall *et al*. 2007) in three types of sound: continuous, transient and repeated (or multiple) transient sound. Each can be subdivided into three characters: incoherent broadband, narrow band and coherent broadband. Next, sound indicators are described in relation to the environmental effects (i.e. on mammals and fish). Each type of sound is "assigned" a specific metric, an SPL or an SEL. These metrics mostly relate to the studies in which effects were shown on mammals and fish. However, various recent studies show that Temporary Threshold Shifts (TTS) in mammals cannot be adequately described by a cumulative SEL alone.
It appears there are currently no unequivocal metrics to be used in studies on the effects on mammals and fish. During the last meeting (in 2011, TNO Delft) of acousticians, it was basically advised not to use any metrics in laboratory or field studies, but to report the whole of the set up of the study, the sound emitting and receiving/recording machinery, their calibration, and to be sure to record the whole set of characteristics of the sound, including the wave form, length, amplitude etc. In such as case, whatever metric was derived from it, it would always be possible to compare the results of different studies[2].

[2] This remark is the author's representation of a part of the discussion that took place during the 2011 Delft meeting with acousticians.

Weighting of the sound is sometimes used to assess possible risks of the sound to a specific species or group of animals. It makes use of the hearing characteristics of this species or group, and is comparable to the A-weighting done for airborne sound for humans (expressed as dB(A)). However, as there is still a lot unknown about the relevance of weighting for the dose-response relationship, it is currently not advised.
In the remainder of the chapter, noise metrics are discussed that have been and are used during pile-driving projects in The Netherlands, Germany, the UK and the USA. De Jong *et al*. conclude this chapter with a proposal for the minimum requirements for noise metric reporting. Here, they repeat in other words the remark made earlier that as many measurements as possible need to be stored in raw data, so that later on possible additional metrics might be recalculated form these raw data.
In their chapter 3, De Jong *et al*. (2011) describe into detail the procedures, which are being used in The Netherlands, Germany, the UK and the USA for assessment and monitoring of underwater sound for licensing of OWFs. They derive general considerations for standardisation of the monitoring procedures of underwater sound for two categories of sound: the background noise and the specific sounds. Different questions are treated, which cover the when, where, how and what to measure. These will not be described here, since they are quite complex and too numerous to be included in this report.
Chapter 4 in De Jong *et al*. (2011) is their pinnacle: it gives a proposal for a measurement and reporting procedure, specifically focused at the licensing of OWFs in The Netherlands. It distinguishes four phases: a pre-construction phase (T0), the construction phase (T1), the operation phase (T2) and the deconstruction phase (T3). It advises on monitoring of the background noises during all phases, and of the specific sounds during phases T1, T2 and T3. First, they describe the requirements for the terms and definitions for underwater sound, such as the metrics for use of SPL, Peak pressures, SEL, and cumulative SEL. Next, they describe the requirements for the measuring equipment: hydrophones, amplifiers, filtering, conversion and recording, and how to calibrate the instruments. In a following chapter, they describe the various requirements for monitoring in the different phases of the project (T0, T1, T2, and T3). They derive a general set of principles, which are adapted to the 4 phases in the project. Concluding paragraphs are presented on data processing, analysis and storage and on reporting.

3.3.3 Future developments

In a finishing chapter, TNO (2011) describes the way ahead for the development and acceptance of acoustical terminology related to underwater sound. In fact, this document has no formal status, and although a large group of acousticians (in a study group that was formed in the context of the Marine Framework Strategy Directive) have agreed with the content of the report, it still needs to receive a formal status, i.e. acceptance by the ASA and ISO. Dissemination of the content of the report would be advisable.
Such a finishing chapter lacks in De Jong *et al*. (2011), the report aims at developing standards for licensing of future Dutch OWFs exclusively. It mentions that the TNO report describes the minimum requirements for monitoring that fulfil the common requirements, and that additional requirements and scientific needs may lead to further extensions of the requirements. However, the report does not explain what these minimum and common requirements are, and which specific extensions might be developed.

3.4 Knowledge advancements and remaining questions

The advancements in this report mainly consist of crucial procedural advancements. In order to make results from studies and projects comparable or even understandable, it is a prerequisite to use standards in units, in definitions, and in monitoring and measurements.

The question that remains is whether the proposed standardisation in TNO (2011) will be accepted in Europe and worldwide for measuring and expressing under water sound? This is not a question likely to be answered within a short time; such procedures are rather time consuming. Nevertheless, it has become more likely that within Europe there is enough support to use these new standards in future work. Relating to the matters dealt with in the second report (De Jong *et al*. 2011), it is not clear which future procedural advancements are possible; such a chapter is currently lacking in the (draft) report.

Having said that, TNO is working on a report that describes a risk assessment approach for underwater sound from OWFs, which is a procedure for deriving the risk for marine life of the specific aspects of the underwater sound generated by the different phases of construction, operation and deconstruction of an OWF. This risk assessment tool integrates the results of the various reports, which have been written in the shortlist program (including the project described in the next chapter).

4 Underwater noise: source level and propagation modelling

4.1 Research questions
The goal of this project is to be able to describe the sound of underwater noise of piling for wind farms at the source level, i.e. at a standard level that is not dependent on habitat characteristics such as depth, salinity, temperature, et cetera. Together with propagation modelling and effect levels, this would lead to the possibility of assessing the risk of underwater sound for marine life.
The sound source needs to be measured under specified circumstances, and using a source model, the source level can be calculated. E.g., the source level of piling will differ per pile, its length, material, diameter, thickness of the water column, physical properties of the water column, depth into the sediment and sediment characteristics. Using measurements of the source level of a specific pole, and modelling the results for other piles based on knowledge how sound behaves in piles of varying dimensions and materials, a standardised source level can be calculated.

So far, two reports have been presented. One report describes the experimental set up and results of a model piling experiment at Kinderdijk. The other report presents a hybrid-modelling tool, which, making use of the data from the Kinderdijk experiment, is able to describe short-distance sound wave propagation and give insights into the characterisation of the pile as an acoustic source.

4.2 Hypotheses
Thus, axioms and hypotheses can be derived as follows:

Axioms/propositions:
- Source level depends on hammer type and piling energy.
- Source level depends on pile diameter, length, material and penetration.
- Source level depends on water depth and sediment properties.

Hypotheses:
- Source level will increase with higher piling frequency and hammer energy (more an axiom, but how is unknown).
- Source level will decrease with increasing pile diameter and penetration depth.
- Source level will decrease with increasing water depth, and a smaller median sediment grain size (as an example of sediment characteristic).

4.3 Results

4.3.1 Piling experiment at Kinderdijk
In Jansen *et al*. (2011), the results are described of the two piling experiments that have been conducted at the Kinderdijk facility of IHC Hydrohammer. The goal of these experiments was to collect a dataset that could be used to validate a numerical model (which has been published in Zampolli *et al*. 2011).
The piling experiment in Jansen *et al*. (2011) was conducted using a small-scale setup with a pile in a water basin, which was filled with sensors to record the 3D image of the sound waves travelling through the water and the sediment. The pile had a diameter of ca. 0.9 m, a

length of 32.5 m of which 19 m had been piled into the ground. Measurements were conducted with and without a so-called noise mitigation screen. This screen has been engineered and built by IHC Hydrohammer and consists of a steel cylinder which confines an air bubble screen. Each experiment consisted of various replicate series of multiple strokes.
Depending on the hammering (enthru) energy, and without the use of the noise mitigation screen, peak pressure levels (Lpeak) measured at 5 m distance and at 2 to 4 m depth in the water column varied from ca. 205 to 215 dB re 1 μPa^2. At a distance of 68 m, Lpeak was 195 – 200 dB re 1 μPa^2. The Sound Exposure Level (SEL) in the water column was around 180 dB re 1 μPa^2.s at 5m distance and around 170 dB re 1 μPa^2.s at 68 m distance. The use of the noise mitigation screen reduced the noise levels for Lpeak to 185 to 190 dB re 1 μPa^2, and SEL to 160 dB re 1 μPa^2.s, both at 5 m distance. This implies that in this set up, 6 to 8-fold reduction in noise level was reached using the mitigation screen. Also, particle acceleration was measured (but no further elaborated on in this report). Furthermore, sediment noise pressure and acceleration levels were measured as well (neither elaborated on this report).
The data were used for validation of the noise radiation and propagation model described in Zampolli *et al*. (2011), which is discussed below.

4.3.2 Noise radiation and propagation model
The model is actually a hybrid model consisting of a finite element (FE) model (the local model) and a wave propagation model. The FE model describes the acoustics of the pile and the direct surroundings, and the propagation model describes the movement of the sound over large distances.
Here, neither model will be discussed in detail. More important is how the hybrid model performs when validated with the data from the Kinderdijk trials, and if it can be used in real-life circumstances, namely when modelling the sound propagation due to piling of OWFs in the North Sea.
From the results from the validation of the FE model, the following can be concluded:
- The SEL predicted from the model agree fairly well with the measured levels.
- The sound escapes for a large part into the sediment.
- Major disagreements remain between the FE model and some aspects of the measurements, probably due to pile characteristics not taken into account into the model yet.

The propagation model was needed in order to calculate noise wave propagation beyond the ranges used in the Kinderdijk trials. In the study by Zampolli *et al*. (2011), the two models have been coupled into a hybrid model. This hybrid model appears to be able to function properly when compared to the FE model, so for near-field propagation, but no validation has been possible for far-field propagation. One of the advices in the report is to take this as a next step.

4.4 Hypotheses testing
Regarding the answering of the hypotheses, the following can be said:
- Source level will increase with higher piling frequency and hammer energy (more an axiom, but how is unknown): confirmed; the noise level increases with the hammering/piling energy, more or less linearly.
- Source level will decrease with increasing pile diameter and penetration depth: not tested.
- Source level will decrease with increasing water depth, and a smaller median sediment grain size (as an example of sediment characteristic): not tested.

4.5 Knowledge advancements and remaining questions

From the Kinderdijk experiments and the model validation it has become clear that the near-field model from Zampolli *et al*. (2011) is able to reproduce sound exposure levels and near-field propagation fairly. The local model and the far-field propagation model have successfully coupled; near-field propagation can be fairly modelled with the hybrid model.

An important question still is how the model behaves when predicting far-field propagation in realistic circumstances, with changing parameters in time and space. It still is not clear what the influence is of varying soft sediments on far-field propagation, how stratification will affect sound wave propagation et cetera.

5 Underwater noise: effects on fish and fish larvae

5.1 Research questions

Only relatively recently, the effect on fish of high-impulse sound levels from piling the turbine foundations became a research subject. From the hearing capabilities of fish, it can be deduced that fish are sensitive to underwater sound. They may be disturbed, avoid sound sources or be hampered in their usual behaviour. Furthermore (and probably not related to their hearing capacities) high sound levels may damage fish to such an extent that they die from it. When in the vicinity, they may be damaged and die from the sound levels emanated by monopiles being hammered down into the seabed. Prins *et al*. (2008) summarised the knowledge from various studies on the effect of underwater sound on fish. They said, "*Based on current information it is estimated that injury caused by pile driving may occur up to several kilometres distance, whereas disturbance is possible up to tens of kilometres."* The assumption was that what was possible for fish was also possible for fish larvae.

In the Masterplan, the knowledge level is described as follows: “The principal presumed effect of wind turbine farms on fish larvae is damage and death as a result of the pressure waves released with the noise of pile driving work during construction of wind farms (Prins *et al.* 2008). A fish larvae model has been developed that can estimate the consequences of death of fish larvae during their passive transport from spawning grounds to nurseries (Prins *et al*. 2009). However, a very important but poorly substantiated premise is the extent of mortality around the pile driving site. Such information is not available.”

It should be added here, that the few instances where the effects of high levels of impulse sound on fish were studied, it did not concern fish larvae or juveniles, but adult specimens. Due to the legal framework of the appropriate assessment (Bird and Habitat Directives), the concerns were not on reduced stock size (and thus a fish population effect) but on food-web effects through fish as a prey item for coastal breeding birds, marine mammals and thereby the functioning of coastal and inshore lagoons (Wadden Sea) as nursery areas for fish. Only a relatively small fraction of larvae and juveniles is being transported to these nursery areas, so localised effects may be more prominent than regional effects. This may be typical for the southern North Sea situation. In other circumstances, other effect chains may be more important.

The mechanism through which death or damage occurs is unclear. It is postulated that high sound wave pressure causes damage to the swim bladder. Another mechanism might be damage of various tissues through high particle velocity (Popper *et al.* 2006). If the swim bladder is the mechanisms through which death occurs, some groups of fish (e.g. flatfish) are less susceptible than others are (Hastings and Popper 2005).

The tender suggests two experimental set ups. One set up focuses on a laboratory experiment, the other encompasses a field experiment when piling is carried out. However, in the period in which the experiment was planned no piling in the field was planned, because the field experiments exceeded the available budget. Therefore, only the laboratory work was to be carried out in the context of the project ‘shortlist’.

The experiment was specifically set up as a pilot experiment. No earlier experiments were conducted with fish larvae in an especially for this experiment designed sound pressure chamber (the “larvaebrator”). There was no experience with the handling and survival of larvae when preparing experiments like these.

5.2 Hypotheses

The conceptual-propositional analysis is as follows:

Axiom:

- High levels of impulse underwater sound, such as caused by turbine piling, causes damage to fish near the piling location, leading directly or indirectly to death or reduced fitness due to tissue damage. This has been proven in some (but not many) studies.

Propositions:

- Fish larvae are also susceptible to such high levels of impulse sound, maybe even more so than adult fish, since based on Popper *et al*. (2006), fish susceptibility to impulsive sound decreases with size.
- Fish and fish larvae die from or are damaged by sound through some form of tissue degradation.
- Some characteristics of sound, such as wave pressure level, are more responsible for causing the damage than others.
- There is no difference in effect between species groups of fish, such as due to presence or absence of a swimming bladder or being a hearing specialist.

Hypotheses:

- Fish larvae are lethally damaged or die from high-level impulse sounds such as emitted during turbine piling.
- The level of damage decreases with increasing distance from the source, i.e. in an experimental set up, this means damage level decreases with lower sound pressure level (all else being equal).
- Fish larvae show a mortality of 100% up to one kilometre distance from the sound source (related to the former hypothesis, this was the assumption in the Framework and the appropriate assessments)
- The mechanism of damage is via the pressure wave level and not so much the particle motion characteristics of the sound.

5.3 Results

The results of this pilot experiment on the fish larvae were reported in Bolle *et al.* (2011). The experiments consisted of various series of experiments, in which different cumulative sound exposure levels from simulated piling noise (varying peak levels in combination with a varying number of strikes) were applied to batches of larvae in different developmental stages. Especially the development of a swimming bladder in the species used (Sole: *Solea solea*) was assumed to be important. The swimming bladder develops for a short period; it disappears again in the last developmental stage.

No significant effects of exposure to piling noise on the survival of sole larvae were observed. Mortality occurred and was relatively high in both the control and the impact situations. The power of the experiment was limited to detecting significant effects at a 95% level of over 15 to 21% mortality due to piling, so any mortality effect below 15 to 21% could not be detected with this set-up. Based on this, it is concluded that, for sole larvae, the threshold for an effect ≥21% is at a cumulative SEL >205 dB, corresponding to a distance of <100m from a ‘typical’ North Sea piling site. In the report, results are compared to other studies in which fish larvae were exposed to high impulse sound levels. From these studies, it is clear that there is quite some variation in the mortality levels of fish larvae from different species.

5.4 Hypotheses testing

The results show that none of the hypotheses could be confirmed:

- Fish larvae are lethally damaged or die from high-level impulse sounds such as emitted during turbine piling: rejected.
- The level of damage decreases with increasing distance from the source, i.e. in an experimental set up, this means damage level decreases with lower sound pressure level (all else being equal): rejected.
- Fish larvae show a mortality of 100% up to one kilometre distance from the sound source (related to the former hypothesis, this was the assumption in the Framework and the appropriate assessments): rejected.
- The mechanism of damage is via the pressure wave level and not so much the particle motion characteristics of the sound: rejected.

Mortality due to piling
The sole larvae showed a high rate of mortality in both impact and control situations. In some cases, the mean mortality was somewhat higher in the impact trials, but in other cases the reverse was seen. Within the experimental limitations of the set-up, no significant effect of piling on survival of the sole larvae could be detected. Therefore, the first hypothesis cannot be confirmed. As explained by the authors, there still might be a relatively small effect, implying that although the hypothesis should be rejected, this might not be the case for effects under 15 to 21% mortality. The experimental set-up could not detect such small effects with any significance.

Mortality rate decreases with distance
There were no signs that the mortality level decreased with decreased cumulative SEL, or with lower peak pressure levels; variability was too high in both controls and impact trials to detect any effect. Therefore, this hypothesis should be rejected in case of the sole larvae.

In their report, the authors revise the assumption from the Framework (Prins et al. 2008) and the appropriate assessments (Arends et al. 2009) of 100% mortality over 1 kilometre distance from the piling site. They conclude it is safe to assume a mortality of 100% over a distance of 100 metre from the piling site, and 20% mortality from 100 metre to 1 kilometre from the piling site. This would reduce the effects that were reported in the modelling study by Prins *et al.* (2009) with 70%.

Pressure wave vs. particle motion
Due to the lack of effect and of (significant) differences between the experiments where particle velocity was applied and where wave pressure was applied, this hypothesis cannot be confirmed. It is however interesting to see that in one trial the larvae responded differently to the particle velocity effect than to the pressure wave effect. This has not been clarified yet. A large part of the trials was only conducted applying pressure waves.

5.5 Knowledge advancements and remaining questions

It is important to bear in mind that the conducted experiments were pilot trials. Two important methodological issues needed to be treated first to find out if the set-up would actually work:

both the handling of larvae and the functioning of the sound chamber had to be tested. Both issues turned out to be no crucial limitation to perform the experiment. This was a formidable step forward, since these issues were thought to be large obstacles on the way to a proper experiment.
However, some notes need to be made about both issues. The handling of the larvae consistently caused mortality of the larvae, and was usually well comparable between the controls and the impacts. Notable was the variability of the mortality: in some experiments the mortality rates in the controls were as low as 10%, in other cases as high as 60%. These differences in mortality have not been explained and are somewhat worrisome to the usability of this experimental set-up. It needs to be addressed in follow-up studies. Regarding the other issue: the sound chamber was not able to produce a pure pressure wave without particle velocity excitation, as was the idea on beforehand. Hence, any effect that the pressure wave might have had, may be “polluted” by particle velocity effects. The lack of a significant effect (over 20%) on mortality disclaims this problem in this specific case, but it needs to be taken into account in any following experiments.

The lack of a significant effect on the survival of fish larvae that were exposed to the maximum cumulative SEL of 205-206 dB re 1 $\mu Pa^2.s$ (equal to the effect of 100 pulses at 100 meter distance from a ‘typical’ North Sea piling site), means that the assumption of 100% mortality within 1 kilometre from the piling location in the appropriate assessment was overly protective, at least in the case of sole larvae. The authors have set up a more realistic estimate of mortality, 100% mortality within 100 metres and 20 % from 100 to 1000 metres from the piling site. This effect level is based on the power analysis of the experiment, and one must bear in mind that no effect has been shown in the experiment at a level comparable to 100 metres from the source. Therefore, the suggested new effect level can be considered as a new worst-case effect level of piling on fish larvae.

Important are the two questions raised at the end of the report: are the results for sole representative for effects on larvae of other fish species, and can the results of these laboratory experiments be confirmed by field experiments?

Regarding the survival of species in other experiments, the representativeness of sole larvae seems to be somewhat limited. The only way to study this is an additional set of trials with other species, preferably the species that have been assumed relevant as staple food for birds and marine mammals: plaice, flounder, herring, sprat, cod, whiting and smelt, to which sandeel can be added (being a replacement prey for sandwich terns when herring and sprat are less available).

A field experiment would be interesting, but hard to set up. Focus should therefore first be on consolidating and improving the experimental set-up with the “larvaebrator”, resolving the pressure wave vs. particle velocity issue, reducing mortality due to handling, and try to find effects in species, which are more relevant as prey for marine birds and mammals.

6 Distribution of fish larvae on the DCS

6.1 Research questions

Another important factor in the assessment of the survival of fish juveniles in coastal waters is the distribution of fish larvae on the Dutch Continental Shelf (DCS). The distribution of fish is currently only known to a limited extent for a few commercially interesting species. This particular research subject has no clear experimental character. It is a baseline study that has a strong monitoring character. As such, there are no clear experimental hypotheses; results are more or less adopted 'as is'. However, for the design of the field work, various assumptions have been made.
The field work consists of monthly surveys of a week. The survey period will last for a year. According to the tender, this sampling schedule is based on the knowledge and/or assumptions that:

- Axiom: spatial heterogeneity of known fish larvae is such that 3 hauls per ICES rectangle are a minimum for spatial representative sampling and (proposition) is representative for all other species.
- Axiom: development from egg to juvenile lasts between 40 to 70 days (sole and plaice) and (proposition) is representative for all other species.
- Axiom: spawning period of known species lasts about a month and (proposition) is representative for all other species.

It states that based on these assumptions, knowledge will be gathered about the distribution of fish eggs and larvae, and about the approximate spawning locations. To estimate total spawning biomass, weekly sampling is needed.

The axioms and propositions will not be tested specifically by the study on hand; they do not relate to the common goal of sampling fish larvae and juveniles across the DCS. They relate to the representativeness of the sampling methodology. Since sampling methodology is based on extensive experience with plankton sampling in the past, further calibration of the representativeness of the sampling method is not deemed necessary.

Next, sampling occurs on a grid layout, and three layouts have been proposed. The layouts aim to sample representatively and not miss out any important spawning areas. Both the first and the third grid are preferred, the first from a scientific point of view, but is not feasible within 5 days. Therefore, the third layout with a small reduction in spatial coverage and resolution is the only layout, which is scientifically acceptable and feasible within 5 days.

In May 2010, the two sampling grids were studied for effectiveness with a hydrographical larvae transport model. This led to a change in sampling grid after May 2010: from June onward, the grid with 91 stations was chosen.

6.2 Hypotheses

Some general axioms and hypotheses can be described:

<u>Axiom</u>:

- Fish egg and larvae distribution is patchy and varies per species and per month.

Hypothesis:

- There is a continuous concentration of fish egg and larvae in time and space.
- The eggs and larvae occur mostly in the first half of the year.
- These concentrations can be traced back to known spawning locations in the southern North Sea.
- These spawning locations are in agreement with those that have been used in the modelling study for the appropriate assessments (Prins *et al.* 2009).
- These concentrations disperse at least partly towards the coastal areas of the Netherlands.

6.3 Results

The results of the survey have been reported in Van Damme *et al.* (2011). In summary, the results show that the highest concentrations of eggs and larvae occurred in the first half of the year, although in all months eggs and larvae were sampled. To discern patterns, we need to look at specific species. The results of some of the relevant species (prey species for birds and mammals, as discussed in the former chapter: plaice, herring, cod, whiting, and sandeel) will be discussed shortly.

Plaice eggs were found in the English Channel and the southern North Sea from December to March, near their scattered spawning grounds in the Channel and the Southern Bight. Yolk-sac larvae were mostly found from January to March in the southern North Sea and later larval stages were found from February to April, and mostly northwest of the Wadden islands.

Herring eggs have not been found because they do not float. Yolk-sac larvae have been found in December and January in one place: English Channel, which is the spawning area for spring herring, which is found in the Southern Bight and in our coastal waters. Older stages of the larvae were later on found in the coastal waters.

Cod-like eggs were found in December and January in the Channel, and in the southern North Sea in reasonable numbers from January until May. Lower numbers were still found thereafter. Cod larvae were hardly found in the southern North Sea. Only in February and March, some low numbers of non-yolk sac larvae northwest of the Wadden islands were found.

Whiting eggs were hardly found. Only in June, some eggs were sampled in the south. From March to June, larvae were found along the coast and in the central southern North Sea and Dogger Bank. Highest numbers of larvae are found in April.

Sandeel eggs and larvae have been found for four species. Most numerous were greater sandeel and lesser sandeel. For both species, eggs were not found. The greater sandeel bent-urostyle stages and metamorphosing larvae have been sampled throughout the whole area, with an emphasis in March and mostly for the area west of the Voordelta, and northwest of the sampling area. The lesser sandeel was found in yolk sac stage in February and March with later stages shifting northward and sampling in March to April. The lesser sandeel showed a more coastal distribution. Near the Holland coast, no larvae were found, but northwest of the Wadden islands, concentrations were moderately high.

6.4 Hypotheses testing

What do the results mean for the hypotheses?

- There is a continuous concentration of fish egg and larvae in time and space.
- The eggs and larvae occur mostly in the first half of the year.
- These concentrations can be traced back to known spawning locations in the southern North Sea.
- These spawning locations are in agreement with those that have been used in the modelling study for the appropriate assessments (Prins *et al.* 2009).
- These concentrations disperse at least partly towards the coastal areas of the Netherlands.

Eggs and larvae distributions

Many species distributions seem to be in one or a few concentrations in early egg stages and for benthic egg species in the early larval stages, and confined to certain periods. During development, they move with residual currents towards coastal areas in the eastern part of the North Sea, such as the Dutch and Belgian coastal waters. Herring clearly shows up in big concentrations of early stage larvae in the English Channel in December and January with larvae from the autumn spawners (Dogger Bank) in the northwest of the survey area, with later stages spreading along the Dutch coast.

Hake, sardines and anchovy show a strongly phased and localised spring egg stage, mainly in the Dutch and Belgian coastal waters, but during development to larvae they do not move northward with residual currents. Horse mackerel shows an egg phase in June and July in Dutch and Belgian coastal waters, with later stages in July and August, but also confined to the same coastal waters. Lesser sandeel show an early larval stage mostly in February and March mainly in the western part of the survey area with later larval stages in March and April closer to the Dutch shores.

Other species such as sprat and common dragonet show a rather wide distribution in eggs throughout the survey area early spring with later stages in May and June spread throughout the North Sea tending to a northward distribution in August. Cod-like eggs and larvae show a similar (lack of) spatial pattern, but again with a dominance in the first half of the year:

- It seems that for practically all species the hypothesis fails for a dominance of the spawning area confined to the first half of the year. Some species (mackerel, gobies) spawn later on in the end of spring and early summer, but to the end of the summer and in autumn hardly any eggs and larvae are found.
- The report does not go into detail on how spawning areas determine the distribution of eggs. For species such as herring, sandeel, plaice and sole the egg distribution seems to be well related to the spawning areas.
- Spawning seems to be more distributed in time and space than had been assumed in the appropriate assessment, although the periods in which spawning was assumed to take place appear to be fairly right.
- For many species with spawning areas to the south or in the southern and south-western part of the survey area, later larval stages tend to distribute partly or even importantly to the Dutch coastal waters. It is also clear that they are quite less larvae than there are eggs. Mortality may differ per species, and some rough estimates may be derived from the data, which can be used for calibration on the model used in the appropriate assessment.

6.5 Knowledge advancements and remaining questions

Fish eggs and larvae have been sampled in the southern North Sea for the first time year round on a monthly basis. This knowledge is unique and provides a significant improvement to what was known about the spatiotemporal distribution of eggs and larvae in the southern North Sea so far. It also adds to the knowledge needed to improve the estimates of the effects of wind turbine piling on the survival of fish larvae, on the resulting decrease of fish juveniles in coastal waters and the food-web effect on marine birds and mammals.
In the appropriate assessments, data on spawning location as a source of the eggs, the timing and dispersal of eggs and larvae and presumed behaviour of the larvae were used on combination with a hydrological model to describe expected behaviour of larvae in the southern North Sea. The current data can be used to calibrated the model and validate its parameterisation.

Still, various questions remain. Of course, there is the interannual variability in recruitment and development extent, timing and location. It is commonly assumed (and there are sufficient data to show) that recruitment of fish into the spawning stock is more depending on environmental variables than on the production of eggs. However, mortality of eggs and larvae is often based a rough estimates, even for well-studied commercial species. The current data might improve on these estimates, certainly for non-commercial species. Next, questions remain regarding the metamorphosis to the juvenile phase. For species such as herring and sprat, the juveniles have the right size for bird staple food. Especially sandwich terns rely for a good chick growth and condition on the abundant supply of herring (and sprat, Stienen, 2006). Also, the harbour porpoise depends on herring for food, next to species such as whiting and sandeel, which form major prey items (Santos and Pierce 2003). The availability of these staple food prey species and the link from larvae to juveniles to this availability remains an important issue to be resolved in order to understand the effects of piling-induced mortality on fish as prey for birds and marine mammals.

7 Population dynamics lesser black-backed gull

7.1 Research questions

The cause and effect chain between OWFs and (breeding) bird populations is a long one, with many links that are unclear or missing. It consists of two large subsets: one concerning the behaviour of birds in and around OWFs (avoidance behaviour, collision risk, habitat loss), and the other with regard to the effects of the general foraging behaviour of gulls and population dynamics within breeding colonies. Data on the effects on birds in and around wind farms need to be combined with data on foraging behaviour and population dynamics to assess wind farm effects on a breeding population. The studies referred to in this chapter concern the foraging behaviour and (parts of) the population dynamics of gulls from two coastal breeding colonies.

Data on population dynamics are chiefly required for a better assessment of the effects on protected breeding colonies. Seen from the bird's perspective, a wind farm causes loss of habitat for resting, moulting and foraging, a barrier to flying and a collision risk. Any effect the OWF has on the bird may cause an effect on population level. This expresses as a change in breeding success of the population, which is mediated (dampened or worsened) by many internal and external factors such as food availability, predation and the floater population. In the Masterplan, primary concerns were about baseline data on survival (ringing and counting back), the share of floaters (study of breeding colonies) and foraging patterns from the colony (habitat use), and additionally, data on the breeding biology of the gull are needed, all specifically from the breeding colonies on Texel and in the Krammer-Volkerak. The goal of such studies should be to establish a link between survival at the population level (per breeding colony), foraging behaviour/habitat use, food sources (reflecting the food situation in the coastal and offshore waters) and the role of the so-called floaters in buffering mortality of (potential) parent birds.

The studies proposed by Imares and Bureau Waardenburg focus on exactly these aspects:

- Patterns of flight and foraging distribution (in particular a quantification of the presence and activities of gulls within established wind farm sites and in areas planned to be designated as offshore wind farms) of Lesser Black-backed Gulls breeding in the Natura 2000 areas *Lage land van Texel* and *Krammer-Volkerak*.
- Prey item and quantity.
- Assessment of the number of floaters (and/or recruitment into the population).
- Estimates of (annual) survival.

The studies described in this chapter have no experimental set up, so no experimental hypotheses could be deduced. They are field studies on the breeding biology and foraging behaviour of the gulls. However, in the appropriate assessments for the second round of Dutch offshore wind farms, various assumptions were made about foraging behaviour. Next, in the same reports, some assumptions were made and (referenced) data were used about the population dynamics. These assumptions are used as hypotheses in the following paragraph.

7.2 Hypotheses

As mentioned in the last paragraph, assumptions about foraging behaviour and population dynamics originate from the appropriate assessments for the so-called second round of OWFs. These assumptions formed the basis of the axioms, proposition and hypotheses presented below.

Axioms:
- Lesser black-backed gulls from coastal breeding colonies use the coastal North Sea as a foraging area.
- Foraging behaviour affects population dynamics.
- Floaters play an important role in population dynamics.

Propositions:
- Foraging behaviour and population dynamics are colony specific.
- Floaters will (at least partly) recruit into the breeding population, which varies per year and which depends on local circumstances (*e.g.* breeding success, food and habitat).

Hypotheses:
- The lesser black-backed gull flies to a maximum of 100 km from its breeding colony.
- Within each breeding pair, both or only one of the parents is on a foraging trip depending on the breeding phase.
- The foraging area is partly the North Sea, and depends per colony.
    - Birds from the Texel colony forage for 95% of the time at sea[3].
    - Birds from the Volkerak colony forage for 25% of the time at sea.
- The number of foraging birds is distributed evenly over the foraging area, which is a half to three quarters of a circle seaward around the breeding colony.
- The number of foraging flights depends on the phase in the breeding, varies from 3 to 5 per pair per day, and averages at 4 per pair per day.
- The foraging frequency also depends on the distance between the plan area and the colony.
- Floaters are (always) at least 10% of the breeding population.

7.3 Results

Two studies have been conducted on the foraging behaviour and the population dynamics of the lesser black-backed gull in protected Natura 2000 areas, one on the island of Texel, and one in the southwest fresh-water lake Volkerak. These studies have been described in respectively Camphuysen (2011) and Gyimesi *et al*. (2011) and the results were quite unveiling. Some results were quite different from what was expected, and very colony specific. Below, the results of these studies will be treated in relation to the research questions from the Masterplan and the hypotheses that were derived from the appropriate assessments for the second round offshore wind farms.

Regarding distribution of flights, results showed that the tagged birds from the Volkerak did not use the North Sea at all. Only two individuals flew once towards the North Sea, probably

[3] In the appropriate assessment, it is assumed that 95% of the birds forage at sea. This has been translated into 95% of the time spent at sea foraging for all birds, since it is unknown whether all birds forage at various sites, or whether this is bird specific.

after breeding failure. According to the report (Gyimesi *et al*. 2011) this may imply that also other non-breeders (read: floaters) could forage at sea more often than breeding birds do. Breeding individuals flew inland, visiting terrestrial sources, bringing in terrestrial food items from a distance up to 25 km mostly. The birds flew regularly to specific areas, and were not homogeneously distributed.

At Texel, the situation was quite different (Camphuysen 2011). The majority of the males foraged at the North Sea (time spent). The majority of the females foraged at the Wadden Sea, Texel or the mainland. Prey items were predominantly marine species. This sexual difference in foraging areas was not apparent in the Volkerak colony. The distribution of gulls foraging on the North Sea was not homogeneous, but mostly restricted to an area west to southwest of Texel, at a distance of 40 to 45 km (3rd quartile). Birds that failed their breeding had a different foraging behaviour than the breeding birds.

In both colonies, breeding success was relatively high, which in the case of the Volkerak colony was likely due to fencing off the breeding area, making it inaccessible to predatory rats.

Maximum flight distance for breeding birds in the colonies was around 100 kilometres, but only few flights attained this distance, although at Texel, some “freak” flights occurred with trips to northern France (by females).

At neither colony, the share of floaters could be determined. Although there were prospecting birds (potential breeders) sighted at Texel, no actual recruitment has been observed. Notable is that this is the case since 2006, when ringing of fledglings started.

It is notable that the results from the Texel colony are relatively extensive. The study on foraging behaviour and breeding dynamics has been started some years ago, while the Volkerak colony was only studied for one season. However, breeding birds from the latter colony do not forage significantly (not at all for the tagged specimens) at the North Sea. The most important part of the results that will be taken into account will be those of the Texel colony. Where appropriate, a comparison with the Volkerak colony will be made.

7.4 Hypotheses testing

What do the results mean for the above-mentioned hypotheses?

1. <u>Foraging behaviour</u>.

   The foraging behaviour is quite different (at least in 2010) from what was assumed so far (in the appropriate assessment). Actually, the only hypothesis that can be accepted was the one about maximum foraging distance, around 100 kilometres. Foraging areas differed between males and females, as it did between breeding phases. The time spent foraging at sea is zero for the Volkerak colony, and at the Texel colony it is 78% for the males and 33% of the time for the females. Within the potential North Sea foraging area (a semi-circle or larger seaward there is a strong focus of foraging trips on the areas west to southwest of Texel, probably related to the presence of beam trawlers considering the high number of discard prey items in the menu of the gulls. Not much information was given on the number of foraging flights. Two Volkerak specimens were found to forage on average almost 5 to 6.5 times per day, which include nocturnal flights. Also, the Texel birds were found to fly at night. For the Texel colony, no data were presented about the number of daily trips, which took place at the North Sea. With the available data, this should however be able to be calculated. Therefore, there is also no insight into the

relation between foraging distance and foraging frequency. When looking at the presence plots of the Texel colony, there is a clear relation between the presence and distance: the further away, the lower the presence.
Interesting is the continued foraging activity during the night at Texel, more so of females than of males. Also some reports of night foraging by specimens from the Volkerak colony were given.

2. Floaters.
The non-breeding birds that are of importance to population dynamics are called floaters and consist of birds that failed breeding, and (sub-)adults that have not started breeding (yet). At the Texel colony, there clearly were some prospecting birds, but from all fledglings ringed at the colony in 2006 and 2007 (which are most likely to recruit into the breeding population), only relatively few were observed again in the colony in the following years. No recruitment so far has been reported from these ringed birds, in either the Texel colony or elsewhere. Another study indicated that breeding-site fidelity is rather high for breeding lesser black-backed gulls (Camphuysen 2010). Data from the Volkerak colony on floaters are almost absent. The absence of recruitment at the Texel colony (or elsewhere for the ringed Texel fledglings) raises many questions about the cohort dynamics of and the exchange between non-breeders and breeders. Another set of questions is about the dependence of such dynamics on food availability, habitat characteristics and breeding success (history).
Therefore, the results about the floaters are inconclusive as to the size of the floater population or the importance of the floaters in population dynamics. Camphuysen (2011) concludes that assessing this non-breeder pool and its functioning will be cumbersome, since this pool consists of various subgroups and because it is more difficult to prove that a bird is not breeding than that it is breeding.

3. Breeding and survival.
Above, no hypotheses have been mentioned about breeding success or survival of gulls. In the appropriate assessment, only little attention is paid to the effects of mortality on the breeding populations. Assumptions about the floaters were made explicitly to estimate roughly the level of additional mortality a population could sustain before a decrease in breeding individuals would occur. In annex II of the appropriate assessment, survival data from literature gave a value of 0.914 for the lesser black-backed gull. So, this information is crucial to assessing possible effects on the survival of the breeding colonies.
In both colonies, breeding success was relatively good. The Volkerak colony gave a breeding success of 2.0 (for the control group). The Texel colony had a relatively high breeding success of 0.71 in 2010, with the preceding 4 years varying between 0.26 and 0.46. The almost three times higher success of the Volkerak colony was likely due to fencing off the colony; breeding success outside the colony was estimated to be lower.

7.5 Knowledge advancements and remaining questions

The two studies have shown that much information can be gained in a short period, although at Texel, the birds have been part of a research since 2006, thus giving significantly more information on distribution and breeding of birds over a longer period. Nevertheless, the GPS tagging of the birds showed that foraging behaviour of the gulls is complex, and quite different from what was assumed only some years ago in the appropriate assessment. Not mentioned before, but also flying height and movements around the existing two wind farms of the Texel birds will prove to be valuable information in combination with other studies that are or have been performed at these wind farms. Influence of trawlers will be significant in determining forage behaviour. Questions remain on the repeatability of the observed patterns (data from the Vlieland colony may give information on this), the relation with food availability, with trawler discards as an important food source (check AIS data from trawlers, fish survey in this shortlist survey), flying frequency at varying distances (but data are probably sufficient to make a calculation). Behaviour of birds around the existing wind farms was also done in the Texel study, and showed a relatively low presence of birds in the wind farm areas of *OWEZ* and *Princess Amalia*. This might be related to the absence of trawlers, being an important food source for gulls, also during the breeding season.

The floater population and their relevance for survival of a colony remain elusive. The absence of any recruitment by potential breeders at Texel (or elsewhere for any Texel fledglings) is noticeable; what does this exactly signify? Is there no room, where do the fledglings go? Site fidelity appears to be relatively high, but no recruitment takes place. Is the breeding population not rejuvenating, and if so, what does this mean for future survival? Are birds from other colonies stepping in?

Breeding success at Texel varies considerably, from 0.26 to 0.71, averaging at 0.46. In a modelling exercise, Lensink *et al*. (2011) assumed a breeding success of 0.319 for a steady-state situation, with an adult survival of 0.914, and a floater share of 10% of the breeding population. Camphuysen scored better breeding results and a higher adult survival (estimated at 0.95) for the Texel colony. Counting results suggest that the Texel breeding colony is in decline, although there is discussion about the reliability of the counting technique. If the results on survival and the decline of the breeding population are correct, then some other process is responsible for the current decline.

In conclusion, it can be stated that our knowledge on foraging behaviour for the two studied colonies has shown an important change from what was assumed earlier. Data from GPS tagged birds from Vlieland already suggested that the earlier assumptions were not justifiable, but no data from other and relevant colonies were available for the calculations in the appropriate assessment. Knowledge on floaters and their importance for the breeding colony has increased, but the picture seems less straightforward than was originally assumed. Breeding success has been well documented, especially at Texel, but the relation with population viability is still unclear. More data on survival are needed, especially of juveniles and sub adults, together with data on import and export of floaters.

8 DCS distribution seagoing birds

8.1 Research questions

Large-scale offshore distribution data (southern North Sea) are required for avoidance and/or barrier effects (local sea birds and migrating birds), while smaller scale data are required at the site of the plan locations (including changes in foraging behaviour) for OWFs. Aircraft surveys are especially suitable for the larger scale counting of sea birds; ship surveys are required for location-specific counting combined with behavioural observations and measuring flying altitudes.
Comparable to the other monitoring study for marine mammals (par. 3.8), no explicit axioms or assumptions/propositions were defined. In the tender this is expressed as follows: …"there is an urgent need to collect relevant T-zero data on several biological parameters".
In the environmental impact assessments for the second round offshore wind farms, habitat loss for seagoing binds was calculated from species-specific density data and disturbance distances from literature. However, this literature is mostly out dated and with a low resolution (MWTL). Newer data have been collected in project-based studies mostly, and usually encompass relatively small areas. Ship-based observations are scarce and do not describe behaviour, flying heights etc. Moreover, the shortlist study combines both aerial and ship-based observations over the whole of the DCS, and is as such a unique study. One drawback is that the ship-based survey is done on board the larvae survey vessel. This vessel does not stop sampling during the night, which leads to spatial gaps in bird observation data.

8.2 Hypotheses

In general, the following general axioms and hypotheses can be described:
Axiom:

- Seagoing birds show a patchy distribution across the DCS, which varies per species, per month and per marine habitat.

Hypothesis:

- The distribution and density of birds across the DCS has not changed significantly from the data that are present in the existing databases of MWTL and ESAS.

8.3 Results

Results from the surveys for birds have been described in two reports, one from the aerial survey (Poot *et al*. 2011), and the other from the ship survey (Van Bemmelen *et al*. 2011). The aerial survey was a dedicated survey for birds. The ship survey was dedicated to sampling fish eggs and larvae (see chapter 6), which was also used for bird observations. Therefore, there are significant spatial holes in the observations, from when the ship continued sampling for eggs and larvae during the night and made a significant distance during which no bird observations could be performed.

Currently, the results from these reports are treated separately, but they will be integrated into one report. As for now, such integration is not practical, but when species are discussed, some comparison has been made between the two reports.

The results in both reports show the distribution of bird species at the wider DCS for the ship survey, and at the smaller DCS (focusing at offshore area for wind farms) for the aerial survey. Also, observations have been made on bird behaviour, with a particular interest in their behaviour in and around the existing wind farms.

In the aerial survey, about 20 seabird species have been identified, the ship survey found 25 seabird species (but 90 bird species in total). The difference between these two surveys comes from some species that are confined to the part of the wider DCS that was not covered by the aerial survey: the north to western DCS, and parts of the British CS. Little Auk, Atlantic Puffin, White-billed Diver, Black-throated Diver, Manx Shearwater, Balearic Shearwater, Sooty Shearwater, Arctic Skua and European Storm Petrel were uniquely observed in the ship-based survey, while the Long-tailed Skua was only observed in the aerial survey. An advantage of the ship survey is that many birds can be identified more easily because they can be viewed from the side. Note that also many non-seabird species were found, such as geese, ducks, waders, and songbirds. These were not taken up in the further discussion, although the data may be of interest when more knowledge on migrating birds is required. This was however not part of the shortlist project.

Most observed seabird species from the ship were the larger gulls, Guillemot, Northern Gannet, and Northern Fulmar (all in the thousands) followed closely by the terns, the Razorbill, smaller gulls, Great Cormorant and the Common Scoter (all in the hundreds). Other birds were observed in the tens or less.
The aerial survey showed more or less the same pattern, but because of the different spatial coverage (more observations relatively nearshore) the nearshore species showed up in higher numbers in comparison to the offshore birds than in the ship survey. The aerial survey in general showed much higher numbers, simply because of the higher speed.

The aerial survey report makes explicit per-species comparisons to the MWTL data, and where possible to the ESAS data. Although the analysis and comparison with ship data, MWTL data and the ESAS have not been wrapped up in the draft report, Poot *et al*. (2011) conclude that "*The survey design of the Shortlist Masterplan aerial surveys indeed have yielded much more detailed large scale distribution patterns of seabirds compared to the ongoing MWTL monitoring scheme or to the cumulative ship-based ESAS database*".

The report on aerial data has the intention to deliver an integration with the ship data and a comparison with the MWTL and ESAS data. It can already be concluded that the two large-scale surveys in the Shortlist program will be the new standard for bird distribution, densities and fly altitudes for offshore seabirds on the DCS.

8.4 Hypotheses testing

What do the results mean for the hypotheses as described above?
Since both surveys differ in set up and spatial coverage from what has been and is being delivered in the MWTL program and ESAS database, it can confidently be concluded that the presented data are spatially notably better than the MWTL and ESAS data. The two surveys have a higher resolution for those areas where coverage overlaps, and the ship survey has covered areas that are not covered by MWTL and ESAS. This leads to differences in numbers and distributions. For example, due to the design, the MWTL survey is less appropriate for detecting flocks of nearshore birds such as scoters along the Holland and Zeeland coast. Also, the lower flying altitude of the airplane in the shortlist survey disturbs less sensitive birds such as scoters, leading to increased numbers. As a result, both distributions and numbers of Common Scoters in the nearshore waters in the shortlist survey differ notably from the MWTL survey.

One has to bear in mind that the MWTL survey has a long historic data set, and only recent data can be compared, due to significant recent shifts in numbers and distributions of seabirds such as is the case for Common scoters.

From the per-species comparisons made in the aerial survey report, it can be concluded that the distribution of the seabirds as found by the shortlist surveys is not significantly different from those found in the MWTL surveys. Numbers are often higher due to the different survey configuration and lower flying altitude of the airplane. However, important added information from both surveys is on bird flying altitude, which is quite relevant for assessing the ecological effects of wind farms.

8.5 Knowledge advancements and remaining questions

The advancement of knowledge due to the two surveys is mainly on confirming the value of the MWTL program, but adding to the resolution of seabird data, higher densities of birds overall, flying altitude and behaviour. Integrating the aerial data with the ship data and extending the observations with a comparison with the MWTL and ESAS data would yield a quite valuable report on seabird densities, flying altitudes, behaviour, and the intra-annual variability.

The aerial survey did some interesting new observations: the offshore presence of relatively high numbers of sandwich terns and little gulls, and the presence of areas, which are apparently devoid of seabirds.

The report on aerial observations (Poot *et al*. 2011) gives some recommendations for future research pertaining to unresolved or new questions. Unresolved questions relate to missing data, such as the June survey. This month is deemed relatively important because of the large differences between the bird distributions in the spring and in the summer months and the importance of this month for the distribution of breeding birds such as the Lesser black-backed gull and the Sandwich tern.
Another recommendation is an analysis of the relationships between bird distributions with breeding colonies, and offshore human activities (fishing) and man-made structures (wind farms, oil and gas platforms). This analysis would yield important information on the cases of bird distributions.

Since the ship survey was dedicated to larval fish sampling, the data from the bird (and marine mammal) observations contained large spatial holes. Therefore, a repetition of a ship-based survey dedicated to bird and mammal observations is on the wish list. Although interesting data were gathered on bird flying heights, there is a clear bias towards lower flying birds. Additional data on birds flying at higher altitudes is desired to better understand the share of birds flying at rotor level. Finally, yet importantly, no data have been collected on offshore migratory movements. Such data will become important when the planned construction of OWFs in the North Sea work lead to the installation of tens of GWs of wind farm capacity.

9 TTS levels in harbour porpoises and harbour seals

9.1 Research questions

The questions relevant to wind farm decision makers are the following:

- What is the distance from a pile driving site in the North Sea at which TTS will start to occur in harbour porpoises and harbour seals?
- Do the TTS results of this proposed study compare to the TTS distances mentioned in the appropriate assessments for the second round OWFs?

The experimental setup for testing TTS in porpoises and seals is done in two phases, first with noise bands, and second with impulse sound. The second phase is not included in the shortlist work. This setup has been chosen in order to test the sensitivity of the animal for a small part of the larger sound spectrum before using the broadband spectrum of piling sound. Testing narrow-band sound and possible TTS is needed to understand how the animal’s ear reacts to portions of the total sound spectrum of piling noise. Piling noise is not the same for each piling case, so it is important to study a standardised reaction to a standardised sound. Next, and most important: if piling sound levels are potentially damaging, it is safer to first test noise bands.

9.2 Hypotheses

Based on current knowledge described in the tender, the following axioms and hypotheses could be set up for the experiment:

Axiom:

- The animal is sensitive to the sound spectrum of underwater piling noise.
- Underwater piling noise creates temporary shifts in hearing sensitivity for specific sounds (TTS).
- TTS increases (occurs sooner) when the impulse frequency of impulse sound is increased.

Propositions:

- The timing and degree of TTS and recovery time depend on the sound frequency, exposure time, and impulse frequency.

Hypotheses:

- TTS occurs at all (tested) sound frequency ranges.
- TTS is higher at lower sound frequencies.
- TTS is higher with increasing exposure time.
- The degree of TTS increases with exposure time.
- Recovery time increases with the degree and/or timing of TTS.

These hypotheses are also valid for the experiments in which broadband (piling) impulse sound is used instead of noise bands. Based on the results of the piling impulse experiments, one hypothesis can be added:

- The distances at which TTS for porpoises and seals occurs (considering a typical piling location and execution) at the Dutch continental shelf are comparable to those mentioned in the appropriate assessments for the second round OWFs.

9.3 Results

The TTS studies on the porpoises and the seals consisted of four experimental studies:

1. The level/duration combinations of a noise band which cause TTS, the degree of TTS, and the rate of hearing recovery in porpoises.
2. The level/duration combinations of a noise band which cause TTS, the degree of TTS, and the rate of hearing recovery in harbour seals.
3. The level/duration combinations of playbacks of impulsive pile driving sounds, which cause TTS, the degree of TTS, and the rate of hearing recovery in porpoises.
4. The level/duration combinations of playbacks of impulsive pile driving sounds, which cause TTS, the degree of TTS, and the rate of hearing recovery in harbour seals.

9.3.1 Effects on harbour porpoises

Considering the sensitivity to noise bands, TTS in harbour porpoises (of over 2.5 minutes) occurred at a SEL of ca. 152 and 162 dB re 1 μPa^2.s, depending on the Sound Pressure Level of the fatiguing sounds. It appeared that SEL was not a proper metric for predicting the TTS onset level, since the TTS of the porpoises was more dependent on the duration of the exposure sound than on its level.
When exposed to the broadband spectrum of piling sound (for which a recording was used from the OWEZ piling), no TTS of any significance could be induced. The maximum SEL and cumulative SEL that could be produced by the available transducer was 115 and 158 dB re 1 μPa^2.s. Probably, the SEL was too low to induce any TTS. Some avoidance behaviour was noted at this level, which suggests that porpoises are deterred from piling locations at tens of kilometres.

9.3.2 Effects on harbour seals

Comparable to the studies in harbour porpoises, the studies on the narrow-band sensitivity of harbour seals showed the onset for TTS to occur at SEL of ca. 170 and 178 dB re 1 μPa^2.s, depending on the Sound Pressure Level of the fatiguing sounds. As with the porpoise, the seals showed no TTS when confronted with the piling sound. One of the two seals showed clear avoidance behaviour.

9.4 Hypotheses testing

The results showed that not all hypotheses could be confirmed:

- TTS occurs at all (tested) sound frequency ranges: confirmed.
- TTS is higher at lower sound frequencies: confirmed for porpoise, rejected for seals.
- TTS is higher with increasing exposure time: confirmed.
- The degree of TTS increases with exposure time: confirmed.
- Recovery time increases with the degree and/or timing of TTS: confirmed.
- The distances at which TTS for porpoises and seals occurs (considering a typical piling location and execution) at the DCS are comparable to those mentioned in the appropriate assessments for the second round OWFs: rejected.

Two frequency ranges were tested, an octave narrow band centred at 4 kHz, and one centred at 5 kHz. At both test signals TTS occurred. Porpoise did but seals did not show a significantly higher TTS at 4 kHz than at 5.7 kHz. TTS occurs sooner at lower sound frequencies. Furthermore, it has been confirmed that for both species and for narrow-band sound, the degree of TTS indeed increases (i.e. more dB's temporary loss of hearing) and it occurs sooner (i.e. at a lower noise level) with increased exposure time. Also, recovery time increased when the exposure time to the fatiguing noise increased.

In general, it can be concluded that seals are less sensitive to the tested noise bands than porpoises, and (from the behaviour in the basins) it can be derived that porpoises will be deterred to a larger distance than seals. This is counter to what could be derived from the audiograms, and is different from what was predicted in the Framework for the Appropriate Assessments (Prins *et al*. 2008).
Another intriguing result is the fact that the animals were more sensitive regarding TTS for longer exposure than for higher noise pressures. This means that low-level, long-duration noise might affect mammals more than high-level, short-duration noise.

It should be stressed that for the piling experiments, no TTS could be measured in either species. The cumulative SEL for the piling noise was at maximum 183 dB re 1 μPa^2.s (received level). However, one seal (out of two) swam away at this noise level and hauled out, which suggests that some behavioural reaction might occur around this level. Also the porpoise showed behavioural changes at the highest level of piling sound. These results suggest that for piling behavioural changes occur earlier than TTS which could result in loss of habitat (see below).

9.5 Knowledge advancements and remaining questions

In a section on ecological significance of the tests described in the report by Kastelein *et al*. (2011), it is made clear that the results so far can be used to derive conservative TTS distances for these species. The draft report on TTS in harbour seals and porpoise contributes strongly to TTS in these species related to piling of OWFs, but acknowledges that TTS depends on many factors that have not been tested here, such as the spectral content, the temporal pattern (how many pulses in time) and kurtosis (what is the character of the pulse). Originally, the plan for the study encompassed three phases, of which one has now been carried out. Additional funding would be needed timely, since all equipment is already in place, the animals have been trained and the staff has the experience in doing the TTS experiments. The report describes the next step forward in the noise-band experiments: more experiments to model TTS development, experiments focusing at echolocation abilities in porpoises, and studies to assess the effect of other noise bands, and to assess the effect of pulsed noise.
Comparable suggestions are made for the piling experiments: increase SPL to find the TTS onset level, and study the behavioural reactions (not only avoidance/hauling out, but also a focus on respiration rates, energy use and fish intake rate) of the animals.
In the noise-band experiments TTS occurred, but seals neither the porpoise showed behavioural reactions (i.e. swimming away). However, in the piling experiment, one seal swam away, and also the porpoise showed behavioural changes, but TTS could not be assessed. This points to some intriguing aspect of underwater noise from OWF piling: something that causes a behavioural reaction but not TTS is part of the piling noise, which is absent from the third-octave noise bands. As the report describes it: "*In the wild, TTS may*

therefore be caused by sounds at levels that do not deter harbour seals away from the sound source, and it would be difficult to assess whether seals had habituated to a noise source without any adverse impacts, or whether they were experiencing a TTS (which would reduce their ability to hear sounds, and therefore make them less likely to avoid areas close to sound sources)". This means that both reactions may be relevant to effects on mammals in the wild: either they experience TTS while not avoiding the noise and they lose certain foraging or communication abilities, and therefore lose habitat (by quality), or they avoid an area due to a too high sound, but do not experience TTS, and lose habitat (by quantity).
This points to a type of question (and study) that has not been envisaged yet: what noise characteristics make up for this difference in reaction, TTS or avoidance behaviour?

10 DCS distributions marine mammals

10.1 Research questions

What has been mentioned in chapter 8 for seagoing birds also holds for porpoises and dolphin species: there is a large need for baseline data on distribution and densities of these marine mammals. Also here, data were collected by observations from airplanes and from vessels. Data that have been used in the environmental impact assessments for the second round OWFs originate mostly from aerial observations (MWTL) and coastal countings, which are low in resolution in time and or space. Additionally, the surveys included observations on the offshore distribution of harbour seals and grey seals.

10.2 Hypotheses

The same hypotheses as mentioned for seagoing birds apply for marine mammals:

<u>Axiom</u>:

- Marine mammals show a patchy distribution across the DCS, which varies per species, per month and per marine habitat.

<u>Hypotheses</u>:

- The distribution and density of marine mammals across the DCS has not changed significantly from the data that are present in the existing databases of MWTL and coastal countings.
- Marine mammals are present year-round at the DCS.
- The distribution of marine mammals shows a pattern of migration.

10.3 Results

Although in a later stage, the data of the ship-based survey and the aerial survey will be integrated, for now they will be treated separately.

10.3.1 Ship-based surveys

During the ship-based surveys (Van Bemmelen *et al*. 2011), five cetacean and two seal species were observed: harbour porpoise, white-beaked dolphin, short-beaked dolphin, bottlenose dolphin, minke whale and grey seal and harbour seal. Only harbour porpoise was seen on all surveys, the other species were found on occasions, in very low numbers, and along the edges of the Dutch Continental Shelf (DCS). Minke whales were found in May and June, along the flanks of the Dogger Bank, a white-beaked dolphin was seen in May on the northern slopes of the Dogger Bank, in the south-western North Sea and near the Cleaver Bank, in October two short-beaked common dolphins were seen off the Belgian coast, and three bottlenose dolphins were seen southeast of the Dogger Bank.

Porpoises were observed mostly in the spring period, with an apparent movement from offshore to inshore from April to July. From August to January, numbers were relatively low, but this is partly due to larger holes in the daily observations (shorter daytime period) and deteriorating weather conditions. In February, again increased numbers were observed in the Southern Bight.

Both seal species were found with relatively high numbers in coastal waters. Grey seals were found equally in the south-western part (Voordelta) and the outer Wadden delta, while harbour seals were predominantly observed in the outer Wadden delta.

10.3.2 Aerial surveys

The aerial survey (Geelhoed *et al*. 2011) gives a more complete overview of mammal observations on the DCS. This survey did not suffer from shortening daytime periods, although bad weather conditions also affected the observations from the airplane.

The density of harbour porpoises was highest in March, with an estimated total of 86000 animals at the DCS, equalling 1.44 porpoise per km^2. In July and October/November 26000 and 30000 animals at DCS were estimated respectively, equalling 0.44 respectively 0.50 porpoise per km^2. Especially in July, many calves were sighted. The density and distribution of porpoises has been corrected (modelled) for among other things sea state and weather circumstances. Results of this exercise resulted in interpolated distribution and density figures. These figures show that after correction densities are still highest in March, but that autumn densities are notably lower than the spring densities. Distribution appears to be clustered in certain areas, both concentrations around the Brown Bank, Cleaver Bank and Borkum Reef. Autumn distribution is concentrated north of the Brown Bank and at the broader Frisian Front. March distribution is high along the whole of the Dutch coast, the Frisian Front, the Cleaver Bank and (south of) the Dogger Bank.

Other species sighted during the aerial survey were the white-beaked dolphin in the Southern Bight in March and July and in the northern part of the DCS in autumn. Seals were sighted nearshore the Dutch coast, mostly off the Wadden islands and in the Voordelta, but also some offshore observations were made. Most seals could not be identified as being grey seals or harbour seals.

10.4 Hypotheses testing

Regarding the hypotheses, the following can be said:

- The distribution and density of marine mammals across the DCS has not changed significantly from the data that are present in the existing databases of MWTL and coastal countings: confirmed. In general the patterns in porpoise abundance as apparent the two surveys reflect the general trends in porpoise numbers, but the distribution is slightly different.
- Marine mammals are present year-round at the DCS: confirmed.
- The distribution of marine mammals follows a pattern of migration: inconclusive. The temporal variation of porpoises is comparable between the ship-based and the aerial surveys, but the spatial patterns do not compare well. There are some indications of movements, but the aerial survey and the ship-based survey suggest opposite directions. The ship-based survey suggests an inshore movement from late winter to spring/summer, while the aerial survey shows relatively high densities inshore in March with peak densities in the northwest of the DCS in July, suggesting offshore movements.

10.5 Knowledge advancements and remaining questions

The two surveys add valuable information on the presence and distribution of porpoises, and seem to confirm data from MWTL surveys and Belgian and German surveys. Differences were found in distributions and densities, which may point to errors in methodology, but likely reflect real variability as well.

Spatial modelling and correcting for factors that affect countings, such as sea state and weather conditions, might be an important means of integrating information from different surveys, both national and international. However, the models used so far are hard to assess regarding performance; there is a need for comparison, (inter) calibration and validation.

The occurrence of calves point to the importance of the DCS for reproduction, but which factors determine the relative importance of certain habitats remains speculative. In this respect it is questioned if reproductive capacity is hampered by certain factors, such as food availability and habitat quality (e.g. sound, fisheries by-catch).
Concurrently, the factors that determine porpoise distribution in general still seem elusive. Whether there is a structural migration, or if the movements are "stochastic" remains to be solved.

11 Evaluation and follow up

In general, it can be concluded that the “shortlist” program has given the expected advancements in knowledge. That is to say, most of the research questions and derived hypotheses could be answered, although of course the details give a more nuanced picture.

On the acoustics of underwater sound, advancements have been made in the use of definitions, quantities and units, and with regard to source level and propagation modelling. These are both prerequisites for a better understanding of OWF-specific sound generation and propagation and the possible effects on marine life.
It remains to be seen if the proposal for definitions, quantities and units becomes an adopted standard in the EU or outside. Next, source level and propagation modelling has been given an impulse, but far-field validation is needed, and a comparison with other possible sound propagation models seems a reasonable next step.

The pilot experiments of piling sound on the survival of sole larvae was a success in set up and performance. Some adaptations remain needed, such as lowering the mortality in the controls. The low mortality due to piling sound was unexpected, since literature suggested a higher mortality. Moreover, sole larvae were chosen for practical reasons, but in an ecological sense, it would be advisable to follow up on using other species, that are a more important staple food source, such as clupeids, sand eels and gadoids.

The survey for marine larvae was quite successful; it delivered a good overview of the presence, density and spatial distribution of fish larvae in all months during a whole year on the greater DCS. Some cruises in autumn show spatial holes in the data due to bad weather, but it appears that these are of less importance to the overview since this period shows only low densities of fish larvae. These data can be used to further calibrate the model on hydrographical dispersal of fish larvae in the southern North Sea, which was used to assess the effects of piling on the availability of juveniles in coastal waters for mammals and birds.
It has to be noted that there can be significant year-to-year variations in the presence and densities of larvae. Although the results confirm the general idea that was used in the appropriate assessments for the second round OWFs, it remains to be checked to what extent exactly the image from this cruise is representative for other years. Additional work is needed to gain more insight into the spatial relationships of larvae with the spawning grounds, and to assess survival of the larval stage to juveniles. Such data are important to understand how fish recruitment success is related to reproduction of mammals and coastal birds.

The studies on population dynamics and movements of the lesser black-backed gulls from two breeding colonies proved to be quite successful, i.e. they delivered a significant change of insight into how this species was assumed to forage, and its reproductive parameters. Nevertheless, many questions remain. The most relevant questions pertain to the share and behaviour of so-called floaters in the population, the breeding success needed for a stable population, dependability on food sources, meta-population dynamics, and actual numbers of breeding pairs. The latter seems to be a trivial issue, but observations so far give different and contradictive results, quite likely related to counting methodology.

The DCS-wide surveys with ships and airplanes gave variable results on the spatial and temporal variation in bird distribution. Most information came from the aerial survey, since the ship-based survey showed serious holes in the data set. Also, the aerial survey missed an important survey in June. Notable results were the offshore distributions of sandwich terns and little gulls, and the apparent and consistent absence of seabirds in some areas. Additional work would be needed to get more insight into the behaviour of birds at sea (foraging, flying heights, fluxes), and to assess offshore migratory movements. Creating a sensitivity map should be an important next step, and should be based on the integration of the most recent results from the "shortlist" surveys with the MWTL and the ESAS data and those from the observations in the existing OWFs *OWEZ* and *Princess Amalia*.

The TTS studies on harbour seals and harbour porpoise showed to be of great importance. They further elucidated the mechanisms by which TTS is caused, and how this relates to piling noise. Contrary to what was expected from the audiograms (and which was applied in the second round appropriate assessments), the porpoise showed to be more sensitive to (narrow-band) underwater sound than the seals. However, the results also raised additional questions; levels of narrow-band noise that caused TTS did not evoke any behavioural reactions in the animals, but one of the seals clearly swam away from the piling noise and hauled out before TTS was measured. Also the porpoise showed behavioural changes when confronted with piling noise.
Additional work was already described in the phase 2 and 3 in the tender for the shortlist project. The piling experiments have been carried out in the study on seals and porpoise. The results of the study need further detailed research on the effects of pulsed narrow-band noise on TTS, increase SPL levels of piling to find TTS levels and behavioural reactions, and studies to the nature and extent of behavioural reactions to narrow-band and broadband noise. The discrepancy between the reactions of the seals to narrow-band noise (causing TTS, but no behavioural change) and to piling noise (causing behavioural change, but no TTS) is intriguing and needs to be elucidated.

The survey on the distribution of marine mammals was done by ships and by airplanes. Just as for the birds, the ship-based survey was not dedicated, and resulted in large data hole for the autumn and winter periods. The results of the surveys confirmed and updated the general picture of the temporal distribution and density of porpoises. It also showed that the DCS is of importance to porpoise calves in the summer and that densities can be quite high in spring. The ship-based and aerial surveys were not consistent in the temporal picture of the distribution. Partly because of this, the studies did not deliver any insight into the migrational movements of the porpoises, or the existence of sub-populations. The report on the aerial surveys included the setup and results from an interesting modelling exercise to correct for weather and sea state. This model needs to be checked and further calibrated. A logical step in this would be to integrate all data on porpoise distributions, such as from the MWTL programs and the “shortlist” surveys and try to derive some commonalities in distributions from them, and maybe to set up a 3D modelling exercise, including a habitat and food coupling. Information is lacking on what drives porpoise movements, and what the habitat and food boundary conditions are (referring to the physiology and the bio-energetics of the animals).

Abbreviations

AA	Appropriate Assessment
dB	Decibel
DCS	Dutch Continental Shelf
ESAS	European Seabirds at Sea
EU	European Union
FE model	Finite element model
MP	Masterplan
MSFD	Marine Strategy Framework Directive
MWTL	Monitoring van de Waterstaatkundige Toestand des Lands
OWEZ	Offshore Windfarm Egmond aan Zee
OWF	Offshore Windfarms
PTS	Permanent Threshold Shift
SPL	Sound Pressure Level
SEL	Sound Exposure Level
ToR	Terms of Reference
TTL	Temporary Threshold Level

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