Rijksoverheid

Continuation Implementation Masterplan Wind at Sea

Abstracts VUM-studies
8 September 2015

Water. Wegen. Werken. Rijkswaterstaat

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This booklet has been compiled fort he VUM symposium

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Preface

Energy is a prerequisite to function in today's society. In order to meet current and future energy demands, growth in sustainable energy is essential. The Netherlands has accepted the European set goal for sustainable energy, thereby committing to the agreement that in 2020 14% of the Dutch energy consumption originates from sustainable resources.

The objective for wind energy at sea was arranged in the Energy agreement for sustainable energy (September 2013). As stated in the draft of the North Sea Policy Paper 2016-2021; in 2023, 4.450 megawatts (MW) of wind energy output at sea must be operational. Which is 3.450 MW more than the energy delivered by present wind farms and wind farms still under construction. Wind energy at sea therewith makes a large contribution in achieving the target of 16% of sustainable energy which the Dutch cabinet has set for 2023.Enormous investments and policy-efforts are needed to accomplish this enormous task.

Many uncertainties still exist concerning the effects of wind farms on the North Sea's ecosystem. European legislation demands a safety-margin when the consequences of certain processes are unknown; the precautionary approach. The lack of knowledge about the ecological effects also affects cost-efficiency in realizing the set goals for wind at sea. Therefore the Ministry of Economic Affairs and the Ministry of Infrastructure and the Environment have instructed to investigate important environmental questions concerning the construction and exploitation of wind farms. In 2011 the results of the so-called "Shortlist-study Ecological Monitoring Wind at Sea" were published and presented at a symposium. These results led to an adaptation of the methodology in the assessment framework for ecological effects of wind farms at sea.

The next step in increasing knowledge on the ecological effects of wind farms at sea was to follow up on the above mentioned Shortlist-study. The Follow-up Implementation Masterplan (VUM) Ecological Monitoring Wind at Sea was started in 2011 and recently finished. It was carried out by a consortium led by Imares and TNO. The investigations were substantively guided by the Ministry of Economic Affairs, Rijkswaterstaat and the Directorate-General for Spatial Development and Water Affairs of the Ministry of Infrastructure and the Environment.

The research for VUM consisted of 9 sub studies:

- A sound model for piling at sea;
- A classification tool for cumulative effects of underwater sound (SORIANT);
- The effects of offshore piling sound on the hearing of Harbor Seals;
- The effect of piling sound on the survival of fish larvae;
- Swimming speeds of marine mammals in the North Sea;
- Modelling the number of seabird collisions with offshore wind turbines;
- Bat migration at sea;
- The effect of wind farms on seabirds.

In addition, a workshop on international harmonization and collaboration was organized.

This booklet contains a brief abstract of all the VUM-studies. The complete reports are available at the Informatiehuis Marien (www.informatiehuismarien.nl) and the Noordzeeloket (www.noordzeeloket.nl). The findings of the VUM-studies were presented at a symposium at Naturalis in Leiden at 8 September 2015.

The results of the VUM-studies have been and will be applied in the decision-making process for offshore wind farms. Furthermore, the results will be used for the 'Ecology and Cumulation Framework' which was announced in the draft of the North Sea Policy Paper 2016-2021, published in April 2015. The framework is intended to clarify how cumulative ecological effects need to be investigated, it's meant to be applied in future decision-making concerning wind energy at sea.

Besides the above-mentioned VUM-studies, many other studies are implemented in this area. For example the monitoring programs of existing farms and farms that are under construction. A lot of research is also being done abroad. The Ministry of Economic Affairs and the Ministry of Infrastructure and the Environment have taken the initiative in a few processes to stimulate international collaboration and knowledge exchange. In the above mentioned Ecology and Cumulation Framework, as well as during the completion of the VUM-studies, several new knowledge gaps were determined. Therefore, on short term additional research will be initiated.

Our acknowledgements go out to all contributors to the implementation of the VUM-studies.

The ministry of Economic Affairs
Drs. Roel Feringa
Director Nature and Biodiversity

The ministry of Infrastructure and the Environment
Drs. Ing. Donné Slangen
Director Regional and Project Development
Chairman of the Interdepartmental Directors' Consultation Board for the North Sea (IDON)

Footnote: The North Sea Policy Paper 2016-2021 became final in 2015.

Abstract of the VUM-studies

Sound model for pile driving at sea

Predicting ecological effects of pile driving activities starts with determining sound levels caused by these activities. TNO developed a new method based on earlier models developed in the Shortlist-study Ecological Monitoring Wind at Sea. This model allows sound distribution to be calculated as a function of for example water depth, sediment type, pile dimensions and pile drive energy. To be able to predict efficiently and accurately at many depths and distances, the utilized method consists of two interlinked parts: a source model and a propagation model.

The source model describes the production of sound by vibrations in a pile and sound propagation in water and seabed in the pile's direct vicinity, using a (numerical) finite-element-method. With the renewed propagation model it is possible to efficiently determine sound levels in a realistic environment at large distances from the pile. This model is based on the determination of relevant modes of sound propagation in water and uses the output of the source model as input.

In June 2014 TNO organized an international workshop (COMPILE) in cooperation with TUHH (Technical University of Hamburg) to compare predictive models for underwater pile driving sound. Seven research institutes representing six countries, each developing their own predictive model, presented their results of their model calculations.

The research groups all used the same pile driving scenario representing a setup that was used for pile driving noise measure-


Photo: Ruben Fijn

ments TNO carried out in 2010 in Kinderdijk. A pile diameter of 1 meter and pile length of 25 meters were used, in a water depth of 10 meters. Predictions of underwater sound levels were calculated for various depths at distances of 0, 1, 30, 750, 1500 meter and 10, 20 and 50 kilometres. The results of the participating institutes matched convincingly, which supports the validity of the model developed by TNO. The experimental validation of the model however, still awaits the availability of data of the construction of the Dutch wind farms Luchterduinen and Gemini, in which measurements were conducted up to large distances (50-70 km) from the pile driving locations.

For more information:

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Report:
Nijhof M.J.J., Binnerts B., Ainslie M.A., de Jong C.A.F. (2015) Integration source model and propagation model, TNO Rapport, TNO 2015 R10186

Risk assessment tool for cumulative effects of underwater sound (SORIANT)

To estimate the environmental risk of offshore projects and determine the potential need for mitigation measures, it is necessary to bring together the knowledge on underwater sound and its effects on the environment. To this aim, a prototype sound risk analysis framework (SORIANT), has been developed, which is aimed at assessing the impact of underwater sound on marine life.

A complete risk assessment tool has been implemented in the 'VUM SORIANT' project. The tool initially focusses on determining the effects of pile driving sound during construction of offshore wind-farms on the harbor porpoise population. In the assessment process, the effects of accumulation of effects due to multiple windfarms can be accounted for over a period spanning multiple years. The current version makes use of the Interim PCOD model (Population Consequences of Disturbance), developed in the UK, which has been integrated to translate the predicted level of disturbance of construction of multiple farms to the effect on the North Sea harbor porpoise population.
The full risk-assessment chain consists of:

- A module for defining the construction process (e.g. location, duration of piling activities, type of piles).
- A sound mapping module. The source and propagation models for pile driving sound that have been developed within VUM have now been integrated into SORIANT.
- A module for determining effect distances and the number of disturbed animals.
- A module for accumulating the disturbance effects due to the construction activities of multiple windfarms (national and

international projects).
- Integration with a module for determining the consequences for the harbor porpoise population, using the Interim PCOD model (developed by SMRU Marine and the University of St. Andrews).

The risk assessment tool has recently been applied during the development of new guidelines for the licensing process for new offshore wind farms in the Netherlands (Ecology and Cumulation Framework). An estimation of the effects of Dutch as well as surrounding planned wind farms in the North Sea on the harbor porpoise population was taken into account in the assessment process.

The SORIANT risk assessment tool has been set up to be modular and flexible, allowing for an easy extension to alternative assessment methodologies for estimating population level consequences, or to different type of sources (e.g. seismic surveys, shipping, dredging, explosions and sonar), or other species (e.g. seals or fishes). Based on the risk assessment framework used in SORIANT, key knowledge gaps have been identified and described.

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Report:
von Benda-Beckmann A.M., de Jong C.A.F., Binnerts B., de Krom P., Ainslie M.A., Nijhof M., te Raa L. (2015) SORIANT VUM - final report. TNO Rapport, TNO 2015 R10791

Effects of offshore pile driving sounds on harbor seal hearing

During pile driving activities for offshore wind turbines high underwater sound levels are produced. Offshore wind turbines often are constructed in coastal areas in relatively shallow waters which are part of the harbor seal habitat.

To quantify the distance at which harbor seals are able to perceive pile driving sound under water, unmasked hearing thresholds were obtained with a psychoacoustic technique (using trained animals) for series of five pile driving sounds recorded near a pile driving location.
The trained animals responded instantly when exposed to strikes with high sound levels, and with a decreasing sound level, the harbor seals indicated hearing the first hit after an increasing number of strikes. The mean 50% detection threshold sound exposure levels (SELs) for any of the strikes in the series were approximately 39-43 dB re 1 μPa^2s. The mean 50% detection thresholds based on detection of only the first hit of the series were ca. 5 dB higher (showing that it is more difficult to hear one sound than a series of sounds). Detection distances of piling sounds at sea depend on the local propagation conditions and on the degree of masking sounds by ambient noise.

Seals may suffer hearing loss when they are exposed to intense pile driving sounds. When two harbor seals were exposed to playbacks of pile driving sounds, a temporary reduced hearing sensitivity (TTS; Temporary Threshold Shift) was quantified at 4 and 8 kHz (frequencies showing the highest TTS). The pile driving sounds were characterized as followed: pulse duration

126 ms, 2760 strikes per hour, inter-pulse interval of 1.3 s, duty cycle of ~9.5%, and an average received single-strike sound exposure level (SEL_{ss}) of 151 dB re 1µPa2s. Exposure durations were 180 and 360 min [cumulative SEL (SEL_{cum}): 190 and 193 dB re 1µPa^{2}s]. No TTS was measured in control sessions under low ambient noise conditions. Initial TTS between 2 and 4 dB only occurred after 360 min of exposure to pile driving playback sound. Hearing in both seals recovered within 60 min post-exposure. The TTS after 360 min exposure was relatively small, due to the low amount of sound energy per unit time to which the seals were exposed (average sound pressure level; SPL ~151 dB re 1µPa). TTS onset SEL_{cum} is estimated to be around 192 dB re 1µPa^{2}s.

Exposure to higher sound levels may, in addition to hearing loss, have effects on behavior. There are many knowledge gaps for seals. Seals are amphibian, and spend a major part of their time in sea at the surface. Do underwater pile driving sounds reach their hearing when swimming at the surface, or can seals reduce the impact of underwater sound when swimming at the surface? There is still a lot unknown about the relationship between the sensitivity of hearing and the use of hearing for navigation for seals. Often acoustic deterrent devices are used to keep seals at safe distances from pile driving locations before pile driving is initiated. This way the received sound levels are reduced preventing hearing damage at the first pile driving sound. However it is still unknown whether seals are able to determine where these deterrent sounds originate and if they respond by swimming away from the pile driving locations to safe areas.

For more information:

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Reports:
SEAMARCO (2013) Hearing thresholds of two harbor seals (*Phoca vitulina*) for playbacks of multiple pile driving strike sound, Report no. 2013-02

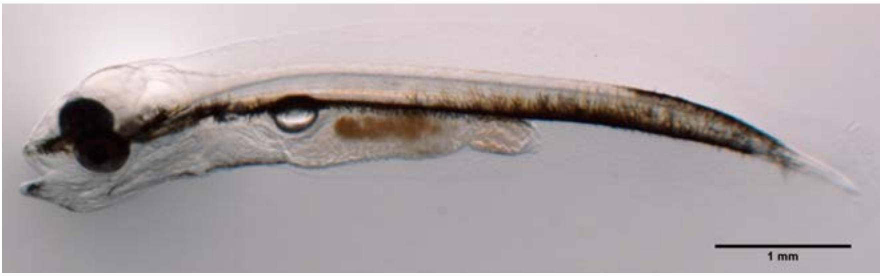
SEAMARCO (2015) Effect of pile driving sounds' exposure duration on temporary hearing threshold shift in harbor seals (*Phoca vitulina*), Report no. 2015-03 (Draft report)

The effects of pile driving sounds on the survival of fish larvae

The effects of underwater sounds, like pile driving sounds, on fish is an area little studied. Exposure to sound waves can cause physical damage or even result in fatal injuries. In the United States, concern about the possible negative effects of pile driving sounds on fish led to the drafting of interim criteria in 2009. These criteria consisted of sound thresholds above which fish would exhibit physical damage (different from hearing damage). These criteria have been applied in a Dutch model-study to investigate the effects of pile driving for offshore wind farms on the migration of fish larvae to Natura 2000 areas.

Model results predicted a decrease of juvenile fish in the Wadden Sea as a result of offshore pile driving. These results contributed to the implementation of a pile driving moratorium; no pile driving is allowed in the months January to June. Due to the fact that the interim criteria have little scientific base, research has been conducted to investigate the effects of pile driving sounds on fish (larvae).

Studying the effects of pile driving sounds in the field is very difficult. Logistical problems limit the number of large samples which in combination with the variability in environmental factors makes it difficult to make solid conclusions. This in particular applies to research on fish larvae, because larvae are more vulnerable than fish in later life stages.



Controlled exposure experiments in laboratories are also challenging because pile driving sounds are difficult to reproduce in laboratory environments, especially at levels which cause physical damage. Therefore a special device was developed for this study (during the past research program Shortlist Ecological Monitoring Effects Wind at Sea), in which impulse-sounds representative for pile driving sounds can be generated. This device, called the "Larvaebrator", consists of a rigid cylindrical chamber, propelled by an electrodynamic sound source. Up to 100 fish larvae can simultaneously be exposed to a homogenously divided acoustic pressure- and particle velocity field. Field recordings of sound pulses can be reproduced in the Larvaebrator in a controlled manner.

The Larvaebrator was used to investigate the effects of pile driving sounds on the survival of fish larvae. First (within the Shortlist research program) the effects were studied on three stages of sole larvae (*Solea solea*). Next (within the VUM research program) the effects of pile driving sounds were studied on two stages of seabass larvae (*Dicentrarchus labrax*) and one stadium of herring larvae (*Clupea harengus*). These different fish species and larval stadia represented different types of swimming bladder development: no swimming bladder, closed swimming bladder (no connection to the intestine-stomach channel) and open swimming bladder (with connection to the intestine-stomach channel).

Additionally relative sizes of swimming bladders differed between species and stadia. Fish with closed swimming bladders are presumed to be the most susceptible for (sound) pressure differences.

The sound signal recorded at 100m distance of a pile for the OWEZ wind farm was replayed in all experiment series, scaled to the desired sound level. In some series other sound signals were used (for example a theoretical exponential pulse). The sound pressure of the replayed sound signal was measured in the Larvaebrator (by four transducers) and quantified in the following parameters: single strike Sound Exposure Level (SEL_{ss} in dB re $1\mu Pa^2s$), cumulative Sound Exposure Level (SEL_{cum} in dB re $1\mu Pa^2s$), zero to peak pressure level (Lz-p in dB re $1\mu Pa^2$). The highest SEL_{cum} in the experiment series of sole larvae was 206 dB re $1\mu Pa^2s$ (100 strikes). This was raised to

216 dB re 1μPa²s (999 strikes) in later experiment series with seabass and herring larvae.

In none of the three fish species significant effects of pile driving noises were observed. The SEL_{cum} threshold for fish larvae (fish < 2 g) formulated in 2009 was 183 dB re 1μPa²s. The highest SEL_{cum} exposure levels which were applied were much higher (206-216 dB re 1μPa²s), without observing any effects on survival. This implies that the thresholds for physical damage formulated in 2009 are likely too low. This conclusion is supported by other recent research on juvenile fish. Based on these new insights, partially because of the research conducted in the Shortlist and VUM research programs, in 2014 these latest views were adopted in the decision framework for offshore wind farms.

Voor meer informatie:

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Report:
Bolle L.J., de Jong C.A.F., Blom E., Wessels P.W., van Damme C.J.G, Winter H.V. (2014) Effect of pile-driving sound on the survival of fish larvae. IMARES, Report no. C182/14

The effects of offshore pile driving sounds on the hearing and behavior of harbor porpoises

SEAMARCO studied the effects of pile driving sounds on hearing as well as behavior of harbor porpoises. To determine the distances at which harbor porpoises can detect pile driving sounds, the hearing thresholds for pile driving sounds were determined using trained animals.

The threshold was determined for a series of five pile driving sounds which were played in a basin. The 50% hearing threshold Sound Exposure Levels (SEL) for the first pile strike of the series (no masking) was around 72-74 dB re 1µPa^{2}s. Consecutive strikes lowered the hearing threshold with ~5 dB (68-69 dB re 1µPa^{2}s). Depending on propagation (sound distribution) conditions, and the ambient sound level, results suggest harbor porpoises can hear pile driving sounds up to dozens of kilometers from the pile driving location.

Harbor porpoises may suffer hearing loss when exposed to high levels of sound generated by pile driving activities. After exposure to replayed pile driving sounds for 60 min, the Temporary Threshold Shift (TTS) was determined for a harbor porpoise at 0.5, 1, 2, 4, 8, 16, 32, 63 and 125 kHz. Details of the pile driving sounds were: pulse duration 124 ms, rate 2760 strikes/hr, inter-pulse interval 1.3 s, duty cycle ~9.5%, and the average received single strike sound exposure level (SEL_{ss}) was 146 dB re 1µPa^{2}s. TTS only occurred at 4 and 8 kHz, and recovery of hearing occurred within 48 min. This shows that exposure to multiple impulsive sounds with most of their energy at low frequency (around 600 Hz) can cause reduced hearing at higher frequencies in


Photo: SEAMARCO

harbor porpoises. The porpoise's hearing threshold for the frequency in the range of its echolocation signals (~125 kHz) was not affected by the pile driving playback sounds.

Once it was clear which hearing frequency of the harbor porpoise was most affected by pile driving sounds, it was possible to measure the effects of exposure duration on TTS. After exposure to playbacks of pile driving sounds for 15, 30, 60, 120, 180, 240 and 360 min, TTS was quantified for two harbor porpoises at 8 kHz. Control sessions were carried out with low ambient sound conditions. Mean initial TTS increased from 0 dB after 15 min exposure to 5 dB after 360 min exposure. Recovery occurred within 60 min post-exposure for both animals. The relatively small increase in TTS between 15 and 360 min exposures can be attributed to the relatively small amount of sound energy per unit of time to which the porpoises were exposed in the pool (average sound pressure level ~144 dB re 1μPa). Policy-makers in many countries have based their underwater noise criteria for cetaceans on the large number of TTS studies conducted with only one harbor porpoise at SEAMARCO. To know whether the hearing of that animal was representative for its species, an audiogram (hearing threshold curve) of another young male harbor porpoise was measured, and both were compared with the audiogram of a third porpoise. The hearing sensitivity of all three harbor porpoises was similar. Therefore, underwater sound criteria based on studies from the last 10 years with one harbor porpoise at SEAMARCO can be accepted as robust.

To estimate the behavioral response for pile driving sounds, a porpoise in a silent pool was exposed to playbacks (46 strikes/min) at five sound pressure levels. A comparison was made between the animal's behavior during test and baseline periods. The porpoise's respiration rate increased in response to the pile driving sounds at and above a received broadband Sound Pressure Level (SPL) of 136 dB re 1 μPa. At higher levels, the porpoise even jumped out of the water.

These results can be used to estimate the distances the porpoises will swim to avoid the offshore pile location when exposed to pile driving activities. The exact distances depend on the context, sound source level, parameters influencing sound propagation and ambient sound levels (masking).

The next step is to use this information to estimate the effects of sound on harbor porpoise population dynamics. To study these effects, models like the PCoD (Population Consequences of Disturbance) model have been designed which can be coupled to the SORIANT-model. Still a variety of parameters related to a.o. reproduction and energetics, need to be determined for these models.

For more information:

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Reports:
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SEAMARCO (2013) Behavioral responses of a harbor porpoise (*Phocoena phocoena*) to playbacks of broadband pile driving sounds, Report no. 2013-04

SEAMARCO (2014) Hearing frequencies of a harbor porpoise (*Phocoena phocoena*) temporarily affected by played back offshore pile driving sounds, Report no. 2014-05

SEAMARCO (2015) Effect of pile driving sounds' exposure duration on temporary hearing threshold shift in harbor porpoises (*Phocoena phocoena*), Report no. 2015-09

SEAMARCO (2015) Hearing thresholds of a harbor porpoise (*Phocoena phocoena*) for narrow-band sweeps (0.125-150 kHz), Report no. 2015-02

Swimming speeds of marine mammals in the North Sea

Wind farms produce sound during the operational phase, but especially during the construction. The possible effects of these sounds depend partly on the duration of the activity. By moving away from the sound source, marine mammals can decrease the exposure time. The maximum speed and persistence at which marine mammals can move away from these sounds, are still unknown.

For this reason, this study first investigates what suitable techniques exist to measure marine mammal swimming speeds in nature. Here we focus on the most common marine mammal species occurring in Dutch waters: the harbor porpoise and the grey and harbor seal.
For estimating swim speed of harbor porpoise, video-surveys were carried out in the Marsdiep, the area between Den Helder and Texel. This technique allows for an accurately estimation of the spatial position and swimming behavior of harbor porpoises in nature. For 90% of over 3000 observations, a swimming speed under 2.95 m/s was measured, 80% was even under 1.57 m/s. Several observations indicated speeds above 3 m/s, but excessive speed estimates can likely be attributed to mistaking two animals for one individual. Tidal currents also have a large influence on observed swimming speeds. The swimming behavior of grey and harbor seals was studied using data from GPS-data loggers. The results show that average swimming speed is related to the distance covered. The shorter the distance, the higher the swimming speed the animals were able to reach. Harbor seals as well as grey seals only

reached speeds higher than 2.5 m/s by exception, in most cases speeds were below 2.0 m/s.

During the pile driving activities of an offshore wind farm, GPS and dive data of grey seals were simultaneously collected. This enabled researchers to investigate whether seals changed their swimming speeds when in vicinity of these activities. In most cases the observed speed was still far below the estimated maximum speed. However, at least one individual, at more than 21 km from the pile driving location, swam over 2 m/s and reached a minimum of 1.82 m/s for more than an hour. This is exceptionally fast for a grey seal. The observed changes can be, but are not necessarily caused by the pile driving activities.

Though high sprint velocities were observed, especially for harbor porpoises, earlier studies and this study show maximum swimming speeds over long distances for harbor and grey seals is approximately 2 m/s, and 2-3 m/s for harbor porpoises. The study by Kastelein et al. show that in captivity a harbor porpoise exposed to intensive pile-driving sound swam at speeds of on average 2 m/s for 30 minutes. These results indicate significantly lower speeds than the earlier assumed 4.9 m/s for seals and 3.4 m/s for porpoises. More research is needed for a proper estimation of fleeing speed and the characteristics of fleeing behavior. For instance little is known about when the animals actually flee, what the spatial components of this behavior are – do they flee vertically or horizontally- and what are the energetic costs of fleeing behavior of marine mammals.

In addition to the above referred studies, in light of the VUM another experimental study was conducted to the swimming speed of harbor porpoises in reaction to pile driving sound. At the time of the publishing of this booklet, the results were not yet presented.

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Reports:
Aarts G.M., Brasseur S.M.J.M., Winter H.V., Kirkwood R.J. (2015) Persistent maximum swim speed of harbour porpoise, harbour seal and grey seal.

SEAMARCO (2015) Swimming speed of a harbor porpoise (*Phocoena phocoena*) in a pool during playbacks of pile driving sounds, Report no. 2015-08

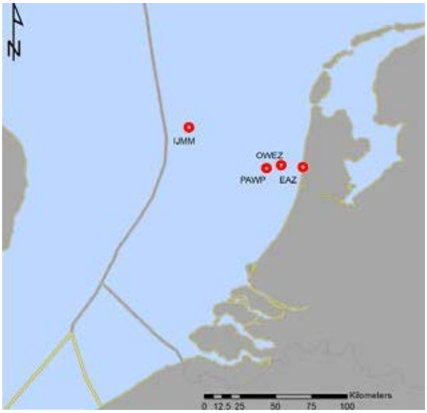
Bat migration at sea

A variety of bat species migrate between their summer and winter residences. Most species travel short or medium long distances, with a maximum of a few hundred kilometers a year. Some species however like the Nathusius's pipistrelle (Pipistrellus nathusii), Common noctule (Nyctalus noctula) and Parti-colored bat (Vespertillo murinus) are long-distance migrants who may travel more than 2000 km between their summer residences in Northern and Eastern Europe and their winter residences in Southern and Western Europe.

Migrating bats do not exclusively migrate over land. A study in southern Sweden has shown that many bats migrate over the Baltic Sea. Additionally local populations have been observed to forage at sea, in many cases nearby offshore wind turbines.

Evidence for bat presence above the North Sea has been available for quite some time. Observers of bird migration regularly report bats arriving from sea during the bird migration counts and during offshore surveys bats have been observed flying above the sea. In addition bats are regularly found on offshore wind turbines, oil platforms and ships.

In September/October 2012 research was conducted using bat detectors in the Princes Amalia Wind Farm (PAWP, 23 km from the coast) and in Offshore Wind Farm Egmond aan Zee (OWEZ, 15 km from the coast). During this study bats were recorded during most nights with favorable conditions (no precipitation, low wind speeds and a high



Monitoring sites in 2014

atmospheric pressure). During the whole season in 2013 bats were monitored in OWEZ and PAWP. The same year a Nathusius's pipistrelle was found in Friesland, which was ringed in England three years earlier, proving irrefutably that bats can successfully cross the North Sea. In 2014 the monitoring network was expanded with a location at the beach near Egmond aan Zee and with the IJmuiden meteomast (85 km from the coastline). The collected data were analyzed in the VUM study.

Based on data collected from the bat detector study from the last three years, the following can be stated about the presence of bats on the Dutch Continental Shelf:

- Bats are more common at sea than previously thought. Most offshore bat activity takes place from late August until early October.
- Nathusius's pipistrelle is the most common species at sea. Other long distance migrants that have been recorded are Common noctule and

probably Parti-colored bat. The non-migrating Common pipistrelle (Pipistrellus pipistrellus) has occasionally been recorded at OWEZ. Pond bat (Myotis dasycneme) and Daubenton's bat (Myotis dabentonii) have been recorded a few times at the coast but never at sea.
- The distribution pattern at sea in combination with the observed species indicate that most offshore bat activity is caused by migrating animals. In some cases bat activity at sea may be caused by foraging animals from local land-based populations.
- A strong relationship between weather conditions and bat activity was found. Practically all offshore bat activity took place during nights with favorable weather conditions (low wind speeds, no precipitation and a high atmospheric pressure). It is therefore unlikely that offshore bat activity is related to animals blown out of course during bad weather.

Very little is known about the number of bat fatalities occurring in offshore windfarms. Because it's impossible to collect victims at sea, researchers are working on the development of an experimental set-up with thermal cameras. This set-up allows not only to observe collisions, but can also study the behavior of bats around wind turbines. Insights into the behavior of bats in vicinity of offshore wind turbines will eventually lead to risk-assessments. In addition to this study, two more studies were conducted in light of the VUM. One study involves the analysis of bat behavior in relation to weather conditions and the other concerns bat behavior in the vicinity

of wind turbines. At the time of publishing of this booklet, the results were still unknown.

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Reports:
Lagerveld S., Jonge Poerink B., de Vries P. (2015) Bat activity at the Dutch continental shelf in 2014, IMARES Wageningen UR, Den Helder, Report no C094/15

Lagerveld, S, Aarts, G, Jonge Poerink B, De Vries, P., Winter E. (in prep.) Offshore bat a

Modelling the number of bird collisions with offshore wind turbines

Birds risk flying into wind turbines. How large this risk is for wind turbines at sea is still one of the largest knowledge gaps, because collision victims disappear in the sea and can therefore not easily be counted. In order to estimate death rate, collision rate models are used instead. This study aimed to investigate which models are available and which ones are suitable for modelling collisions with wind turbines at sea. Additionally data from bird radar was analyzed to investigate whether the design of the wind farms possibly has an effect on the number of casualties.

In the past decennia several collision models were developed, allowing prediction of the number of collision victims for planned wind farms at sea and on land. These are primarily theoretical models in which the chance of collision is calculated based on the dimensions and movements of wind turbines as well as birds. In the Netherlands and the surrounding countries nowadays the Band-model is used in particular. Furthermore a few empirical models exist, using field data to estimate collision risks. Collision models are based on four principal aspects, each crucial for a proper calculation of the number of victims:

1) number of birds risking collision;
2) percentage of birds avoiding the wind farm or individual turbines;
3) number of turbines a bird encounters when flying through a wind farm;
4) collision risk of a bird with a turbine.

In collision models based on empirically determined collision risks, such as Bureau Waardenburg's flux- collision- model, avoidance has a far smaller effect than in theoretical models. The disadvantage of empirical models for applications at sea is that there are no collision risks available explicitly for seabirds, because collision risks are only known from casualty studies on land.

At the moment the Band-model is the most commonly used model in countries bordering the North Sea. The advantages of this model are that formulas are completely available (in spreadsheets) and that it offers many possibilities to adapt the various components of the model to the local characteristics and available data. In the model aspects such as tilting of the roto blades, rotor size, rotation speed and size of the bird play a prominent role. However, these aspects have little effect on the resulting number of bird casualties.

The aspect that plays the largest role in determining the number of victims is the percentage of birds that avoid the entire wind farm or the individual turbines. And precisely this avoidance rate is poorly known because it has hardly been studied. At present, estimates of avoidance rate range between 95 and 99.9 %, with large differences between bird species. Similarly, also estimates of the percentage of birds diverting to altitudes above or below the turbines have a large effect on the resulting number of victims. The Band model is very sensitive to small changes in avoidance rate

Photo: Jan Dirk Buizer

or flight altitude. As a result, a small change in these parameters can have a large effect on the estimated number of collision victims, and can determine whether the effects of the wind farm are just below or just above significance levels. Because estimates of avoidance rates and flight altitudes have such a high level of uncertainty, and because of the large impact they have on Band modeling results, we have to be cautious both with applying avoidance rates and with interpreting the modeling results.

Different bird species respond differently when encountering a wind farm (table). Most gull species will fly around the wind farm just as easily as through them, apparently depending on the location of their food source. Cormorants are attracted to wind farms at sea, provided that they are not too far from the coast, because they can use the structures to rest and dry their feathers. Many typical seabirds such as gannets, guillemots, scoters and divers, fly around the wind farms. Migrating land birds, which cross the sea in large numbers, respond in various ways. Migrating songbirds that usually fly at night can be attracted to (brighter) turbine lighting, increasing their chances of collision. The above patterns are consistent between the studies carried out to date on the flight behavior of birds around offshore wind farms (i.e. Petersen et al. 2006, Krijgsveld et al. 2011, Leopold et al. 2011, Vanermen et al. 2013, Walls et al. 2013, Mendel et al. 2014).

When the distance between wind turbines is smaller, as in the Princess Amalia Wind Farm, avoidance of birds is many times larger. Similarly more birds fly in wind farms where turbines are spaced further apart (OWEZ, Horns Rev) of in the vicinity of turbines that are idle. Not enough data is available to underpin these findings, but is does provide a base to minimalize the number of bird casualties and barrier effects.
One of the possibilities is to create flight corridors between turbines, along important flight routes. Another is to maintain a minimum distance between wind farms that is large enough to allow the most cautious birds to pass the wind farm, on their way to and from their breeding,- resting- and foraging grounds.

The best method to estimate the number of collision victims offshore has been the use of models in which the collision rate is calculated mathematically. The Band-model is very suitable and is often used. To be able to compare the predictions for large wind farms throughout the North Sea, calculations should be done in a similar manner as much as possible, and hence with the same model. Because many other models are not

Overview of avoidance behavior of the main bird species groups at sea. For each species group the number of studies is shown that report avoidance (AV), indifference (I) of attraction (ATT) of birds when passing offshore wind farms, or mixtures thereof. Color indicates which behavior is most common in each species group.

	number of studies					
	AV	AV/I	I	ATT/AV	ATT	total
Other seabirds	27	3	0	1	2	33
Cormorants	0	0	1	0	3	4
Gulls	5	0	21	1	11	38
Terms	1	4	0	0	2	7
Migrating landbirds	4	0	8	0	0	12

freely available and because no model had been shown to outperform others, it is advised to use of the SOSS-BAND-model to predict the number of bird victims in the future Dutch offshore wind farms.

Actual measurements of collision rates are needed to verify estimates from collision rate models. As soon as data become available on the actual number of collision victims in existing offshore wind farms, empirical models are just as suitable as or even better than theoretical models. Second, research should currently be focused on determining avoidance rates, because, apart from actual collision rate measurements, this will result in the largest improvement of the reliability of collision rate modeling.

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The effects of wind farms on seabirds

Wind farms can have effects on sea birds. Often the collisions between passing sea birds and the turbine blades, attract the most attention, however there are more subtle effects as well. Birds can be attracted by the wind farm, for example because there is more food available, or because the wind farm offers shelter and resting places. Birds can also be put off by wind farms, resulting in avoidance behavior.

Both phenomena have advantages and disadvantages for birds. Attractiveness means birds can easily forage and rest at sea, but it increases the risk of collision. Avoidance means less collisions, but means habitat loss which can become a problem at population level: when the remaining sea surface decreases to this amount, the population size will structurally decrease until a new balance has been established. Such a development is unwanted because seabirds, as international migrating birds, are protected under the EU Birds Directive and the derived national legislation.

The North Sea countries have drafted ambitious and advanced plans for development of (more) wind farms in the North Sea. This possibly creates an international, cumulative problem for sea birds, at least for the species avoiding wind farms. With each new wind farm, the remaining available sea-surface decreases, whether the proposed wind farm is realized in Dutch waters or in the territory of another North Sea country. Space for wind farms is limited because other human activities at sea, like shipping, also need to be taken into

account. The different North Sea countries have appointed areas for further development of wind farms at sea. The exact planning for the appointed areas in many cases still needs to solidify. It is not unreasonable to think the differences in arrangement will lead to different degrees of avoidance and therefore different degrees of habitat loss. Development of larger turbines results in larger distances between individual turbines. If these design and arrangement parameters turn out to have important consequences on the avoidance behavior of birds, possibly planning can be adapted. Research on two different wind farms with different lay-outs in the Dutch North Sea sector, OWEZ and PAWP, has increased credibility for the theory that the use of larger turbines, with larger spacing, results in lower avoidance.

In this VUM study, the differences in avoidance behavior of guillemots between various arrangements of wind farms were investigated by analyzing data collected on ship counts. Ship count data was collected for an (international) range of wind farms at sea, in which sea birds were counted in a comparable manner, and avoidance was recorded. Specifically this study aimed for guillemots, which are very common on the North Sea and occur in high enough densities in most areas of the North Sea to enable the study of effects; and a species which is affected by wind farms. Guillemots avoid wind farms, but not totally: this offers the opportunity to measure the degree of avoidance in different wind farms, with varying turbine types. Data was gathered and analyzed of the wind farms: OWEZ, PAWP, Horns Rev I, Horns Rev II, Alpha

Ventus, Blighbank, Thornton Bank, Robin Ridge and Sheringham Shoal. The results indicate a possibly positive relationship between the turbine density (reciprocal of turbine size) and the degree of avoidance of guillemots. This means that larger turbines, with larger spacing indeed seem less deterring than small turbines in higher densities. These results however need

Among licensing authorities there was a widely shared desire for more knowledge exchange, exchange of experiences in relation to assessment of complex projects and access to consistent scientific information concerning i.e. cause-effect relations. There also proved to be a need to improve collaboration concerning the initiation of research on common knowledge gaps, to improve the efficiency of research and to prevent the same research being conducted by multiple countries. The scientists on the other hand indicated a need for more research to the effects of underwater sound on species other than marine mammals, i.e. fish. Furthermore, more research needs to be done on the effects of underwater sound on behavior and the long term effects on individuals and populations. A very important desire of the scientists is to standardize units and to share all data.

This workshop has partially been the reason for the Ministry of Economic Affairs and the Ministry of Infrastructure and the Environment to include international farms when assessing the cumulative effects of the construction of wind farms for the implementation of the Energy Agreement for sustainable energy. Cumulation of international farms has been included in the Ecology and Cumulation Framework, in which international knowledge and methods have also been applied. For the purpose of this Framework, international collaboration and exchange is being intensified, with respect to methodologies for calculating and assessment of effects as well as to measures that need to be taken to minimize those effects.

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International harmonization and collaboration

In most countries bordering the North Sea, an environmental impact assessment is a standard requirement in the permitting process for constructing wind farms at sea. Species and habitats which are the subjects of these assessments are not bound to borders and occur in the Exclusive Economic Zones of several countries. Nevertheless the assessment of these effects and the actions which need to be taken to bring these effects to acceptable levels differ in the various countries, especially concerning underwater sound.

These differences can be traced back to science (knowledge gaps and differences in the definitions of effects) and authorization (differences in implementation of European directives in national legislation). This causes a lot of uncertainty with the internationally operating wind sector and repeatedly results in differing construction and operational procedures.

This was the motive for the VUM project to organize an international workshop aiming to establish international exchange of knowledge and initiate harmonization of authorization. The workshop was organized following the international conference "Effects of Noise on Aquatic Life, 2013", a well reputed conference participated by leading scientists and a large group of licensing authorities and stakeholders.

The workshop was visited by 102 persons consisting of licensing authorities as well as scientists and stakeholders. In preparation for the workshop, a white paper was drafted

Photo: Salko de Wolf

with licensing practice in different countries. On the basis of this white paper and short plenary presentations, varying groups discussed the scientific knowledge as a basis for legislation and the improvement of knowledge exchange, and working on a more consistent assessment of the effects in licensing. Important issues were identified and reported in these groups.

Among licensing authorities there was a widely shared desire for more knowledge exchange, exchange of experiences in relation to assessment of complex projects and access to consistent scientific information concerning i.e. cause-effect relations. There also proved to be a need to improve collaboration concerning the initiation of research on common knowledge gaps, to improve the efficiency of research and to prevent the same research being conducted by multiple countries. The scientists on the other hand indicated a need for more research to the effects of underwater sound on species other than marine mammals, i.e. fish. Furthermore, more research needs to be done on the effects of underwater sound on behavior and the long term effects on individuals and populations. A very important desire of the scientists is to standardize units and to share all data.

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