

# Did the pile driving during the construction of the Offshore Wind Farm Egmond aan Zee, the Netherlands, impact porpoises?

Mardik F. Leopold<sup>1</sup>  
Kees (C.J.) Camphuysen<sup>2</sup>

Report number C091/09



<sup>1</sup> Wageningen IMARES

<sup>2</sup> Nederlands Instituut voor Onderzoek der Zee

Institute for Marine Resources and Ecosystem Studies

# Wageningen *IMARES*

Location Texel

Client:

NoordzeeWind  
2e Havenstraat 5-B  
1976 CE IJmuiden  
NoordzeeWind Rapport OWEZ\_R\_252\_Tc\_20080219 harbour porpoises



NoordzeeWind



Publication Date: February 2008

- Wageningen **IMARES** conducts research providing knowledge necessary for the protection, harvest and usage of marine and coastal areas.
- Wageningen **IMARES** is a knowledge and research partner for governmental authorities, private industry and social organisations for which marine habitat and resources are of interest.
- Wageningen **IMARES** provides strategic and applied ecological investigation related to ecological and economic developments.

Cover Photo: Harbour porpoise in the wind farm OWEZ, after completion of the park (Hans Verdaat, IMARES).

© 2007 Wageningen **IMARES**

Wageningen IMARES is a cooperative research organisation formed by Wageningen UR en TNO. We are registered in the Dutch trade record Amsterdam nr. 34135929, BTW nr. NL 811383696B04.

The Management of IMARES is not responsible for resulting damage, as well as for damage resulting from the application of results or research obtained by IMARES, its clients or any claims related to the application of information found within its research. This report has been made on the request of the client and is wholly the client's property. This report may not be reproduced and/or published partially or in its entirety without the express written consent of the client.

A\_4\_3\_2-V4

# Contents

Summary ..... 4

Introduction..... 5

Significance of observed trends for the construction of OWEZ..... 9

Study Methods ..... 11

Results ..... 12

Discussion and Conclusion ..... 14

References ..... 15

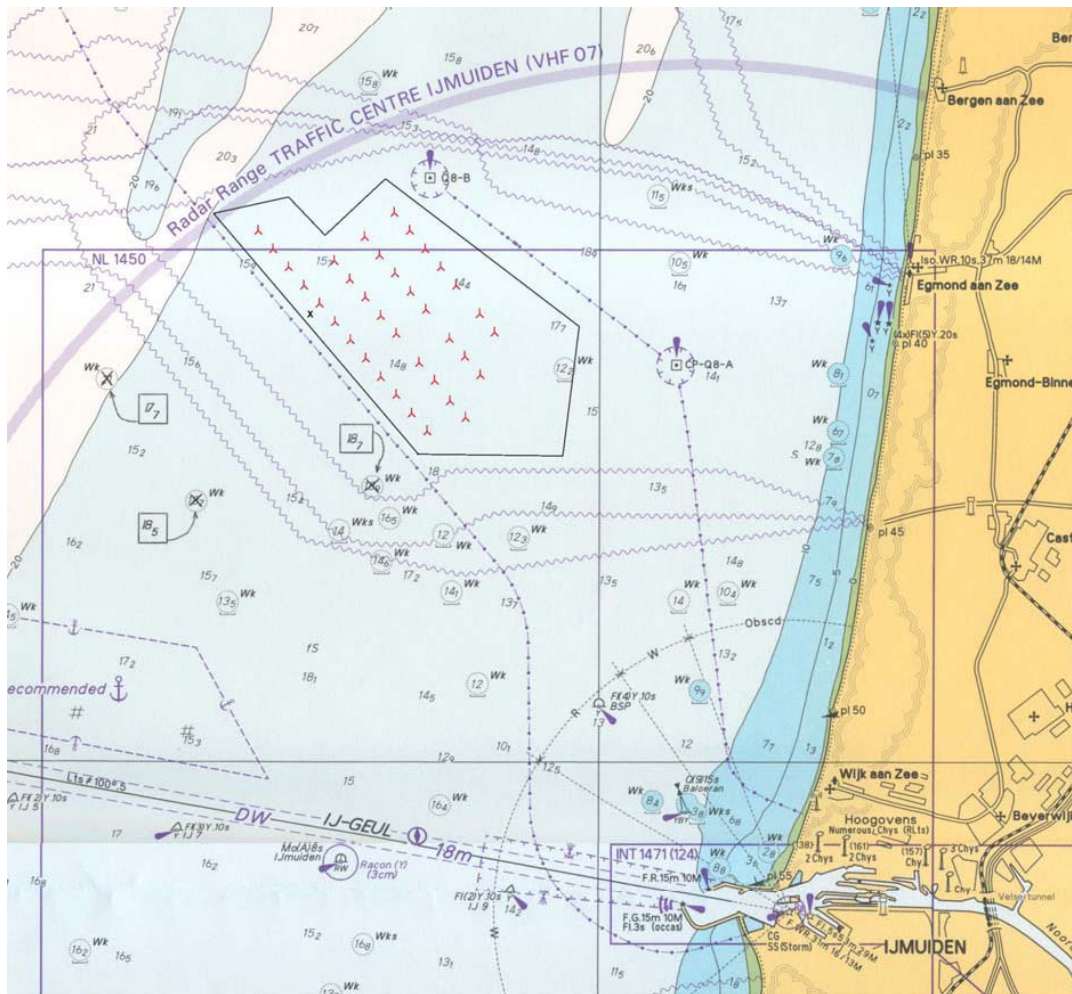
Referees and Authors ..... 17

## Summary

The Dutch consortium "NoordzeeWind" has built the first offshore wind farm in Dutch North Sea waters, known as "Offshore Wind farm Egmond aan Zee" (OWEZ) Part of the construction works consisted of driving 36 monopiles into the sea floor, during April-June 2006. The noise levels that attended this activity may have been detrimental to marine life forms. Cetaceans in particular are sensitive to very high noise levels and a possible impact on the most abundant cetacean living off the Dutch coast, the harbour porpoise was therefore studied. Direct observations were hard to conduct, given the low (summer) densities of porpoises around the construction site. Pathological observations on stranded specimen failed to produce clear results. Inner ears of freshly stranded porpoises were examined for possible damage, but before necropsies could be conducted the animals had been stored frozen and this had destroyed any visible signs of noise-induced damage to the inner ear. Thus, the spatio-temporal pattern of porpoise strandings was examined. Porpoises did not strand in higher numbers on the coastal stretch directly east of the construction site, or to the north-east of this location (downstream) compared to other parts of the country. Porpoises also did not strand in higher than expected numbers near the construction site, at the time of construction. It was therefore concluded that the construction did not lead to visibly increased mortality of harbour porpoises. In retrospect this might have been expected, given that densities of porpoises are normally very low in summer at the site, that the building process is noisy anyway, scaring porpoises off (to safe distances) before the actual pile driving commences. A ramp-up procedure and usage of a pinger further helped to ward off porpoises from the site, before full-power pile driving started. These factors combined (timing and high before-pile driving noise levels) made it very unlikely that porpoises got in harm's way during the construction of OWEZ.

# Introduction

The Dutch consortium "NoordzeeWind" operates the first offshore wind farm in Dutch North Sea waters. The park, consisting of 36 turbines on monopiles, is located NW of IJmuiden harbour, some 8 NM off the Dutch mainland coast. Named after the nearest town ashore, the park will be known as "Offshore Wind farm Egmond aan Zee" (OWEZ; Figure 1).



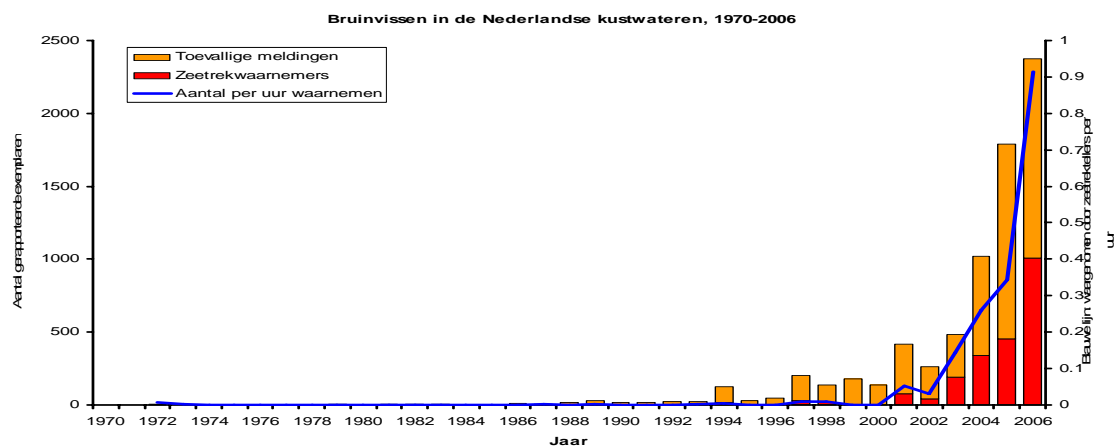
**Figure 1. Location of OWEZ (polygon off Egmond aan Zee) with the 36 turbines.**

The construction of this wind farm has taken many months and constituted among others several ship-based site surveys, cardinal buoys around the perimeter of the site, the laying of foundations for the monopiles (rocks being dropped into the sea from a barge), pile driving of the monopiles and attachment of transition pipes for the monopiles and further attachments of the turbines (at 70 m asl) and rotor blades (reaching up to 115 asl, NoordzeeWind 2003), and trenching cables. The ships involved in these tasks and for trafficking workers and equipment to and from the site and performing guard duties will all have impacted local wildlife. These impacts may range from attraction to deterrence from the site and, in a worst case scenario, to the death of some individuals.

The location of OWEZ is within the Dutch EEZ, but outside any of the proposed NATURA 2000 sites within this area (Lindeboom *et al.* 2005). However, the Southern Bight of the North Sea site may hold rather large numbers

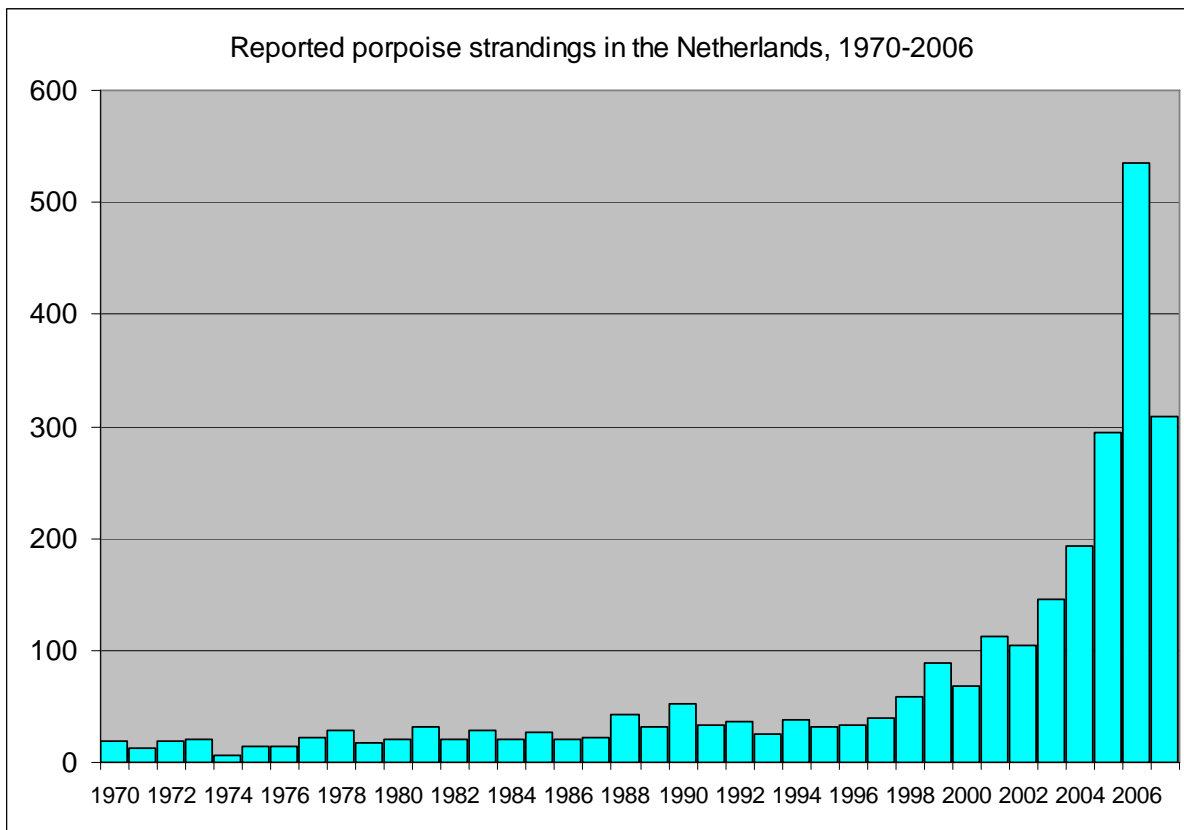
of vulnerable and protected marine mammals that are protected under the EU Habitat Directive and the Dutch Flora and Fauna Law. Three species in particular enjoy this highest legal protection level possible in the area: the harbour porpoise *Phocoena phocoena*, the harbour seal *Phoca vitulina* and the grey seal *Halichoerus grypus*. Of these, harbour porpoises are probably the most numerous although good population estimates on the national level are still lacking. With an estimated population size of some 250,000 in the North Sea at large (Hammond et al. 2002), porpoises are the most numerous marine mammals in the North Sea. The Dutch sector of the North Sea measures circa 10% of the whole North Sea, so if numbers would be evenly distributed, the Dutch population would be 20-30,000 animals. However, until recently porpoises were rare in the Dutch sector, at least in nearshore waters and total numbers for the Netherlands were tentatively estimated at no more than 1000 animals in the early 1990's (Camphuysen & Leopold 1993; Reijnders et al. 1995).

Things have changed dramatically since then. The first dedicated porpoise survey, aimed specifically at porpoises, conducted in summer 1994, failed to find many porpoises in Dutch waters (Hammond et al. 2002), but a second, similar survey in 2005 found much higher numbers here (Hammond et al. in prep.). At other times of year, porpoises were seen with increasing frequencies, both during aerial and ship-based surveys in the Dutch sector, that were principally aimed at seabirds (Arts & Berrevoets 2006; Camphuysen & Peet 2006). Increasing numbers of porpoises were also seen from coastal sites, first mainly by "seawatchers" and later also by the general public (Camphuysen 2004a,b, 2006; Camphuysen & Peet 2006). Seawatching is carried out by keen birders that monitor seabird passage along the Dutch coastline from several vantage points dotted along the coast (Camphuysen & van Dijk 1983; Platteuw et al. 1994). Using high-powered binoculars mounted on a tripod, they scan the nearshore waters for migrating seabirds and systematically note numbers passing in either direction. Other animals of interest, such as cetaceans are also systematically noted and entered in the central database of the Dutch Seabird Group. Effort, in terms of hours on watch is also known and this time series allows for an analyses of a possible trend in numbers spotted along the Dutch coasts. Numbers seen were virtually zero in the 1970's, 1980's and early 1990's but then started to increase, at a stunning annual rate of 41% (Camphuysen 2004b; Figure 2). This trend was matched by numbers reported by the general public, to the Marine Mammals Database, maintained by Kees Camphuysen (see: <http://home.planet.nl/~camphuys/Cetacea.html>).



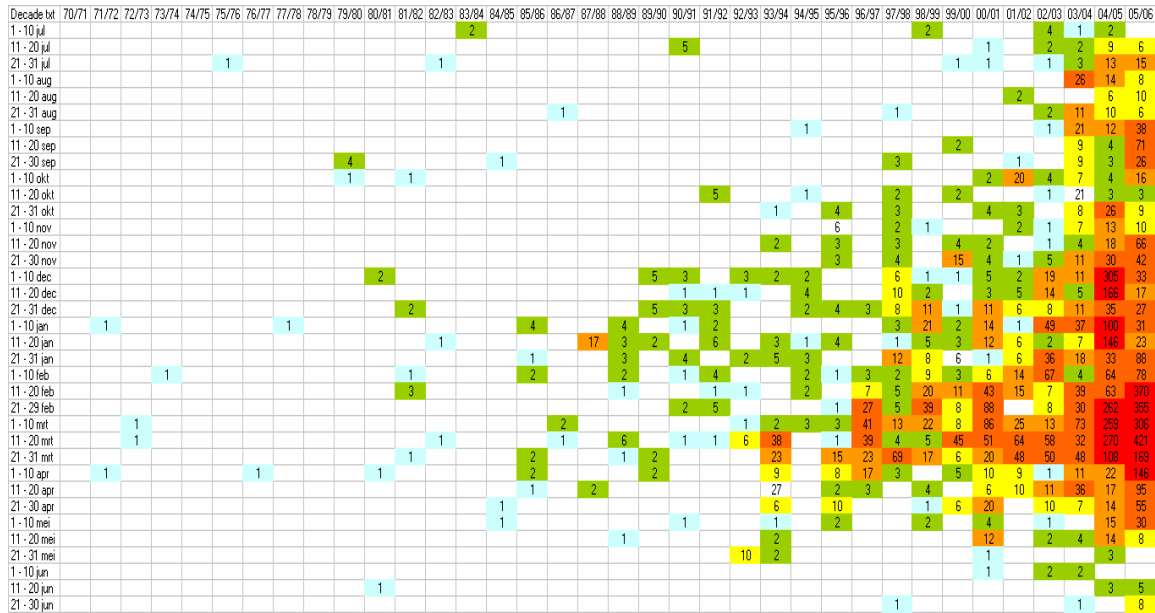
**Figure 2 (taken from Camphuysen 2006). Reported porpoises by seawatchers (red bars) and the general public (orange bars) in the Netherlands, 1970-2006. The blue line shows the numbers reported by the seawatchers, per hour of observation. Such a correction for effort is not possible for the numbers reported by the general public, but both datasets show a similar trend.**

The increasing trend of numbers of porpoises seen in Dutch waters was also matched by numbers stranding, mostly dead, on Dutch beaches and dikes. Data on cetacean strandings are collected by Naturalis (see: [www.walvisstrandigen.nl](http://www.walvisstrandigen.nl)) and numbers of stranded porpoises have increased markedly in recent years (Figure 3).

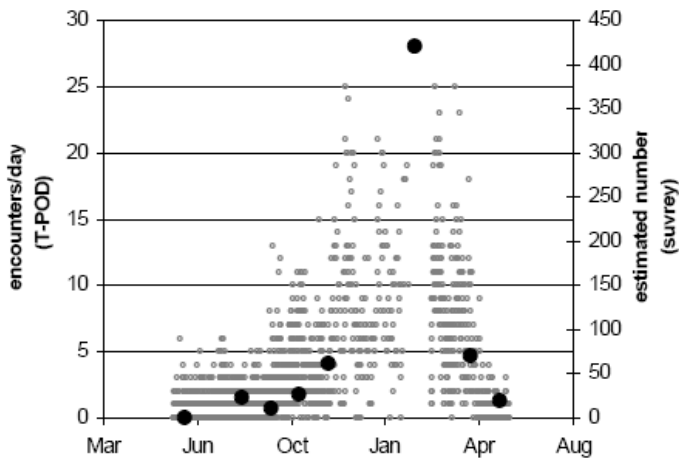


**Figure 3. Numbers of stranded porpoises, reported from Dutch beaches, per year. Data: Marine Mammals Database (Kees Camphuysen).**

An in-depth analysis of the underlying patterns has shown that numbers have increased in all seasons, and that the peak-season of winter to spring has considerably broadened (Camphuysen 2006). Porpoises are now present in all months of the year, but still have the highest abundance, at least in nearshore waters, in late winter and early spring (Figure 4). This seasonal pattern was also found at sea, during the so-called T-0 surveys for seabirds and cetaceans at and around the OWEZ site that ran from September 2002 to February 2004 (Brosseur et al. 2004). Both ship-based visual surveys and passive acoustic surveys using porpoise detectors (T-PODs) moored at the seafloor in the (then still future) windpark and in its vicinity, showed a marked peak in porpoise presence from January through March (Figure 5). A tentative estimate total numbers present during the February survey in a block of circa 1000 km<sup>2</sup> around OWEZ yielded a total number of 3350 porpoises present in this area at that time (Brosseur et al. 2004).



**Figure 4. Numbers of porpoises reported from the Netherlands, per 10 day period, 1970-2006. All available data, from surveys at sea, from seawatching, from strandings and miscellaneous (from the general public) are included, up to and including June 2006 (Marine Mammals Database; figure from Camphuysen 2006). Colours represent relative numbers per 10 day period; the seasons have been centered along the vertical axis around midwinter. Although porpoises may now be seen throughout the year, very small numbers are seen in the summer months (June/July).**



**Figure 5. Encounter rate provided by the 8 T-PODS (grey circles: porpoise click trains recorded per day) and the number of porpoises in the study area provided by the ship-based surveys (surveys lasted 5 days each; black dots). Figure taken from Bresseur et al. 2004).**

An in-depth analysis of the underlying patterns has shown that numbers have increased in all seasons, and that the peak-season of winter to spring has considerably broadened (Camphuysen 2006). Porpoises are now present in all months of the year, but still have the highest abundance, at least in nearshore waters, in late winter and early spring (Figure 4). This seasonal pattern was also found at sea, during the so-called T-0 surveys for seabirds and cetaceans at and around the OWEZ site that ran from September 2002 to February 2004.



## Significance of observed trends for the construction of OWEZ

The construction process of an offshore wind farm is a complex affair, going through many subsequent phases. Some work may significantly impact porpoises living in the area, that might be disturbed by the survey activities by the building activities. Of particular interest are activities that produce high levels of underwater noise that might be detrimental to porpoises in the vicinity. Noise activities include initial seismic surveys aimed at mapping the seabed for any anomalies that might impact the subsequent construction (not executed in the OWEZ project), laying scour protection (rock dumping), trenching for cables, both within the park and between the park and the shore, pile driving, building up the monopiles and other parts and any shipping movement connected to the park. Of all activities, the pile driving is considered the most detrimental, due to the very high noise levels involved (de Haan et al. 2007a,b). Porpoises are fully dependent on hearing, as they navigate and find prey by using their sonar. Any hearing impairment, particularly if this involves permanent damage, will have severe consequences for the animals and instant death in cetaceans that have been exposed to high noise levels has been reported. Cetaceans tend to avoid sources of loud noise, but may be taken by surprise by sudden loud noises, such as sonar beams from (particularly military or seismic survey) vessels (Richardson & Thomson 1995; Frantzis 1998; Parsons et al. 2000; Beerens 2003; Simmonds et al. 2003), and guidelines have been developed by several countries to safely use loud underwater sound (e.g. JNCC 2004; van der Ent 2005; Theriault 2005). Offshore construction, particularly pile driving produces very high noise levels (e.g. Verboom 2005) and concerns regarding the safety of marine mammals in the area of construction work has recently prompted several studies (Nedwell & Howell 2004; Madsen et al. 2006; Thomsen et al. 2006; Carstensen et al. 2006) that generally showed marked porpoise reactions to pile driving. Reactions varied from changed echo-sounds levels of the animals, to animals leaving the area, sometimes over large distances from the sound-source and with long returning times.

Construction of a wind farm in Dutch waters may long have been considered to have little impact on cetaceans, for a general lack of their presence here. However, with the marked increase of porpoise presence in our waters, this position can no longer be maintained. Porpoises have been shown to be present in the area of construction, and sometimes in high densities. However, there is also a marked seasonal variation and the summer months still are marked by a very low presence of porpoises. Construction (pile driving) took place from 17 March to 28 July 2007, with most activity from May to July (data Noordzeewind; Table 1). The first few, scattered days of pile driving within this period is within the early spring when numbers of porpoises are high, even at peak levels (Figures 4 and 5), while most of the building took place in summer, at low porpoise densities. Apart from building in the "off season" other mitigation measures are also possible and have, in fact been used during pile driving (de Haan et al. 2007a,b). A so-called ramp-up procedure was followed that generally increased noise levels. This would facilitate the porpoise to flee to safe distances, before full power, possibly at lethal sound levels, was used. Furthermore, a pinger, intended to scare off porpoises to safe distances was applied.

Date	Start piling	Stop piling	WTG nr.	break
17-04-06	15:00	17:05	13	
30-04-06	20:30	22:55	01	
4-05-06	22:50	0:00	22	***
5-05-06	0:30	0:50	22	***
7-05-06	16:45	17:35	02	
11-05-06	14:45	16:10	03	
14-05-06	20:25	21:50	04	
25-05-06	23:15	0:00	05	***
26-05-06	0:30	3:13	05	***
2-06-06	18:40	19:00	07	***
2-06-06	19:20	20:20	07	***
4-06-06	22:30	23:45	06	
7-06-06	11:15	13:30	08	
9-06-06	7:25	9:00	09	
11-06-06	2:20	4:00	12	
13-06-06	11:35	11:56	10	***
13-06-06	14:50	16:20	10	***
16-06-06	15:20	16:52	11	
18-06-06	4:45	6:05	14	
20-06-06	2:10	3:30	15	
24-06-06	21:34	23:15	16	
27-06-06	22:35	23:15	17	***
28-06-06	0:15	1:00	17	***
29-06-06	12:30	15:30	18	
3-07-06	2:42	3:50	19	
4-07-06	17:17	18:30	20	
6-07-06	17:45	18:55	21	
8-07-06	5:25	6:40	27	
10-07-06	21:00	22:10	28	
12-07-06	4:51	6:10	29	
16-07-06	15:05	16:25	23	
18-07-06	2:45	3:55	25	
19-07-06	7:10	8:05	26	
20-07-06	12:50	13:30	24	
21-07-06	19:30	20:20	30	
22-07-06	20:55	21:30	31	
23-07-06	19:45	20:30	32	
25-07-06	4:00	5:30	33	
26-07-06	10:15	11:45	35	
27-07-06	14:05	15:05	36	
28-07-06	17:55	19:25	34	

**Table 1.** Dates and times (from, to) of pile driving for OWEZ. Note that technical difficulties caused some pile driving sessions to be interrupted, to be continued and finalized later. These are marked \*\*\* in the last column.

## Study Methods

Measuring reactions of porpoises to pile driving is no simple matter. Given the expected long-distance reactions to pile driving (Thomsen et al. 2006; Carstensen et al. 2006) a large area would have to be surveyed, either by passive acoustic devices or by plane. Ship-based surveys would probably be too slow, given the expected short bouts of pile driving (several hours at the time). Aerial surveys would be hampered by problems with timing, as the exact start and end points of pile driving could not be guaranteed. Most importantly, expected porpoises were low in the period of most intensive pile driving and finding even a single porpoise in summer, during pile driving would have been a lucky event. At-sea surveys were thus not attempted.

This left us with two alternative ways to approach the problem, both of which were pursued. First, a post-hoc analysis of stranding patterns was performed. Numbers of stranded porpoises had been increasing for years already in 2006, resulting in unprecedented numbers available for analysis in the year of construction (Figure 3). Stranding patterns near the construction site could also be compared to numbers stranding elsewhere. We considered the coastal stretch from Den Helder to IJmuiden (Noord-Holland) as the impact zone. Porpoises killed by high sound levels would probably mostly strand here, given the prevailing wind direction (SW) and residual currents (northward). However, the power of this approach would be considerably compromised if many near-lethal effects would result from pile driving that would make porpoises die only after some time, during which they could have moved over considerable distances. This approach would thus mainly pick up severe effects, such as immediate mass die offs, and strandings in the impact area (cf American military sonar events).

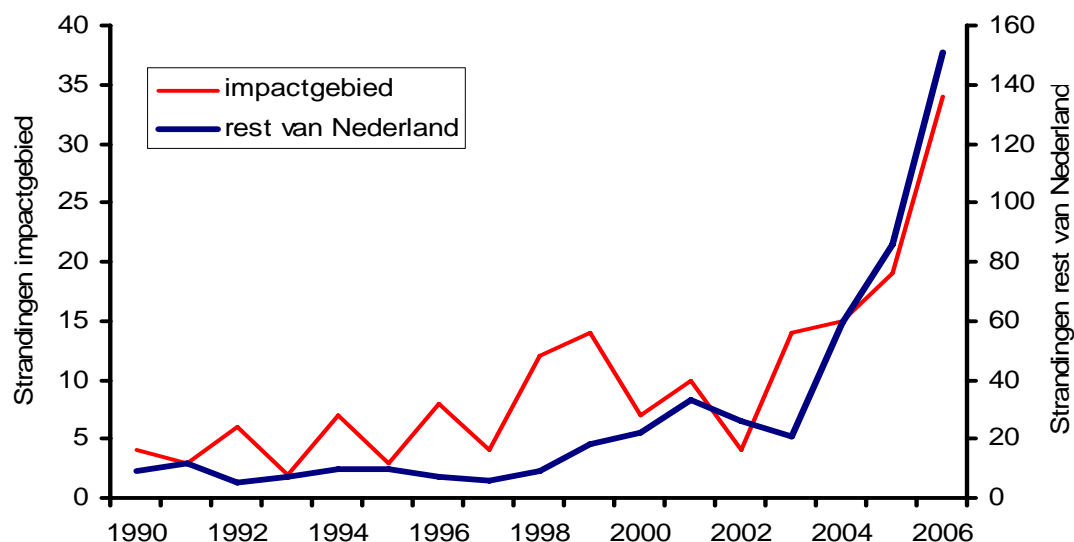
The second line of research was to collect as many stranded porpoises as possible in the year of construction, both from the impact zone and from reference areas further away, and both from the construction (pile driving) period and from earlier and later month. Detailed autopsies were performed on these animals later in the year, with a special focus on inner ear morphology and possible ear damage. To this end, two experts were invited to perform this specialized work, because the expertise is not available in the Netherlands and, in fact, is still being developed in some other European countries. One Spanish expert, Maria Morell Ybarz of the Laboratori d'Aplicacions Bioacústiques Universitat Politècnica de Catalunya (UPC) in Barcelona, Spain, studies inner ear morphology. Kristina Lehnert, of the Forschungs- und Technologiezentrum Westküste-FTZ in Büsum, Germany studies inner ear histopathology.

A total of 64 porpoises were collected in 2006 (Leopold & Camphuysen 2006) and the left and right inner ears were dissected from all animals that were (reasonably) fresh, regardless of stranding location or time of stranding. Both experts were present at the autopsy session (September 2006) and dissected most of the ears themselves, other ears were dissected by other, trained veterinary pathologists that were hired for the autopsies. One inner ear was taken to Germany, the other to Spain and the experts conducting the inner ear study only had a reference number for each ear, no details on the animal itself, to ensure a double-blind research procedure. Preparations of the samples for examination under light (Germany) and scanning electron (Spain) microscope involved several staining and "softening of the bone tissue" procedures that took several months to complete, before the actual examination of possible ear damage could be performed.

Inner ears have a subtle morphology that is easily damaged, for instance by storage in a freezer. Logistics determined that all animals had been kept frozen before autopsies, and the freezing and subsequent thawing of the animals, and their inner ears, made this line of research an enterprise with a high risk of failure. It was, however, the only line open for study of possible victims of pile driving.

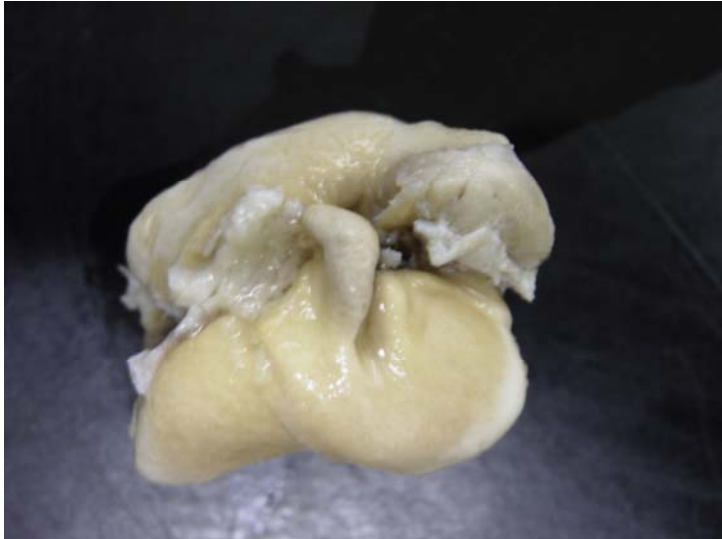
## Results

Figure 6 shows the trends in numbers of stranded porpoises in the impact zone and along the remaining Dutch coastline. Strandings were relatively frequent in the impact zone before 2004 and were lower in a relative sense from 2004-2005. In absolute numbers, strandings slowly increased until the end of 2003 and then showed a marked increase, that was very similar in the impact zone and in the other parts of the Netherlands. There is no deviation from this pattern in the year 2006, or during the time of pile driving within 2006. Therefore, nothing out of the ordinary (apart from the steep increase in overall numbers) was found for the impact zone at the time of pile driving that would suggest that construction of OWEZ had any effect on numbers of porpoises beaching in the Netherlands. There were certainly no mass die-offs represented by mass-strandings or other indications that pile driving had resulted in additional mortality off Noord-Holland. Also, there was no indication that the sea off Noord-Holland was left by all porpoises for any length of time.



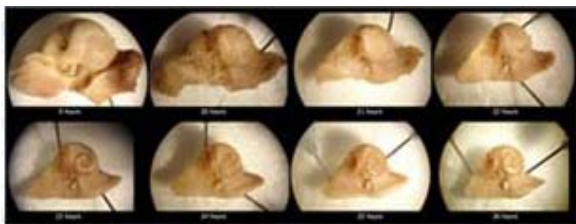
**Figure 6. Numbers of stranded porpoises in the presumed impact zone (“impact gebied”, coastline from Den Helder to IJmuiden; Noord-Holland) compared to the rest of the country (“rest van Nederland”), 1990-2006. The blue line and left Y-axis represent the impact zone; the red line and right axis the rest of the country.**

Histopathological work in Germany only showed a lot of post-mortal freezing damage to the inner ear, that made useful comparisons between ears of different animals meaningless. Figure 7 shows a lateral view of an ear complex from a harbour porpoise after dissection from the skull. Additional information on thawing artifacts was gained from experts of Harvard Medical School and this confirmed that such damage would be too severe for the inner ears to be useful for determining hearing impairment due to exposure to loud noise. Additional problems identified were the possibility that other non-acoustic diseases of the ear may be present (e.g. due to pollution or disease) or that other sources of loud noise may have contributed to inner ear damage, such as underwater detonations of old ammunition by the Dutch Navy (the Navy periodically disposes of WW-II bombs and other explosives found on land and sea, off the Noord-Holland coast line and does so without any use of pingers, observers or ramp-up procedures as we understand it). Until present, the German researchers have not been able to identify ears with chronic or acute noise damage from German or Danish waters, so natural incidence appears to be low (Kristina Lehnert, pers. comm.).



**Figure 7. Lateral view of an inner ear complex, taken from the skull of one of the dissected harbour porpoises. Photo: Kristina Lehnert.**

In Spain, similar negative results were obtained. Ears were first de-calcified to gain better access to the organ of Corti inside that is considered sensitive to damage from noise. It was found that the freezing process causes dehydration and intercellular ice formation that induces artifacts that are too severe for any useful analysis. Moreover, the organ of Corti's cells were found to be especially sensitive to decomposition and it is now recommended that inner ears should be extracted immediately upon stranding, preferably within several hours after death and certainly before storage in a freezer. The German and Spanish experts thus both concluded that this part of the study could not produce meaningful results regarding possible ear damage from loud underwater noise.



**Figure 8. Decalcification process of a harbour porpoise inner ear complex (the periotic bone). Photos : Maria Morell.**

## Discussion and Conclusion

The building of the first offshore wind farm in Dutch waters was a complex enterprise and timing of critical phases was aimed at optimizing the probability of good weather (low seastates). A swell of 1 m or more would prevent pile driving and therefore this part of the building process took place in spring/summer. By coincidence, this is also the time of year when porpoise presence is minimal in the general area and this will have contributed to a lower probability of impacting porpoises. Second, a ramp-up procedure and a pinger were always followed, so that any porpoises in the vicinity were given the chance to flee to safe(r) distances before full hammering power was applied. This contrasts to detonation procedures used by the Navy for disposal of old ammunition that is blasted off without any preceding warning for underwater life. Third, the sheer presence of the pile-driving ship, the very large *Svanen*, that was working in the area many hours before the actual pile driving to anchor itself at the exact required position was already a ramp-up procedure in itself. No porpoises were seen during three lengthy visits to the site, during three pile driving events (Leopold & Camphuysen 2007) and there was no indication from numbers and locations of strandings that any additional mortality has been caused by the pile driving for OWEZ. Although we have not been able to demonstrate, from morphological work on the inner ear of stranded porpoises from period and place of pile driving that ear damage never occurred, we still conclude, from the strandings patterns, and the way pile driving was conducted, and the timing of pile driving in relation to general porpoise presence, that no significant mortality of porpoises has occurred.

## References

- Arts F.A. & Berrevoets C.M. 2006. Monitoring van zeevogels en zeezoogdieren op het Nederlands Continentaal Plat 1991-2006. Rapport RIKZ/2006.018. Rijksinstituut voor Kust en Zee, Middelburg, 40p.
- Beerens S.P. 2003. The influence of sonar systems on marine mammals. TNO-report FEL-03-A177: 1-46, TNO, den Haag.
- Brasseur S., Reijnders P., Henriksen O.D., Carstensen J., Tougaard J., Teilmann J., Leopold M., Camphuysen K., & Gordon J. 2004. Baseline data on the harbour porpoise, *Phocoena phocoena*, in relation to the intended wind farm site NSW, in the Netherlands. Alterra-rapport 1043, 80p.
- Camphuysen K. 2004a. A marked increase in Harbour Porpoises in the southern North Sea 1990-2005. Shetland Sea Mammal Report 2004: 20-24.
- Camphuysen C.J. 2004b. The return of the harbour porpoise (*Phocoena phocoena*) in Dutch coastal waters. *Lutra* 47: 135-144.
- Camphuysen C.J. 2006a. Bruinvisen langs de Noord-Hollandse kust. *Tussen Duin & Dijk* 5(1): 4-8.
- Camphuysen C.J. 2006b. Historisch overzicht: Bruinvissen vroeger en nu. Ch. 6 in: M.F. Leopold & C.J. Camphuysen (2006). Bruinvisstrandingen in Nederland in 2006. Achtergronden, leeftijdsverdeling, sexratio, voedselkeuze en mogelijke oorzaken. Wageningen IMARES Report C083/06; NIOZ rapport 2006-5.
- Camphuysen C.J. & Dijk J. van 1983. Zee- en kustvogels langs de Nederlandse kust 1974-79. *Limosa* 56:81-230.
- Camphuysen C.J. & Leopold M.F. 1993. The harbour porpoise *Phocoena phocoena* in the southern North Sea, particularly the Dutch sector. *Lutra* 36(1): 1-24.
- Camphuysen K. & Peet G. 2006. Walvissen en dolfijnen in de Noordzee / Whales and dolphins in the North Sea. Fontaine Uitgevers BV, 's Graveland / Stichting De Noordzee, Utrecht.
- Carstensen J., Henriksen O.D. & Teilmann J. 2006. Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echo-location activity using porpoise detectors (T-PODs). *Mar. Ecol. Prog. Ser.* 321: 295-308.
- de Haan D., Burggraaf D., Asjes J., & Hille Ris Lambers R. 2007a. Background noise measurements for MEP-NSW Baseline T0. Report Wageningen IMARES C049/07; Report OWEZ\_R\_251\_ T0 20070323 part 1.
- de Haan D., Burggraaf D., Ybema S. & Hille Ris Lambers R. 2007b. Underwater sound emissions and effects of the pile driving of the OWEZ windfarm facility near Egmond aan Zee (Tconstruct). Report Wageningen IMARES C106/07; Report OWEZ\_R\_251\_ Tc 20071029.
- Hammond P.S., Berggren P., Benke H., Borchers D.L., Collet A., Heide-Jørgensen M.P., Heimlich S., Hiby A.R., Leopold M.F. & Øien N., 2002. Abundance of harbour porpoise and other small cetaceans in the North Sea and adjacent waters. *J. Appl. Ecol.* 39: 361-376.
- Frantzis A. 1998. Does acoustic testing strand whales? *Nature* 392: 29.
- JNCC 2004. Guidelines for minimising acoustic disturbance to marine mammals from seismic surveys. [www.jncc.gov.uk/marine](http://www.jncc.gov.uk/marine), 9p.

- Leopold M.F. & Camphuysen C.J. 2006. Bruinvisstrandingen in Nederland in 2006. Achtergronden, leeftijdsverdeling, sexratio, voedselkeuze en mogelijke oorzaken. Wageningen IMARES Report C083/06; NIOZ rapport 2006-5.
- Leopold M.F. & Camphuysen C.J. 2007. Did the pile driving during the construction of the Offshore Wind Farm Egmond aan Zee, the Netherlands, impact local seabirds? IMARES Report C062/07; NoordzeeWind Rapport OWEZ\_R\_221\_Tc\_20070525.
- Macleod C.D., Santos M.B., Reid R.J., Scott B.E. & Pierce G.J., 2007. Linking sandeel consumption and the likelihood of starvation in harbour porpoises in the Scottish North Sea: could climate change mean more starving porpoises?. Biol. Lett. online: doi:10.1098/rsbl.2006.0588.
- Madsen P.T., Wahlberg M., Tougaard J. & Tyack P. 2006. Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Mar. Ecol. Prog. Ser. 309: 279-295.
- Nedwell J.R. & Howell D. 2004. A review of offshore wind farm related underwater noise sources. Subacoustech Report 544R0308. available from [www.subacoustech.com](http://www.subacoustech.com).
- Parsons E.C.M., Birks I., Evans P.G.H., Gordon J.C.D., Shrimpton J.H. & Pooley S. 2000. The possible impacts of military activity on cetaceans in West Scotland. European Research on Cetaceans 14: 185-191.
- Platteeuw M., van der Ham N.F. & den Ouden J.E. 1994. Zeetrekellingen in Nederland in de jaren tachtig. Sula 8(1/2, special issue): 1-203.
- Reijnders P.J.H., Leopold M.F., Camphuysen C.J., Heessen H.J.L. & Kastelein R.A. 1995. Status of the harbour porpoise *Phocoena phocoena* in Dutch waters and state of related research in The Netherlands: an overview. IWC-Sci Ctee SC/47/SM41: 7p.
- Richardson W.J. & Thomson D.H. 1995. Marine mammals and noise. Academic Press.
- Simmonds M., Dolman S. & Weilgart L. (eds) 2003. Oceans of noise. Whale and Dolphin Conservation Society (WDCS) Science Report, 164 pp.
- Thomsen F., Lüdemann K., Kafemann R. & Piper W. 2006. Effects of offshore wind farm noise on marine mammals and fish. Report Biola, Hamburg, Germany, on behalf of Cowrie Ltd. Available from: [www.offshorewind.co.uk](http://www.offshorewind.co.uk).
- Verboom W.C. 2005. Bulderen windmolens de bruinvis weg? Nieuwsbrief Nederlandse Zeevogelgroep 6(3): 12.



# Referees and Authors

Rapport Number C091/09  
Project Number: 430.61018.09

This report has been professionally prepared by Wageningen IMARES. The scientific validity of this report has been internally tested and verified by another researcher and evaluated by the Scientific Team at Wageningen IMARES.

Approved: Prof. dr. H.J. Lindeboom  
(general project manager IMARES-North Sea Wind)

Signature:

b/a



Date: 19/02/2008

Approved: Drs. F.C. Groenendijk  
Head of Ecology Department IMARES

Signature:



Date: February 2008