

ECHOLOCATION ACTIVITY OF HARBOUR PORPOISES (*PHOCOENA PHOCOENA*) AROUND AN OFFSHORE GAS-PRODUCTION PLATFORM-DRILLING-RIG COMPLEX

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1 INTRODUCTION

Harbour porpoises (*Phocoena p. phocoena* L.) are vocal animals and their activity can be monitored effectively using underwater, autonomous, passive-acoustic cetacean-click detectors called T-PODs [e.g. 1, 2, 3].

The characteristics of porpoise-echolocation clicks have been described in great depth over the last forty years [4-10]; clicks can be emitted singularly or in groups known as 'trains'. There is a linear correlation between porpoise-echolocation pulse intervals and target range [11, 12] with a peak in repetition rate as the animal nears the target, analogous to the 'terminal buzzes' repeatedly observed in echolocating bats [13]. Determination of a successful prey-capture event in wild echolocating bats has been achieved effectively [e.g. 14], but for wild porpoises, underwater filming of prey-capture attempts is extremely troublesome. Moreover, in the wild, without visual confirmation, any correlation between porpoise buzz activity and feeding success cannot be assumed *a priori* without experimental evidence, because a high buzz rate may simply be associated with increased foraging effort for the same amount of prey. Nonetheless, it is conceivable that by using acoustics alone, a proxy of feeding activity could be surmised by examining the relative incidence of increasing click rates, emitted during range-locking echolocation behaviour, and the associated decreasing interval between clicks, known as 'inter-click-intervals (ICI)' [see 2]. While we cannot exclude the possibility that that a decrease in ICI could be associated with inanimate object investigation, such as the rig structures, a link between feeding and decreasing ICI has been established for foraging Blainville's beaked whales (*Mesoplodon densirostris*) [15] and harbour porpoises [16].

Previous research on harbour porpoise echolocation behaviour has focused on inshore populations [e.g. 2] or on captive animals [see 17 and refs. therein] and knowledge of their offshore echolocation behaviour remains scarce. It is a well accepted tenet, however, that offshore installations may act as artificial reefs, effective in aggregating benthic, demersal, and pelagic marine species [18-20] and in the North Sea, fishing is not permitted within the 500 m exclusion zone around each installation, further enhancing the properties of these 'reefs' as refuges for marine life.

World-wide rigs-to-reef studies (i.e. decommissioned rigs left *in situ* for the benefit of marine life) have focused mostly on quantifying aggregations of fish and invertebrates and there have been only a few isolated studies in the North Sea [e.g. 21, 22]. No research to date has considered the potential of these installations to serve as foraging sites for marine mammals even though the short-term activity of porpoises appears to be unaffected by routine oil-and-gas operations such as drilling, tender-boat operations, and cementing and casing [23]. It is hypothesised here that areas in the near vicinity and between the legs of such structures might serve as reefs for potential prey of harbour porpoises, and thus porpoises, in otherwise significantly overfished or disturbed parts of the North Sea [38].

Between 2005 and 2006, monitoring was carried out from a gas production platform-drilling-rig complex in the Dogger Bank region of the North Sea, in order to establish whether porpoises were present around the installations, using autonomous underwater porpoise echolocation-click detectors called T-PODs (see: <http://www.chelonia.co.uk>). Replicated work was not undertaken as this was not a comparative study, and no assumptions on whether porpoises were attracted to installations were made. The objectives of the T-POD study described here were to (i) determine whether porpoises were present around the installation; (ii) examine any diel patterns in echolocation activity; and, (iii) use the inter-click interval as a proxy indicator of feeding.

2 MATERIALS AND METHODS

2.1 STUDY LOCATION AND TIMING

Monitoring was performed from the A6-A gas-production platform operating under the auspices of the North Sea oil-and-gas branch of BASF (Wintershall AG) in the Northeast German Sector of the Dogger Bank (Figure 1). The A6-A platform has been in location (55°47'28.895"N, 003°59'39.584"E) inside the natural-gas field sector A6-B4 since July 1999. During the monitoring period, the *Noble Kolskaya* 'jackup' drilling rig was positioned and fixed alongside the A6-A at its southern end. Monitoring at the A6-A-*Kolskaya* complex took place over a six-month period from 30 July 2005 to 27 January 2006.

2.2 INSTALLATION AND SITE DESCRIPTION

The A6-A-*Kolskaya* complex was situated in a mean water depth of 47.80 m with a semi-diurnal tidal range of 0.5 m, on a seabed of very soft clay and sand on a heading of 180.30°. The A6-A had a typical six-legged steel construction with a base area of 1015 m², a length of 52 m and width of 33 m. The *Noble Kolskaya* had a typical triangular-shaped barge hull, with a deck area of 1765 m² and three legs at 53.95 m spacing. The hull length was 69.25 m, with a maximum centre-depth of 8.55 m.

2.3 LOGGING PORPOISE ACTIVITY

A manual for T-POD data acquisition and analysis and a detailed description of associated software can be found at <http://www.chelonia.co.uk>. T-POD functionality and settings have been described, in detail, elsewhere [24-27]. In brief, T-PODs comprise a hydrophone, an analogue processor, a digital timing/logging system, and analysis software (TPOD.exe) that filters the data for porpoise clicks, after they have been transferred to a PC. T-PODs log the time and duration of porpoise-clicks to 10 µs resolution, distinguishing between other sources of energy in the same frequency band, such as boat sonar. T-POD settings are given in Table 1.

2.4 T-POD DEPLOYMENT

Following three days of trial and optimisation, three T-PODs were deployed from the A6-A-*Kolskaya* complex from custom-designed hand-winches to depths of 10 m, 25 m and 35 m. The T-PODs were permutations of v. 3s (identification numbers 406, 407, and 408) and a v. 4 (identification number 516). T-POD memories were updated from industry standard to 128 MB RAM and ran on 12 × 3.4 V D-cell alkaline batteries. Every 4–5 weeks, T-PODs were retrieved, the logged data downloaded onto a laptop PC (Sony Vaio VGN-S1XP, PGC-6C1M, Tokyo, Japan), the D-cells replaced and T-

PODs re-deployed. At no point were all T-PODs recovered simultaneously, ensuring a continuous monitoring dataset.

2.5 INDICATORS OF PORPOISE ACTIVITY

Data were analysed through T-POD.exe v. 8.17. We analysed trains using the CetHi setting, which positively identifies porpoise clicks with the highest degree of certainty. Data for each porpoise train were exported from the T-POD software into Microsoft Excel™ for analysis. We used two indicators of porpoise echolocation behaviour that each measured different aspects of activity: encounter rate and minimum inter-click interval (MICI).

2.5.1 Encounter Rate

An encounter is defined as a group of trains that are separated by periods of silence with a minimum duration of 10 min, after [2]. The encounter rate (encounters per h) was calculated as the number of porpoise encounters divided by the mean duration of each diel phase multiplied by the number of recording days. See Section 2.6 for diel phase determination.

2.5.2 Minimum Inter-click Interval

A description of the minimum inter-click-interval (MICI) per train is given in [2] and [26]. An MICI of <10 ms was used as a proxy indication of porpoise-feeding activity, as per [2].

2.6 DIEL CLASSIFICATION

A custom-written computer algorithm categorised porpoise trains into four diel phases: morning, day, evening or night (Table 2), by comparison with civil twilight and sun-state tables from the US Naval Observatory (<http://www.usno.navy.mil/>). Technical definitions for precise rise, set, and twilight are explained on the USNO site at <http://www.usno.navy.mil/USNO/astronomical-applications/astronomical-information-center/rise-set-twi-defs>. The effects of the lunar cycle were not considered. The algorithm revealed the diel phase in which a train was detected and sorted the trains by whether they had a MICI of less than 10 ms, a proxy indicator of feeding behaviour.

2.7 STATISTICAL ANALYSIS

Statistical tests were performed using SigmaStat v. 3.1 (Systat software Inc., California, USA). Data from each T-POD were analysed separately for calculations. Data were non-normally distributed (Kolmogorov–Smirnov tests $p < 0.05$); logarithmic and arcsine transformations failed to normalise data. Non-parametric Kruskal-Wallis, one-way ANOVAs, with the appropriate *post hoc* tests, were thus employed to assess significant differences for the indicators of porpoise activity.

3 RESULTS

Tidal heights and currents at all three locations were minimal (0.5 m, and 0.51–1.03 ms⁻¹, respectively), because of the installations' proximity to an amphidromic point i.e. position within a tidal system where the tidal range is almost zero, within the German Bight.

All T-PODs logged 2479 porpoise encounters during a total of 756 369 monitoring minutes (525.26 d).

3.1 ENCOUNTER RATE

Significantly more porpoise encounters were recorded at night (Kruskal-Wallis, one-way ANOVA on ranks, d.f. = 3, $H = 8.638$, $p = 0.035$). All *post hoc*, pairwise, multiple-comparison procedures (Tukey method) revealed this difference to exist between night and day ($p < 0.05$).

3.2 MINIMUM INTER-CLICK INTERVAL

The median MICI was shorter at night (Figure 2). This result was significant throughout all T-POD deployments (Kruskal-Wallis, one-way ANOVA, $p < 0.001$; all *post hoc*, pairwise, multiple-comparison procedures, Holm-Sidak method, are illustrated in Figure 2). The shortest ICI in the entire dataset was 0.74 ms.

4 DISCUSSION

Overall results sustain the hypotheses that (i) porpoises are present at the offshore installation or, at least, within a few hundred metres of them and (ii) there is a marked diel pattern in echolocation activity; and, (iii) an equitable interpretation of this pattern is that porpoises are probably feeding at night below or around the platform complex.

Although a correlation between low inter-click intervals (ICIs) on T-POD recordings and feeding behaviour has not been verified experimentally (and this research cannot prove *per se* that the MICI is a reliable indicator of feeding behaviour in porpoises), we can conclude at the very least that it is a useful indicator of the presence of a certain type of trains, though further evidence involving independent studies on the behaviour of porpoises, from cameras, time-depth recorders or similar instruments, is needed to establish the link to feeding.

Diel patterns in Cetacea are common [see review by 28, where the term 'diurnal' is mistakenly used], but it is not clear whether these observations are related to circadian rhythms, external cues (e.g. light/lunar cycles), diel activity in their prey species, or to some combinations of all three. There are no *a priori* reasons to expect diel patterns to be the same for all porpoises around the world and at all times of the year and in different tidal regimes. The results presented here, however, agree fundamentally with those of [2], who reported that when using one POD only, the rate of Scottish harbour porpoise echolocation encounters and the proportion of trains with MICI < 10 ms all peaked at night and were at their minima by day. Similar diel patterns have also been reported for a single POD study of wild porpoises in the Bay of Fundy, Canada [29].

Porpoises may produce more click trains and click bursts (inferred feeding attempts) at night to compensate for lack of light, although porpoise studies so far have been inconclusive or based on small sample sizes [e.g. 30, 31]. It is more probable that the nocturnal increase in proxy feeding behaviour is related to increased nocturnal hunting effectiveness associated with the concurrent increase in the availability of their prey. Porpoises use click bursts to investigate specific objects at close range, but also during the pursuit of live fish [30]. While in our study, we have no empirical evidence on fish species diversity, distribution and behaviour, or the prey-preferences of porpoises around installations, North Sea porpoises are known to feed on sandeels (Ammodytidae) and herring (*Clupea harengus*) [32, 33], both of which are present in the Dogger Bank region [33, 34], and both exhibit diel patterns in behaviour [35, cited in 36, 37]. Diel periodicity in fish species has also been found around installations [21]; however, detailed discussions on prey behaviour are beyond the scope of this paper.

In conclusion, harbour porpoises frequented the offshore installation, possibly to feed, mainly at night. Replicated and controlled experiments should be carried out to explore the possibility that installations are important foraging areas, which has implications for rig-decommissioning decisions.

If porpoises regularly cluster around installations within the 500-m exclusion zones, then they may historically have been omitted from density and abundance surveys, resulting in potentially significant underestimations of their true population status in the North Sea and other areas.

5 FIGURES AND TABLES

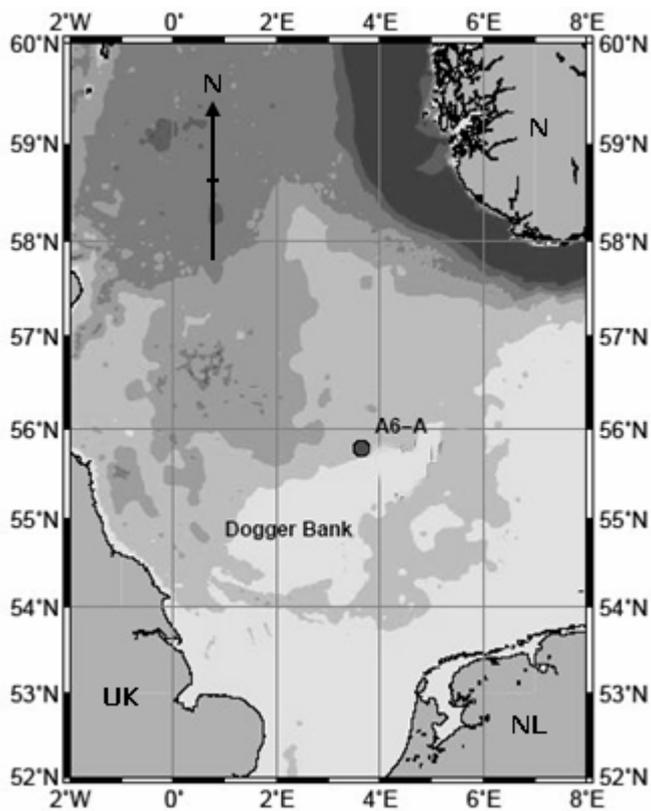


Figure 1: Location of A6-A-Kolskaya complex in the German Sector of the North Sea. Lightest grey bathymetry region delineates 30 m contours. Map projection: Mercator.

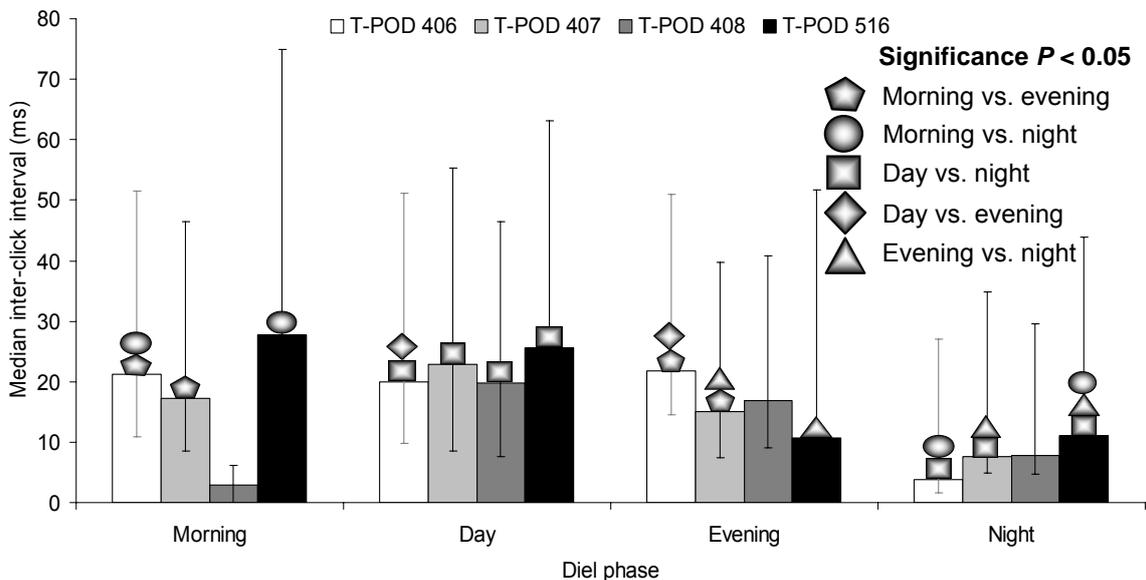


Figure 2. Minimum inter-click intervals (MICI) and inter-quartile ranges. The shapes refer to *post hoc* Dunn's tests that gave significant results at the level $p < 0.05$.

Version 3 T-PODs (identification numbers 406, 407 & 408)						
Scan	1	2	3	4	5	6
Target A filter frequency (kHz)	130	130	130	130	130	130
Ref. B filter frequency (kHz)	90	90	90	90	90	90
Selectivity ratio (A/B)	5	5	5	5	5	5
A integration period	Short	Short	Short	Short	Short	Short
B integration period	Long	Long	Long	Long	Long	Long
Minimum intensity	6	6	6	6	6	6
Scan limit no. clicks logged	160	160	160	160	160	160
Version 4 T-POD (identification number 516)						
Scan	1	2	3	4	5	6
Target A filter frequency (kHz)	130	130	130	130	130	130
Ref. B filter frequency (kHz)	92	92	92	92	92	92
Click bandwidth	4	4	4	4	4	4
Noise adaptation	++	++	++	++	++	++
Sensitivity	6	6	6	6	6	6
Scan limit no. clicks logged	240	240	240	240	240	240

Table 1: T-POD settings used throughout study.

(a)

T_1	T_2	T_3	T_4
Civil twilight start	(2 x sunrise) – (civil twilight start)	(2 x sunset) – (civil twilight end)	Civil twilight end

(b)

Diel phase	Time of day
Morning	From T_1 to T_2
Day	From T_2 to T_3
Evening	From T_3 to T_4

Night	From T_4 to T_1 the following day
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Table 2: (a) Calculation of the four diel phases for input into the diel phase algorithm. T = start time. (b) Explanation of diel phases intervals.

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REFERENCES

- [1] J. Tougaard, J. Carstensen, O. D. Henriksen *et al.*, *Short-term effects of the construction of wind turbines on harbour porpoises at Horns Reef*, Technical report to TechWise A/S. HME/362-02662, Hedeselskabet, Røskilde, Denmark, 2003.
- [2] J. Carlström, "Diel variation in echolocation of wild harbour porpoises," *Marine Mammal Science*, vol. 21, pp. 1-12, 2005.
- [3] P. T. Madsen, M. Wahlberg, J. Tougaard *et al.*, "Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs," *Marine Ecology Progress Series*, vol. 309, pp. 279-295, 2006.
- [4] W. E. Schevill, W. A. Watkins, and C. Ray, "Click structure in the porpoise, *Phocoena phocoena*," *Journal of Mammalogy*, vol. 50, no. 4, pp. 721-728, 1969.
- [5] W. W. L. Au, "Transmission beam pattern and echolocation signals of a harbour porpoise (*Phocoena phocoena*)," *Journal of the Acoustical Society of America*, vol. 106, pp. 3699-3705, 1999.
- [6] B. Møhl, and S. Andersen, "Echolocation: high-frequency component in the click frequency of the harbour porpoise (*Phocoena ph. L.*)," *Journal of the Acoustical Society of America*, vol. 54, no. 5, pp. 1368-1372, 1973.
- [7] J. Teilmann, M. Miller, R. A. Kirkterp *et al.*, "Characteristics of echolocation signals used by a harbour porpoise (*Phocoena phocoena*) in a target detection experiment," *Aquatic Mammals*, vol. 28, pp. 275-284, 2002.
- [8] W. C. Verboom, and R. A. Kastelein, "Acoustic signals by harbour porpoises (*Phocoena phocoena*)," *Harbour Porpoises: Laboratory Studies to Reduce Bycatch*, P. E. Nachtigall, W. W. L. Au and A. J. Read, eds., pp. 1-39, Woerden, The Netherlands: De Spiel Publishers, 1995.
- [9] W. C. Verboom, and R. A. Kastelein, "Structure of harbour porpoise (*Phocoena phocoena*) click-train signals," *The biology of the harbour porpoise*, A. J. Read, R. W. Piet and P. E. Nachtigall, eds., pp. 343-362, Woerden, The Netherlands: De Spiel Publishers, 1997.
- [10] A. Villadsgaard, M. Wahlberg, and J. Tougaard, "Echolocation signals of wild harbour porpoises, *Phocoena phocoena*," *Journal of Experimental Biology*, vol. 210, no. 1, pp. 56-64, Jan, 2007.
- [11] W. W. L. Au, *The sonar of whales and dolphins*, New York, USA: Springer Verlag, 1993.
- [12] U. K. Verfuß, L. A. Miller, and H.-U. Schnitzler, "Spatial orientation in echolocating harbour porpoises (*Phocoena phocoena*)," *Journal of Experimental Biology*, vol. 208, pp. 3385-3394, 2005.
- [13] D. R. Griffin, *Listening in the dark*, New Haven, CN: Yale University Press, 1958.
- [14] V. L. G. Todd, and D. A. Waters, "Strategy switching in the trawling bat," *Journal of Zoology*, vol. 273, pp. 106-113, 2007.
- [15] M. Johnson, P. T. Madsen, W. M. X. Zimmer *et al.*, "Foraging blainville's beaked whales (*Mesoplodon densirostris*) produce distinct click types matched to different phases of echolocation," *Journal of Experimental Biology*, vol. 209, pp. 5038-5050, 2006.
- [16] U. V. Verfuß, L. A. Miller, and H. U. Schnitzler, "Comparing echolocation behaviour during orientation and foraging of the harbour porpoise (*Phocoena phocoena*)."
- [17] Author ed.^eds., "Harbour Porpoises: Laboratory Studies to Reduce Bycatch," Woerden, The Netherlands: De Spiel Publishers, 1995, p.^pp. Pages.

- [18] D. R. Stanley, and C. A. Wilson, "Factors affecting the abundance of selected fishes near oil and gas platforms in the Northern Gulf of Mexico," *Fishery Bulletin US*, vol. 89, no. 1, pp. 149-159, Jan, 1991.
- [19] J. G. Carlisle, C. H. Turner, and E. E. Ebert, "Artificial habitat in the marine environment," *Bulletin of the Department of Fisheries and Game in the State of California*, vol. 124, pp. 1-93, 1964.
- [20] E. A. Shinn, "Oil structures as artificial reefs," in Proceedings of an International Conference on Artificial Reefs, Texas A & M University, 1974, pp. 91-96.
- [21] A. V. Soldal, I. Svellingen, T. Jørgensen *et al.*, "Rigs-to-reefs in the North Sea: hydroacoustic quantification of fish in the vicinity of a "semi-cold" platform," *ICES Journal of Marine Science*, vol. 59, pp. S281-S287, Oct, 2002.
- [22] A. J. Guerin, A. C. Jensen, and D. Jones, "Artificial reef properties of North Sea oil and gas production platforms," in Oceans 2007 - Europe, Aberdeen, UK, 2007, pp. 795-800.
- [23] V. L. G. Todd, P. A. Lepper, and I. B. Todd, "Do porpoises target offshore installations as feeding stations?." p. 62.
- [24] F. Thomsen, N. van Elk, V. Brock *et al.*, "On the performance of automated porpoise-click detectors in experiments with captive harbour porpoises (*Phocoena phocoena*) (L)," *Journal of the Acoustical Society of America*, vol. 118, no. 1, pp. 37-40, 2005.
- [25] J. Tougaard, J. Carstensen, M. S. Wisz *et al.*, "Harbour porpoises on Horns Reef - effects of the Horns Reef wind farm," *Annual Status Report 2004 to Elsam Engineering A/S*, pp. 71, July 2005, 2005.
- [26] E. Philpott, A. Englund, S. Ingram *et al.*, "Using T-PODs to investigate the echolocation of coastal bottlenose dolphins," *Journal of the Marine Biological Association of the United Kingdom*, vol. 87, no. 1, pp. 11-17, 2007.
- [27] L. A. Kyhn, J. Tougaard, J. Teilmann *et al.*, "Harbour porpoise (*Phocoena phocoena*) static acoustic monitoring: laboratory detection thresholds of T-PODs are reflected in field sensitivity," *Journal of the Marine Biological Association of the United Kingdom*, vol. 88, no. 6, pp. 1085-1091, 2008.
- [28] M. Klinowska, "Diurnal rhythms in Cetacea: a review," *Reports of the International Whaling Commission*, vol. Special Issue 8, pp. 75-88, 1986.
- [29] T. M. Cox, A. J. Read, A. R. Solow *et al.*, "Will harbour porpoises (*Phocoena phocoena*) habituate to pingers?," *Journal of Cetacean Research and Management*, vol. 3, pp. 81-86, 2001.
- [30] R. A. Kastelein, S. H. Nieuwstraten, and W. C. Verboom, "Echolocation signals of harbour porpoises (*Phocoena phocoena*) in light and complete darkness," *Harbour Porpoises: Laboratory Studies to Reduce Bycatch*, P. E. Nachtigall, J. Lien, W. W. L. Au *et al.*, eds., pp. 55-67, Woerden, The Netherlands: De Spiel Publishers, 1995.
- [31] T. Akamatsu, T. Hatakeyama, H. Kojima *et al.*, "The rate at which a harbour porpoise uses echolocation at night," *Marine Mammal Sensory Systems*, J. A. Thomas, R. A. Kastelein and A. Y. Supin, eds., pp. 299-315, New York, USA: Plenum Press, 1992.
- [32] M. B. Santos, "Feeding ecology of harbour porpoises, common and bottlenosed dolphins and sperm whales in the northeast and Atlantic. Ph.D. thesis," School of Biology, University of Aberdeen, Aberdeen, Scotland, 1998.
- [33] C. Vergeer, "MSc thesis: Harbour porpoise (*Phocoena phocoena*) and herring (*Clupea harengus*) in Southern North Sea. A study into seasonal movements and prey," M. Sc., Centrum voor Milieuwetenschappen Leiden, CML Afdeling Industriële Ecologie, University of Leiden, Leiden, The Netherlands, 2006.
- [34] ICES, *Report of the ad hoc group on sandeel*, ICES, Copenhagen, Denmark, 2007.
- [35] P. R. Winslade, "PhD Thesis: Behavioural and embryological investigations of the lesser sandeel (*Ammodytes marinus*)," Ph.D., University of East Anglia, Norwich, UK, 1971.
- [36] S. Freeman, S. Mackinson, and R. Flatt, "Diel patterns in the habitat utilisation of sandeels revealed using integrated acoustic surveys," *Journal of Experimental Marine Biology and Ecology*, vol. 305, no. 2, pp. 141-154, 2004.
- [37] J. H. S. Blaxter, and F. G. Holliday, "The behaviour and physiology of herring and other clupeids," *Advances in Marine Biology*, vol. 1, pp. 261-393, 1969.
- [38] H. K. Lotze. Rise and fall of fishing and marine resource use in the Wadden Sea, southern North Sea. *Fisheries Research*, 87: 208-218, 2007.