Short-term effects of the construction of wind turbines on harbour porpoises at Horns Reef

Technical Report to Techwise A/S

Kunde

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Revisions nr.	2
Godkendt af	Preben Boock
Udgivet	9. april 2003

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Please cite this report as: Tougaard, J., Carstensen, J., Henriksen, O.D., Skov, H. and Teilmann, J. (2003): *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, Roskilde.

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1 Summary

In 2002 the Worlds largest offshore wind farm, consisting of 80 2MW wind turbines, was constructed on Horns Reef in the Danish North Sea. Ship based visual surveys and long-term deployment of acoustic dataloggers (PODs) were used to assess short term effects of construction on behaviour and abundance of harbour porpoises (*Phocoena phocoena*). Most focus was put on mounting of steel monopile foundations for the turbines, as they were rammed into the seabed. This type of operation is known to generate very loud underwater sound levels.

Combined evidence from animal densities obtained from visual surveys, behavioural observations during surveys and acoustic activity data in and outside the construction area demonstrated effects on the behaviour and abundance of animals on both short-term (hours) and long term (entire construction period) scales. Acoustic activity by the porpoises decreased dramatically on the entire Horns Reef at the onset of ramming operations and returned to higher levels a few hours after each ramming operation was completed. A reduction in abundance close to ramming operations was anticipated, as deterring devices (pingers and seal scarers) were deployed prior to each ramming operation to deter marine mammals from the area and thus protect them from exposure to the lound sound levels generated by the ramming procedure. The changes in abundance and behaviour over large distances are unlikely to be explained by the deterring sounds, which have comparably lower intensities than the ramming sounds and these effects must be attributed to the ramming.

A general effect on the behaviour of animals was seen during the construction period and at distances of up to 10-15 kilometers from the construction site. Compared to observations before and after construction there was a decrease in non-directional swimming, a behaviour assumed to correlate with feeding activity. Animal density estimates indicates that there were fewer animals present on the entire Horns Reef during the construction period compared to observations before and after the construction phase. Whether these changes are attributtable to the construction activities or are related to overall temporal variation cannot be determined without further observations in the post-construction period.

2 Introduction

In 2002 ELSAM constructed the Horns Reef wind farm in the North Sea approx. 15 km off shore, west of Blåvandshuk. The wind farm with a capacity of 160 MW is the largest offshore wind farm in the world and the first in the North Sea. It consists of 80 Westas V80 2.0 MW turbines mounted on steel monopile foundations, which were rammed into the seabed. Construction started in March 2002, the last turbine was mounted in August 2002 and all turbines were in operation in December 2002.

A wide range of environmental monitoring programs was initiated with the decision to build the park. These include monitoring of benthic fauna, fish, birds and marine mammals. This report deals specifically with harbour porpoises and will focus on the short-term effects of the construction of the park in 2002. Monitoring will continue and subsequent reports will focus on possible long-term effects of the park on harbour porpoises.

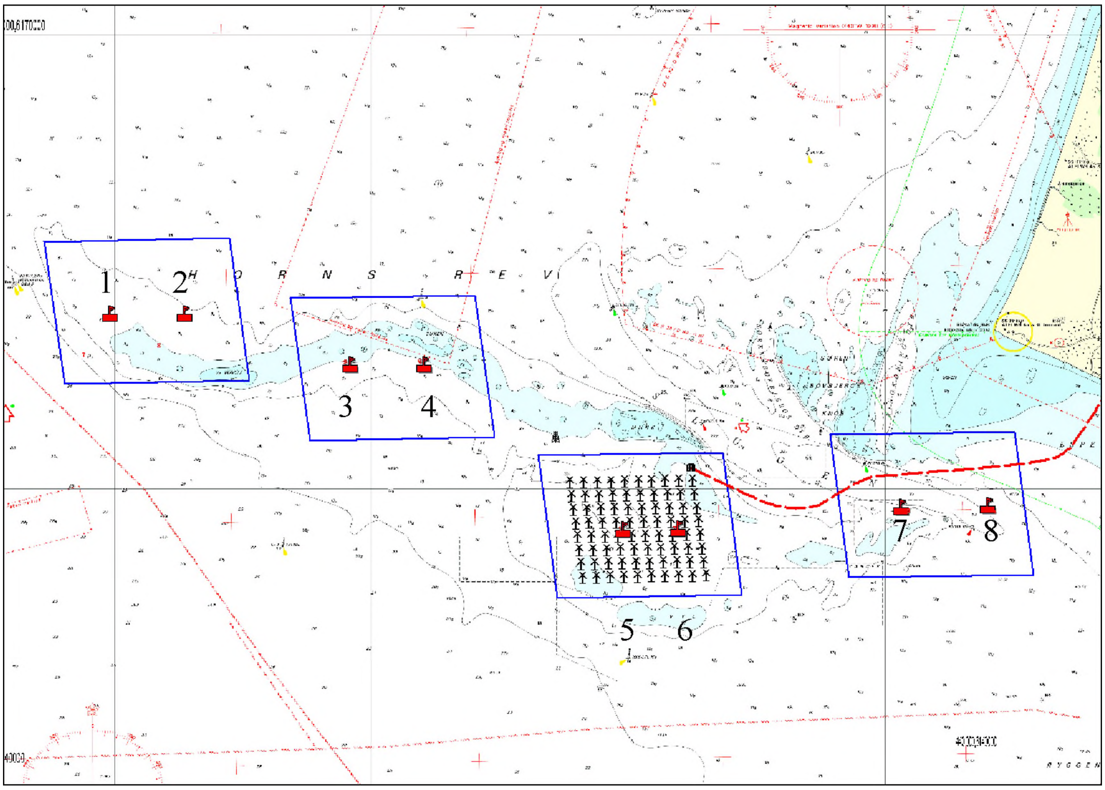


Figure 1. Horns Reef with the wind farm and reference areas (one impact area containing the turbines and three reference/control areas). Red flags indicate positions of acoustic dataloggers (PODs) and red dashed line indicate the power cable to land.

3 The investigations of harbour porpoises at Horns Reef

Previous studies of harbour porpoises at Horns Reef were conducted in connection with the Environmental Impact Assessment (EIA, Skov et al, 2000) and in 2001, where baseline data were collected for subsequent evaluation of the influence of the park. The latter results are reported in Skov et al. (2002). Two techniques are used: visual surveys and stationary deployments of acoustic dataloggers (PODs).

3.1 Ship-based surveys

Surveys are conducted with several objectives, each influencing the particular survey design and choice of methodology. Aims include obtaining estimates of relative population size and descriptions of variation and changes in animal densities, both temporally and spatially. For the current investigation most effort has gone into describing the distribution of harbour porpoises in the survey area and less focus has been on obtaining accurate figures on population size. The central questions for this investigation deals with possible effects of the wind turbines on distribution, both on a short time scale (during construction) and a longer, possibly permanent scale.

Visual surveys for sea birds, with concurrent recordings of marine mammals, were conducted at Horn's Reef area since 1987 and surveys directly aimed at harbour porpoises have been conducted from 1999 and onwards in connection with the wind farm project. A main conclusion from these surveys is strong indications of a correlation between porpoise abundance and large-scale hydrographical features. Horns Reef is located in an area where relatively brackish water from the German rivers flowing into the Wadden Sea mix with the more saline water masses of the North Sea. Harbour porpoises appears to favour this estuarine frontal zone where mixing occurs, in line with what has been shown for species of piscivorous sea birds (Skov and Prins, 2001).

3.2 Acoustic dataloggers (PODs)

The biosonar signals of harbour porpoises are well suited for automatic monitoring. The signals are extremely stereotypic, of short duration and narrow bandwidth. Practically all energy is above 100 kHz, with a centre frequency of 125-130 kHz. Duration is between 50 µs and 200 µs. An example is shown in Figure 2. The narrowband nature of the signals and the fact that there is little background noise in the sea above 100 kHz makes the signals ideal for detection by a sharp band-pass filter.

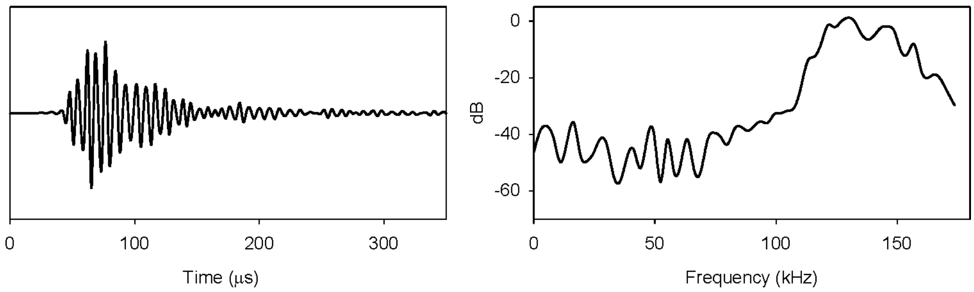


Figure 2. Typical sonar signal from a harbour porpoise. Left: time signal, right: power spectrum.

A porpoise detector (POD) developed by Nick Tregenza, UK, is used for stationary monitoring of harbour porpoises. This detector is a battery operated, self-contained unit, consisting of a sensitive hydrophone, a set of six adjustable filters and 8 Mb memory for storage of logged activity. The filters are set up to listen for particular types of signals, primarily harbour porpoises, but also other frequency bands can be scanned in order to separate harbour porpoise activity from background noise, ship noise, boat sonars and other underwater sounds, including other species of marine mammals. Filters are scanned sequentially and activity in any one filter exceeding an adjustable threshold is logged with information on signal parameters as well as time of the event. Up to several months of events can be stored in the unit, depending on the settings and the activity in the area where the POD is deployed.

3.3 Acoustic surveys (towed POD)

Several inherent problems are present for ship based visual surveys for harbour porpoises, all linked to the difficulties of observing diving animals at sea. A strong dependence on weather in observations is present and observations above sea state 2 are generally not reliable, as detection rate is too low (Teilmann in press). Even in calm weather all animals may not be observed, as the animals spend most of their time submerged and duration of each surfacing is often only 1-2 seconds.

Acoustic monitoring during visual surveys, performed by towing hydrophones after the ship and continuously monitor for possible porpoise sonar signals, could potentially give additional data on porpoise density. Ideally one would use a towed array of two or more hydrophones, but equipment for this was not commercially avilable in 2002. In an experimental approach to develop a towed acoustic monitoring system, the feasibility of monitoring with a single POD towed behind the survey ship was tested.

3.4 Expected effects of wind farms on harbour porpoises

In the Environmental Impact Assessment study preceding the permission to build the wind farm two types of effects of the turbines on harbour porpoises were outlined: Expected short-term effects during construction phase and possible long-term effects during the operational phase.

3.4.1 Construction phase

The turbines are raised through a series of steps. First a layer of pebbles is placed on the seabed on the position where the turbine is to be placed. Then the steel monopile foundation is rammed into the seabed with a hydraulic hammer, a fitting section mounted and finally the turbine is erected. Alongside cables are drawn between turbines and transformer platform and a layer of protective boulders placed on the seabed around the monopile foundation.

Figure 3. Jack-up rig Buzzard during ramming operation

All activities involve ship traffic, both with larger ships and jack-up rigs as well as smaller fast-going ships for crew transport. Unfortunately ship traffic during construction of the wind farm was not recorded systematically and therefore the effect from ship traffic could not be assessed.

Increased ship traffic in the area is likely to have affected harbour porpoises to some degree, but the most disturbing activity is no doubt the ramming of monopiles into the seabed. This procedure generates high intensity sounds, potentially able to cause permanent hearing damage to marine mammals and likely to affect animals over larger distances (entire wind farm area and possibly beyond, Henriksen et al. 2000). Main focus has thus been given to possible effects of this particular type of activity.

3.4.2 Mitigations

Mitigations aimed at reducing the risk of inflicting permanent hearing damage to marine mammals were adopted during ramming procedures. Two types of procedures were used. In the first period (from March 30th to April 12th) a ramp up procedure was followed, which consisted of 2-3 light blows to the monopile followed by a 2 minute break, all repeated three times. The ramming then proceeded with gradually increasing energy. This procedure generates sounds of high intensity, yet still within safe limits and allows for escape of any seals or harbour porpoises close to the ramming site.

In the remaining period (April 14th and onwards) acoustic warning/deterring devises were employed. These consisted of a porpoise pinger (Aquamark100) mounted on each of the anchors of the ramming rig (Buzzard) and automatically activated when the anchors were set about 1,5 hours prior to ramming operations. In addition a single seal scaring device (Lofitech) was lowered from the ramming rig about 0,5 hours prior ramming.

Aquamark pingers emit a broadband frequency modulated signal with peak energy around 70 kHz and are designed and known to deter porpoises from bottom set gill nets. The Lofitech seal scarer emits a sound of significantly higher intensity than the pingers and are designed to deter seals from fishing gear and aquaculture installations.

4 Methods

4.1 Visual surveys

4.1.1 Investigation of distribution responses

The central questions for this investigation deals with possible effects of the wind turbines on distribution of harbour porpoises on a short time scale (during construction). Two types of surveys have been conducted: regular and additional surveys. In the regular line transect surveys the same set of parallel transect lines is sailed on all surveys, assuring even coverage of all areas and direct comparability between surveys (Figure 4). In addition, surveys lines are laid out *ad hoc* in order to maximise the number of animals observed and conduct behavioural observations (see below). Survey data have been utilised to compare the difference in the density of animals just before, during and just after the construction phase with focus on the changes in relation to periods where ramming operations took place.

A total of 12 surveys were made between 12 March 2002 and 18 March 2003 (see Table 1 in results section), of which eight were regular surveys. One survey was carried out on the 12 March 2002 before the construction activities started. During the ramming phase of the construction period, monthly surveys were made in March, April and May 2002. During the last part of the ramming phase in late July and beginning of August 2002 the day to day variation in the distribution and behaviour of harbour porpoises at Horns Reef was followed closely. After the ramming activities ceased one survey was made in August 2002, followed by a pause of almost six months due to the close down of the environmental investigations in September 2002. After the investigations resumed in 2003 two surveys were made in February and March.

The survey design allowed for the determination of the fine-scale distribution of animals, which was mapped over a one-day survey. Relative densities of harbour porpoises were sampled along 12 east-west running transect lines (Figure 4). A relatively high resolution of the data was achieved by dividing each transect into segments of 2 time minutes (approximately equivalent to 500 m transect distance). Each segment constituted a sample of relative density within 800 m perpendicular distance. The distance between lines was 1.25 nautical miles. In addition to the estimation of fine-scale distribution patterns the surveys were also used to produce estimates of the relative abundance of harbour porpoises in the surveyed area. The surveys were made using line transect methodology following standards developed during the base-line investigation (Skov et al. 2000, Skov et al. 2002).

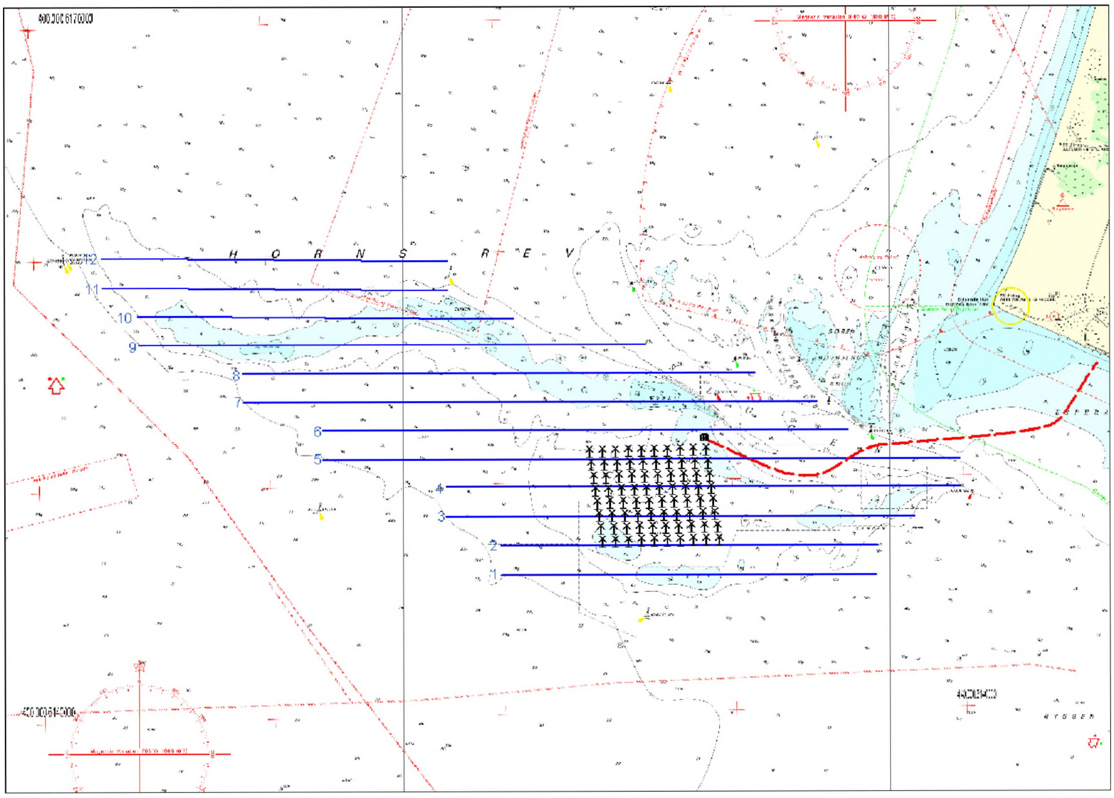


Figure 4. Transect lines used in the study of distributional responses (blue lines).

4.1.2 Behavioural responses

In order to describe possible reactions from the harbour porpoises on the noise emissions from the ramming operations behavioural observations were carried out. It was envisaged that possible behavioural reactions of harbour porpoises to the noise emissions would include strong escape reactions at close range and interrupted feeding activities out to distances of several kilometres. Behavioural characteristics of the animals, in particular feeding activity and type and direction of movements were determined by sailing at low speed along lines oriented in a zigzag pattern towards the ramming site, scematically illustrated in Figure 5. Lines were laid out after regular surveys had provided information on areas with high densities of porpoises. Actually sailed lines are shown in Figure 8 in results section.

The following codes were used for harbour porpoise behavioural responses:

Directional	Calm movement with clear direction
Non-directional	Calm movement without clear direction (foraging)
Logging	Calm rest at the surface
Porpoising	Rapid swimming near the surface

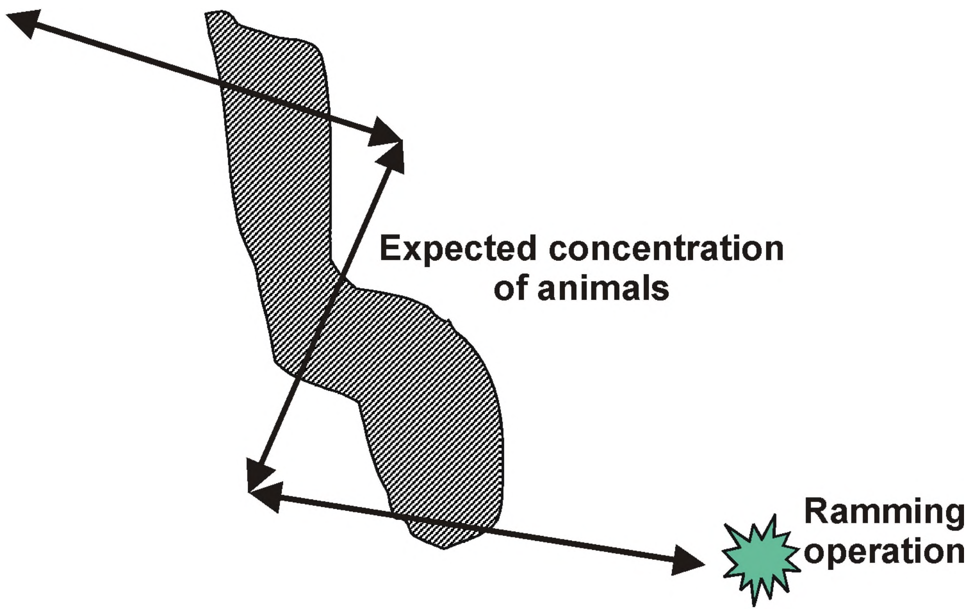


Figure 5. General layout of additional survey lines for behavioural observations, aimed at maximising number of observed animals during ramming operations.

In order to evaluate possible differences in behaviour with distance from ramming operations, the distance to the centre of the wind farm was calculated for all observations and observations grouped into four distance categories. Categories were arbitrarily selected to assure an approximately even distribution of observations across classes. The four classes were below 5.4 nautical miles (10 km), between 5.4 and 8 nautical miles (10-15 km), between 8 and 11 nautical miles (15-20 km) and above 11 nautical miles (20 km) from centre of wind farm.

Behavioural observations were conducted on surveys before ramming commenced, during ramming and after ramming was completed. Data were grouped into observations during ramming operations (March 30th to August 2nd) and outside (before and after).

4.1.3 Collection of hydrograpical data

One CTD station (Anderaa RCM 9), which logged temperature and salinity was deployed at 10 m depth in the construction area, and has measured temperature and salinity with 10-minute intervals. At 13 March 2002 the CTD was lost, and was replaced by mid July 2002. The spatial hydrographic variability encountered during ship surveys was recorded by continuous measurements of temperature and salinity at a depth of approximately 3 m using a calibrated salinometer (WTW LF340). In order to collect more information on the large-scale variability in hydrography, especially of the oscillation of the Continental Coastal Current, NOAA AVHRR SST data with a spatial resolution of 1.1 km were delivered by Geographic Resource Analysis and Science A/S at the Institute of Geography University of Copenhagen. A total of 14 scenes (both day and night scenes) were selected from the survey periods. The SST data were processed and geo-referenced to UTM 32 - WGS 84. Clouds were masked following manual checking and correction. Surface temperatures were determined by applying NOAA/NESDIS global operational algorithms (NLSST splitwindow for day scenes and NLSST Tripple window for night scenes).

4.1.4 Geo-statistical analyses

Densities of harbour porpoises were calculated for each transect segment using a general probability of observation (Buckland et al, 1993) within the scanned transect area of 0.39 (95% confidence interval 0.36-0.42), which was derived from analyses of sighting distances from all regular surveys by using the uniform model with cosine adjustments in DISTANCE (Laake 1993, Ver. 4.2). DISTANCE was also used for estimation of total abundance for each survey (see below). Sighting rates change considerably with Beaufort sea state. Therefore, only data collected during sea state 2 or less were used for analysis.

Analysis of the spatial continuity in the distribution of harbour porpoises and salinity as reflected by the data obtained during the surveys was made on the basis of variogram models fitted to experimental variograms. Corrected densities of harbour porpoises were log-transformed (log10 (n +1)) before analysis. Several models including nugget effect were tested visually, including nesting of variograms before deciding on the selection of the spherical model with a nugget effect for harbour porpoise data and on linear models for the salinity data. Anisotropy ratios and angles were determined by the Autofit module in Surfer 8.0. Interpolation was made by using ordinary kriging on the selected variograms at a resolution of 0.5 km. As the variograms of the densities of harbour porpoises were non-linear and all showed a clear range structure, the range parameter was used to constrain extrapolation from sample segments. The resulting interpolated grid of harbour porpoise densities consisted of continuous fields of density grid points for the well-surveyed parts of the study area, and blanked grid points for those parts of the area where the distance between samples exceeded the maximum extrapolation range. The spatial distribution pattern was plotted on maps in UTM 32 N projection by assigning contours and colour codes to the density grid points.

4.1.5 Line transect population estimation

Total estimates of the abundance of harbour porpoise in the investigation area during each regular survey were made using the model for general detection described above in DISTANCE (Ver. 4.2). Several perpendicular line transect models were evaluated, using Akaike's Information Criterion (AIC), and the model with the smallest AIC value was selected (Buckland et al, 1993). Perpendicular distances to porpoises were pooled into intervals of 50 m. The relationship between distance of sightings and pod size was assessed by making a regression of pod size (after log transformation) on distance. The correlation was non-significant ($p<0.01$) in all cases, hence no adjustments were made to f(0) for pod size bias.

4.1.6 Statistical tests of survey data

Statistical tests were made in order to assess large scale differences in abundance of harbour porpoises before and during the ramming phase. Log-transformed corrected densities of harbour porpoises within four areas separated by approximately 5 km distance were compared between these two periods by means of generalised linear modeling. The four areas, of which the first three can be regarded as reference areas, were defined as:

Western edge of Horns Reef (west of 7°13’ E)

Central part of Horns Reef (between 7°13’ E and 7°20’ E)

Slugen (between 7°35’ and 7°40’ E)

Wind farm area.

We hypothesise that due to the magnitude of sound emissions from the ramming operations the abundance of harbour porpoises will be negatively affected near the wind farm area during the whole period, when ramming took place. We tested for differences between the period before ramming operations started (base-line data and 12 February 2002) and the period during the ramming operations (March – August 2002). We assumed no marked seasonal pattern of abundance. Effects for all four areas combined (general effects on the whole survey area) were determined by using the concurrent salinity measurements as a covariate.

We used the kriged data as input to the statistical tests in order to minimise spatial auto-correlation effects. The geostatistical analysis (kriging) of log-transformed corrected densities of harbour porpoises produced surfaces of continuous (interpolated) values. Statistical tests based on links between interpolated grids typically produce invalid correlation coefficients and unrealistically high P-values. To account for this we constructed a sub-sample of the GIS coverages in Idrisi32 by filtering the grid cells which overlapped the survey lines, and retained the filtered data for analysis.

4.2 Towed POD

In addition to visual surveys the feasibility of using towed PODs to detect porpoises acoustically during surveys was tested. During 8 of the visual surveys a POD was towed after the survey boat (Table 10, results section). The POD used for towing was a more sensitive version (T-POD2) than the permanently deployed PODs (T-POD).

During surveys the POD was towed in a rig approximately 200 meters behind the survey boat. The rig was made of 8 mm nylon rope, a float to keep the POD from going too deep and a downrigger sledge to keep the POD at a certain depth (Figure 6).

The construction is very flexible and could be towed at speeds up to 15 knots, although only 10 knots was used in this study to reduce the wiggling of the POD in the water. The towed POD is orientated horizontally in the water.

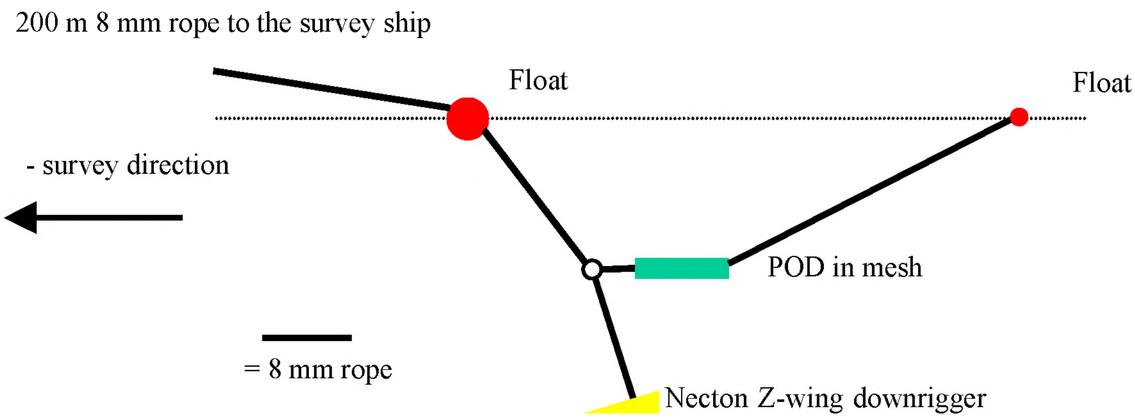


Figure 6. Drawing of the POD towing rig used for the acoustic surveys. The aft float was only used on some surveys, as it was found not to contribute significantly to stability.

The sensitivity of the POD used for towing was compared to the deployed PODs in a calibration procedure in an indoor tank (Teilmannet al, 2002) and found to be within normal ranges. Compared to the stationary PODs the filter settings were altered from deployment to deployment to obtain the best signal-to-noise ratio. The towed POD experiences a substantially higher background noise level than the moored POD, due to flow noise and general high level of turbulence around the towed POD.

Due to the relatively short duration of the surveys (compared to the long deployments of the stationary POD), all data sets were analysed manually and every click train evaluated and compared with results from the visual surveys. For each survey all click trains were logged. Each train was then manually validated and positive harbour porpoise click trains noted.

Since the POD does not have the ability to separate different porpoises within an encounter but only gives an indication of the presence of at least one porpoises, the acoustic data obtained from the POD is compared with the number of porpoise sightings (i.e. groups) rather than the actual number of porpoises seen.

4.3 Stationary PODs

The methods used for long-term deployment of PODs in the Horns Reef area have been described extensively in previous reports (Skov et al, 2002; Teilmann et al, 2002). Only a short introduction is given here as well as information on the changes in deployment design and data handling.

4.3.1 Deployment of PODs

Compared to the period covered by the previous status report (2001 season) a few changes were made in the handling of the PODs. Deployment of PODs on position 8, which is the innermost position on the eastern side of Slugen has been discontinued and thus only 7 positions have been monitored. PODs deployed on position 8 were extremely vulnerable to damage from fishing vessels operating in the area and after several instances of either direct vandalism or accidents resulting in loss of buoys and PODs it was decided to withdraw the equipment and skip the position.

Steel cages for mounting PODs implemented in the spring 2002 are now in use on all positions with good results. No PODs mounted in cages has disappeared. Nevertheless, problems related to mounting the POD in the cage and retrieval of the case have resulted in the loss of two PODs. One was lost due to an accident during a service visit and one POD was mounted incorrectly and consequently broke into two pieces.

From January 2003 two new PODs (T-POD3) with higher sensitivity deployed together with old T-PODs to intercalibrate the data obtained from the two versions of the PODs.

Problems during the regular service visits to the PODs, scheduled at 60-days intervals as well as other factors has resulted in considerable periods where data were not collected, as described in the results. Unfortunately, this weakens the power of conclusions that can be drawn on impact of the construction activities.

Programming of filters in the PODs was still under development at the time of submission of the last status report (Skov et al, 2002). Settings are now well tuned to the environment at the Horns Reef and the 8 MB memory is now sufficient for collecting data for two months, about the longevity of the Li-Ion batteries used

4.3.2 Indicators of harbour porpoise activity

Four indicators have been derived from POD signals. The T-POD program extracts the number of porpoise clicks for every minute – denoted x_t . These files always contain relatively few observations above zero. The recorded activity is aggregated into daily observations of:

$$\text{Click frequency} = \frac{\text{Number of minutes with clicks}}{\text{Total number of minutes}} = \frac{N\{x_t > 0\}}{N_{total}}$$

$$\text{Click intensity} = \frac{1}{N\{x_t > 0\}} \sum_{x_t > 0} x_t$$

Another approach to analyse POD signals is to consider periods with click activity as events separated by periods without activity. Here, click events are defined as periods with click activity separated by periods with no click activity for more than 10 minutes. Thus, two recordings separated by 9 minutes without click activity are still considered to belong to the same event. The choice of 10 minutes for separating events was found to be an appropriate limit for separating independent visits by porpoises. The events provided two indicators to characterise the harbour porpoise activity: duration of click event and waiting time between click events. The mean click intensity during an event did not provide any additional information relative to the daily intensity.

All indicators except the event duration could be made approximately normally distributed by transforming the data. Daily intensity and waiting time was log-transformed while an arc-sin was applied after squareroot transformation of the daily frequency data.

5 Results

5.1 Surveys

Surveys were conducted throughout the period, with a total of 17 surveys days. Table 1 presents an overview of the surveys.

Table 1. Surveys conducted during construction phase from March 2002 to March 2003. Surveys marked with "A" were sailed along ad hoc lines, the rest along the predefined lines L1-L12.

Survey	Ship	Date	Time	Lines	Porpoise sightings	Porpoises total	Seal sightings	Seals total
S02N01	M/S Alice Becker	12-03-2002	7:58-18:32	1,3,5,6,7,8	11	13	4	4
S02N02	M/S Gitte Iversen	23-03-2002	6:52-18:50	1,2,3,4,5	10	14	0	0
S02N03	M/S Gitte Iversen	24-03-2002	6:00-16:38	12,11,10,9,8,7,6,5	30	49	5	5
S02N03A	M/S Gitte Iversen	24-03-2002	16:42-19:04	Behaviour	31	96	9	9
S02N04	M/S Gitte Iversen	20-04-2002	7:48-20:40	1,2,3,4,5,6,7,8,9	30	63	19	19
S02N05	M/S Gitte Iversen	21-04-2002	16:32-19:32	4,5,6	2	3	4	4
S02N05A	M/S Gitte Iversen	21-04-2002	6:22-13:26	Behaviour	54	80	22	22
S02N06	M/S Christoffer	08-06-2002	10:21-20:54	1,2,3,4,5,6,7	1	1	1	1
S02N07	M/S Christoffer	09-06-2002	5:26-9:12	8,9,10	3	4	1	1
S07N07A	M/S Christoffer	09-06-2002	9:18-16:04	Behaviour	1	1	2	2
S02N08	M/S Gitte Iversen	28-07-2002	6:50-21:13	1,2,3,4,5,6,7,8.9,10	54	143	11	15
S02N09A	M/S Gitte Iversen	29-07-2002	9:42-20:02	Behaviour	29	89	4	4
S02N10A	M/S Gitte Iversen	30-07-2002	6:04-19:16	Behaviour	92	287	10	10
S02N11A	M/S Gitte Iversen	31-07-2002	9:12-20:23	Behaviour	38	94	8	8
S02N12A	M/S Gitte Iversen	01-08-2002	8:50-21:40	Behaviour	70	151	16	16
S02N13A	M/S Gitte Iversen	02-08-2002	6:06-13:23	Behaviour	4	5	4	4
S02N14	M/S Christoffer	08-08-2002	6:09-20:59	1,2,3,4,5,6,7,8,9,10	96	306	17	17
S03N01	M/S Christoffer	12-02-2003	8:00-17:06	1,2,3,4,5,6,7	8	13	1	1
S03N02	M/S Christoffer	13-02-2003	8:00-14:48	8,9,10,11,12	5	10	0	0
S03N02A	M/S Christoffer	13-02-2003	14:48-17:05	Behaviour	2	4	1	1
S03N03	M/S Christoffer	18-03-2003	6:50-18:22	1,2,3,4,5,6,7,8.9,10	12	15	1	1

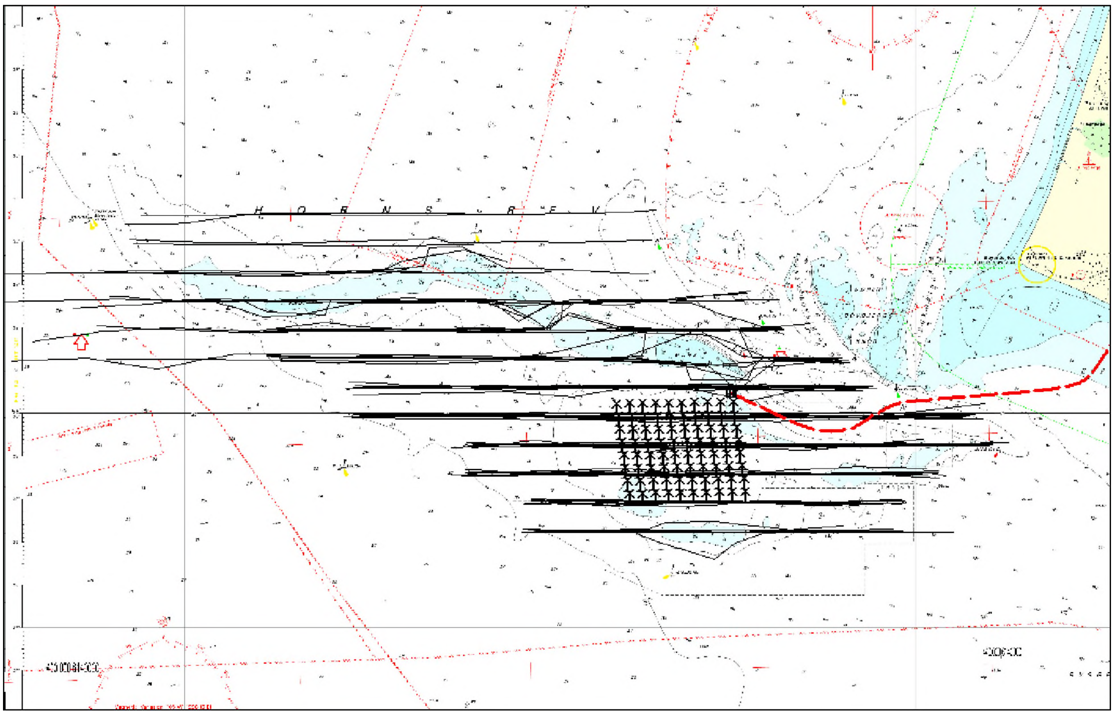


Figure 7. Survey effort - regular surveys. All actually sailed lines in 2002 and 2003 are shown (dates: 12.3.2002, 23-24.3.2002, 20-21.4.2002, 8-8.6.2002, 28.7.2002, 8.8.2002, 12-13.2.2003 and 18.3.2003).

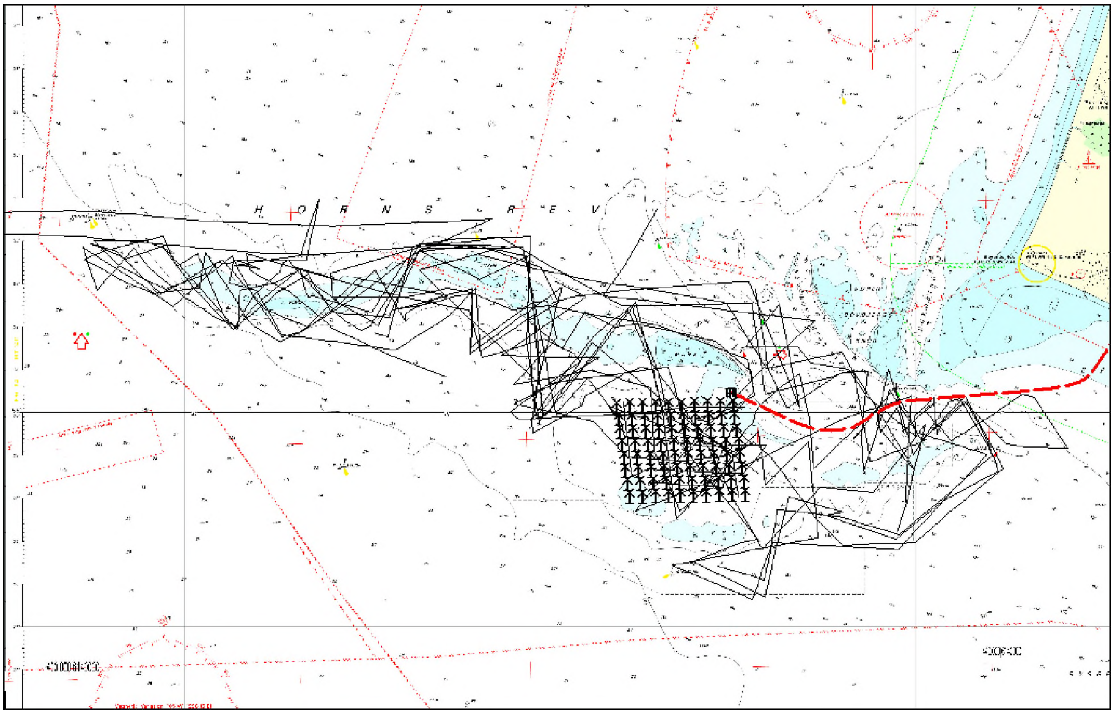


Figure 8. Survey effort - additional surveys. All *ad hoc* lines sailed in 2002 and 2003 are shown (dates: 24.3.2002, 21.4.2002, 9.6.2002, 29.7-2.8.2002 and 13.2.2003).

5.1.1 Hydrographic variability

The hydrographic data, as reflected by both the CTD station, the surveys and the SST images, show a significant inflow of estuarine water masses from the rivers in the German Bight during the whole investigation period. This is indicated both by relatively low salinities for the wind farm area and by the width of surface waters with low salinities (< 30 psu) and relatively high temperatures in both winter and summer. The variability displayed by the CTD station shows oscillations occurring over one to two weeks associated with cyclonic/anti-cyclonic periods (Figure 9). The frontal oscillation is apparent in the kriged survey data (figure 10), except for the extraordinary stable period between 28 July and 8 August 2002.

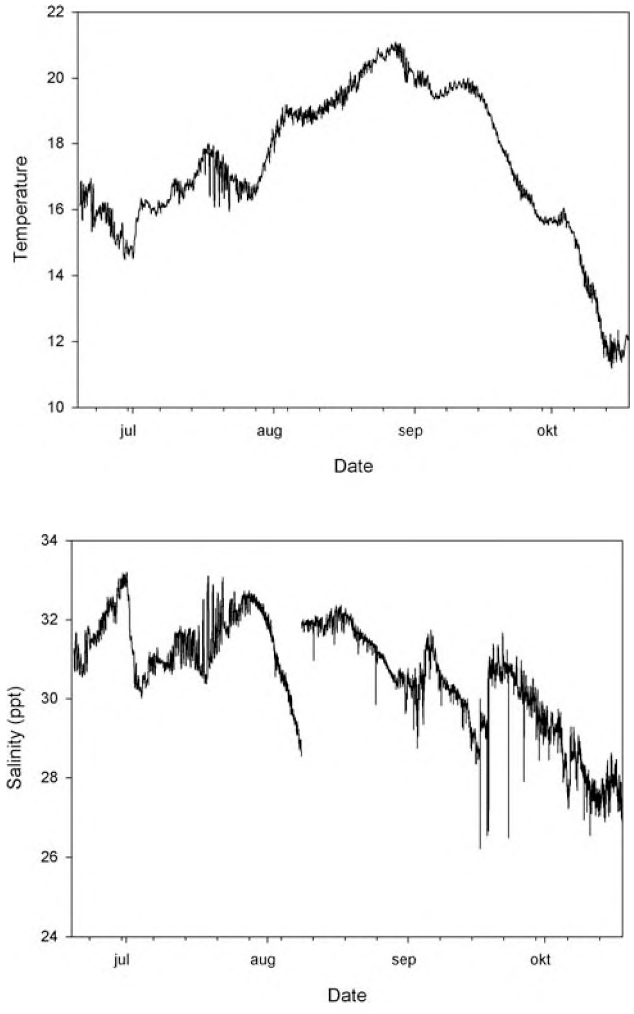


Figure 9. Distribution of salinity and temperature at 10 m depth in the wind farm area between 15 June and 15 October 2002. The graphs shows values measured with 10 minute intervals. Both graphs have a jagged appearance, which is due to small-scale oscillations caused by the tides. Small and large ticks on x-axis indicate weeks and months, respectively.

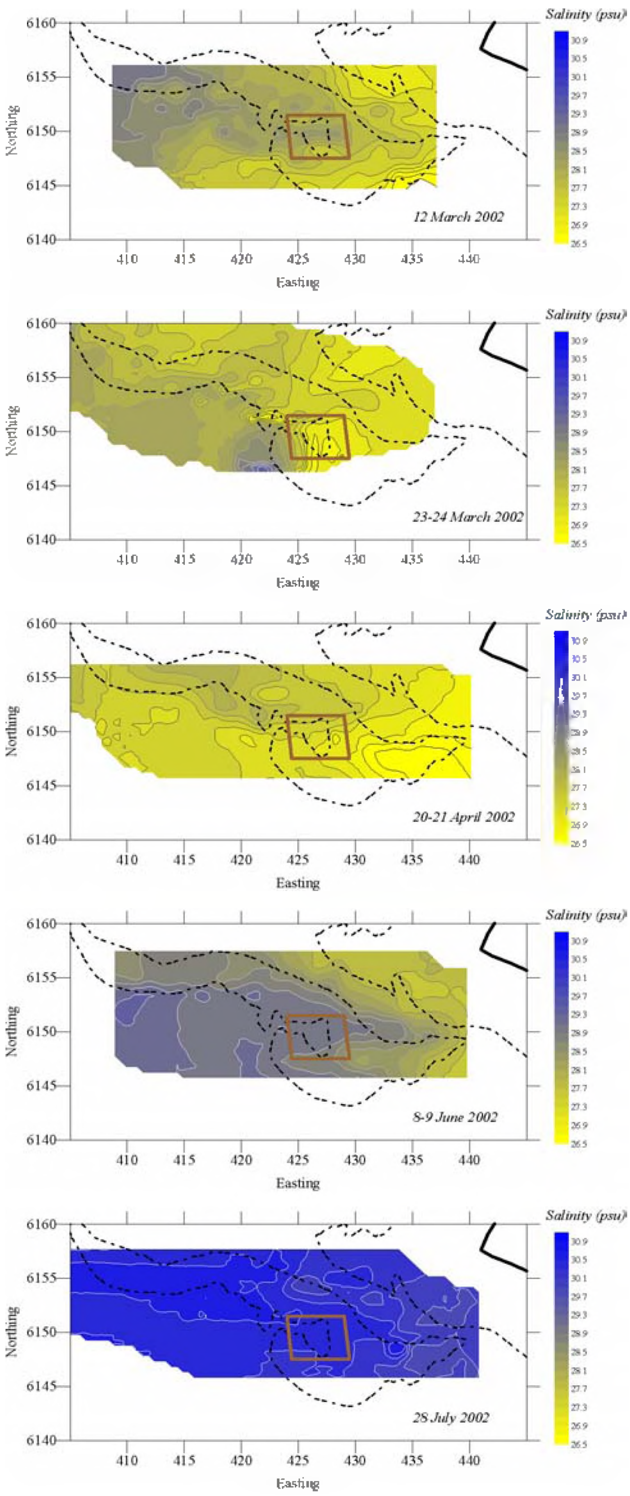


Figure 10. Spatial models (kriging) of the distribution of surface salinity during the 12 surveys. Salinity of surface water (2-3 meters depth) was measured continously on surveys.

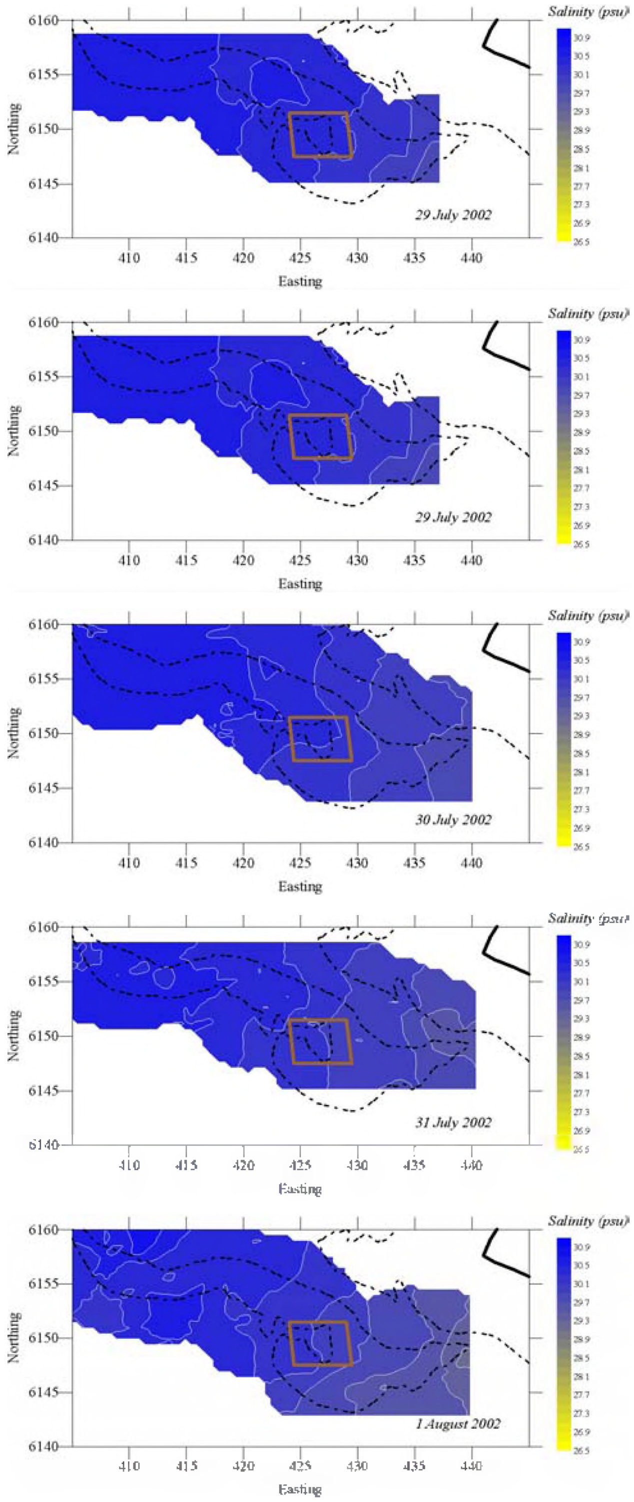


Figure 10 (cont.)

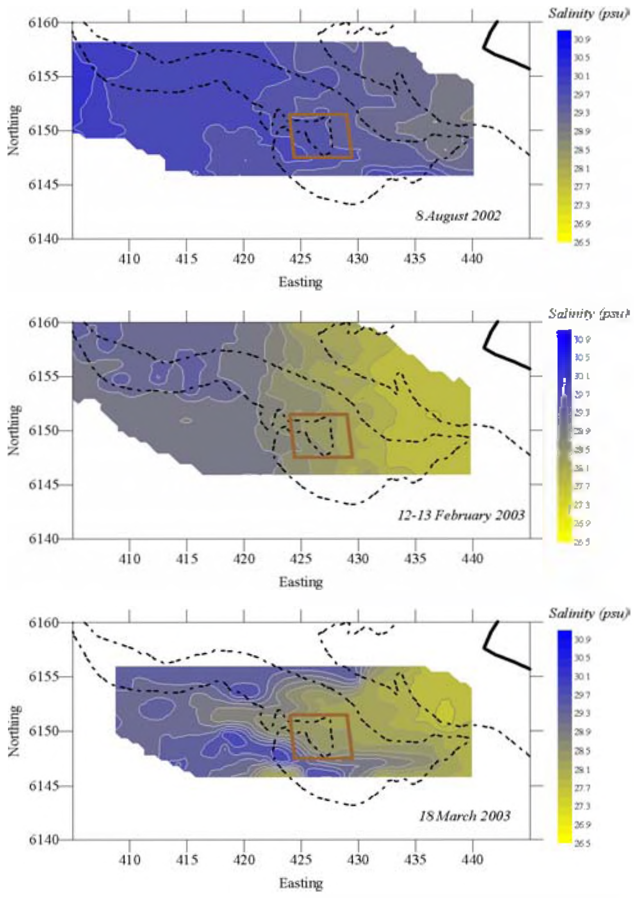


Figure 10 (cont.)

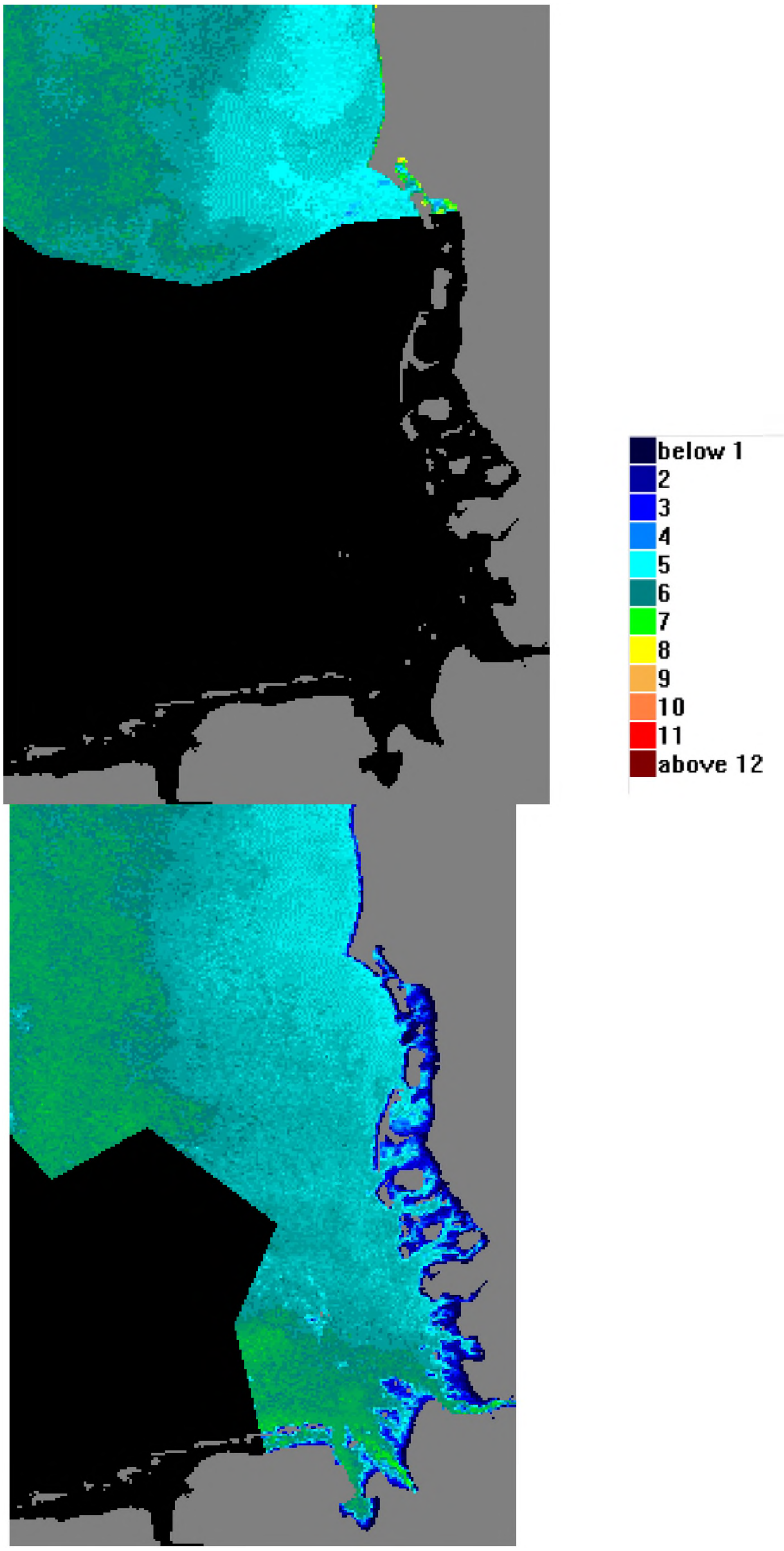


Figure 11. Surface sea temperature image from March 15th 2002 (top) and March 23th 2002 (bottom). Black areas were invisible due to clouds.

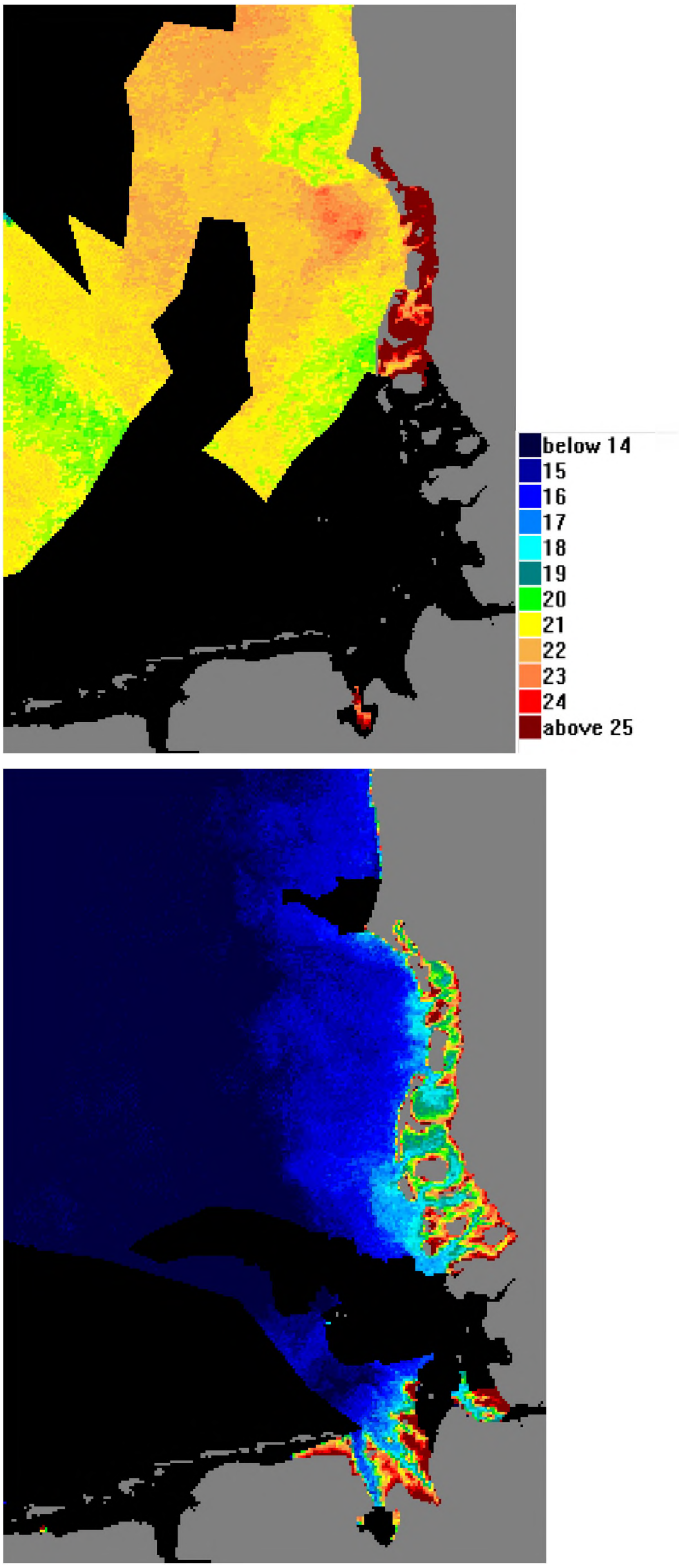


Figure 12. Surface sea temperature image from April 20th. 2002 (top) and June 8th 2002 (bottom).

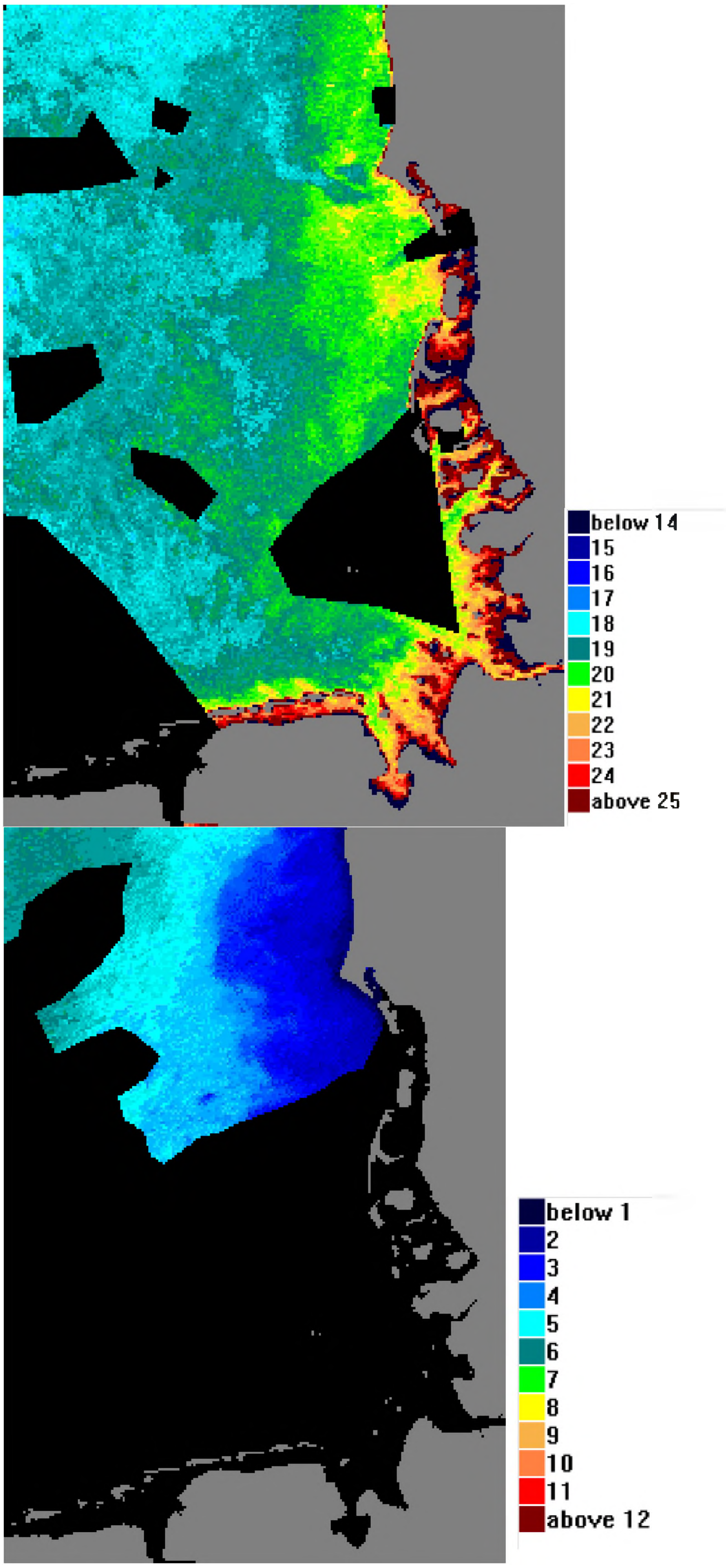


Figure 13. Surface sea temperature image from July 31st (above) and February 13th 2003 (below).

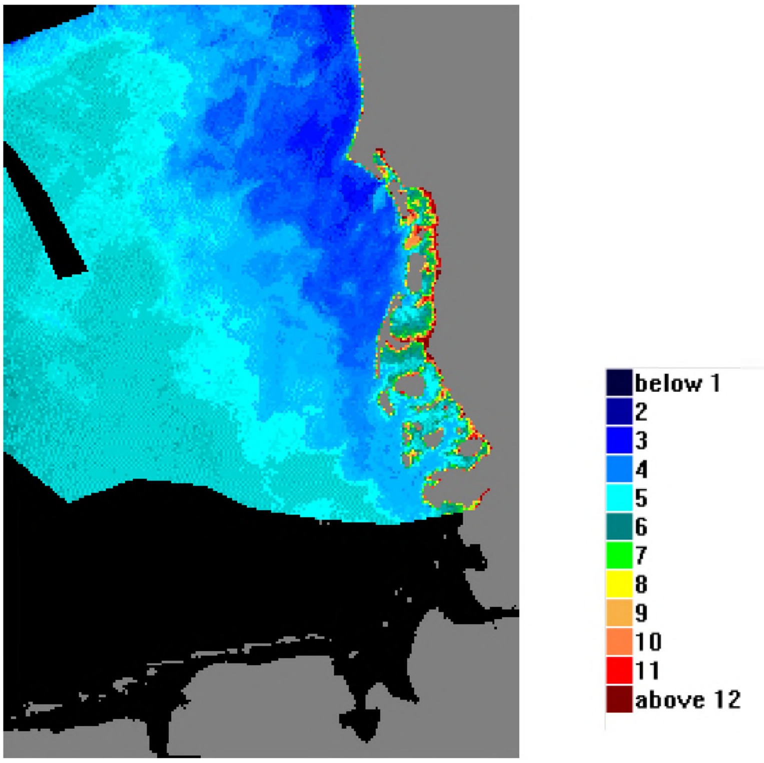


Figure 14. Surface sea temperature image from March 17th 2003.

5.1.2 Harbour porpoise distribution

The series of surveys revealed large variations in the abundance of animals at Horns Reef (see below). Individual surveys were characterised by medium or high densities (> 3 animals per km^2) mainly within a restricted area over the central and western parts of the reef, and in Slugen. No concentrations were seen near or within the wind farm area. Strong salinity fronts were apparent on the 23-24 March and 8-9 June 2002 as well as on the 12-13 February and 18 March 2003. Concentrations of harbour porpoises were aligned along these fronts, except on the 8-9 June when very few animals were sighted. The fronts passed through the wind farm area or in the immediate vicinity of the area during all four periods, but only one sighting of one animal was made (23 March 2002). During the period of daily surveys between 28 July and 1 August the variation in the distribution could be followed. During this period of stable and relatively moderate salinity over the whole area, the main concentration of animals was very resident around the Vov Vov bank on the western edge of the reef, and the core of the popoise distribution only changed position over a range of less than five km during these five days.

Calves were observed in the same areas as the main concentrations of harbour porpoises with the bulk of observations being made in the central and western parts of the Horns Reef (Figure 15). A single calf was observed in the wind farm area.

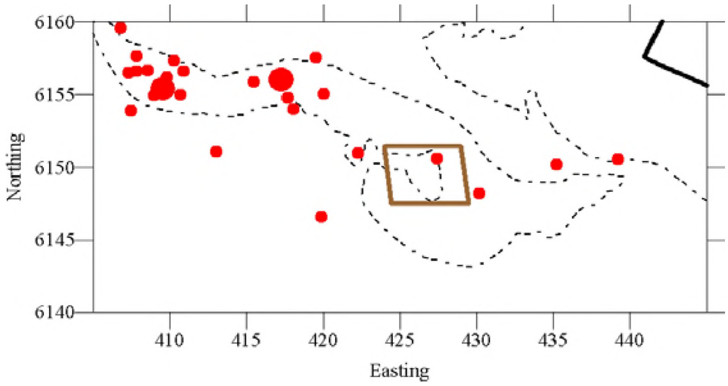


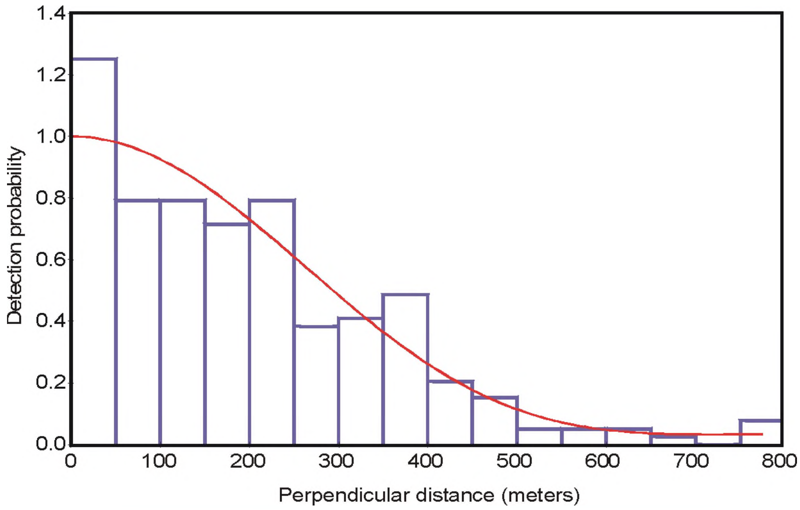
Figure 15. Sightings of calves during the surveys on Horns Reef in 2002. Smaller dots indicate one animal; larger dots two animals.

5.1.3 Population estimates

An average detection probability curve was fitted to the pooled harbour porpoise sighting data of six regular line transect surveys (Figure 16). This resulted in a common set of detetion parameters, shown in Table 2 and used to calculate estimates of pod size, sigthing rates and total density for the six regular surveys (Table 3). The abundance of animals clearly increased from spring/early summer to late summer/early autumn in 2002, whereas the abundance estimate for February 2003 was comparable to early March 2002. During the peak period coinciding with the period in which young calves are normally seen, the point estimates indicated a density of 1.1-1.5 porpoises/km^2, corresponding to a total population of 700-1000 animals (multiplying density estimate with a total area of 660 km^2). This is in line with prior estimates of the number of porpoises in the area (Skov et al. 2000, Skov et al. 2002). It should be born in mind, however, that both the estimates from 28 July and 8 August have wide confidence intervals, due to the high variance in sighting rates between transect lines.

Table 2. Estimates of overall detection parameters from the six line transect surveys in Table 3.

Parameter	Point Estimate	Standard Error	Percent Coef. of Variation	95 Percent Confidence Interval	
Probability of observation	0.39	0.016	4.12	0.36	0.42
Effective search width (m)	312	12.8	4.12	287	338



Figur 16. Average detection probability curve (uniform model) fitted to perpendicular sightings collected during the six surveys listed in Table 2

Table 3. Line transect estimates of pod size, pod and animal density and total abundance for six regular surveys on Horns Reef in 2002-2003. SE: standard error, CV: coefficient of variation.

Date	*Parameter*	Point Estimate	SE	CV (%)	95% Conf. Int.	
12.Mar. 2002	*Sighting rate (pods/transect km)*	0.071	0.023	32.6	0.034	0.148
	Pod Size	1.21	0.15	12.3	1.00	1.59
	Density (porpoises/km²)	0.14	0.048	35.1	0.065	0.29
23-24. Mar.2002	*Sighting rate (pods/transect km)*	0.18	0.046	25.6	0.10	0.31
	Pod Size	1.53	0.114	7.5	1.32	1.78
	Density (porpoises/km²)	0.44	0.12	27.0	0.25	0.79
20-21. Apr.2002	*Sighting rate (pods/transect km)*	0.17	0.067	40.1	0.069	0.41
	Pod Size	2.14	0.26	12.1	1.67	2.74
	Density (porpoises/km²)	0.58	0.24	42.1	0.23	1.42
28. July 2002	*Sighting rate (pods/transect km)*	0.34	0.15	45.2	0.12	0.97
	Pod Size	1.99	0.19	9.6	1.64	2.42
	Density (porpoises/km²)	1.07	0.50	46.4	0.37	3.09
8. Aug. 2002	*Sighting rate (pods/transect km)*	0.37	0.12	32.1	0.19	0.76
	Pod Size	2.59	0.179	6.9	2.25	2.97
	Density (porpoises/km²)	1.56	0.52	33.1	0.76	3.20
12-13. Feb. 2003	*Sighting rate (pods/transect km)*	0.051	0.017	33.6	0.025	0.11
	Pod Size	1.97	0.34	17.4	1.35	2.88
	Density (porpoises/km²)	0.16	0.062	38.0	0.075	0.35

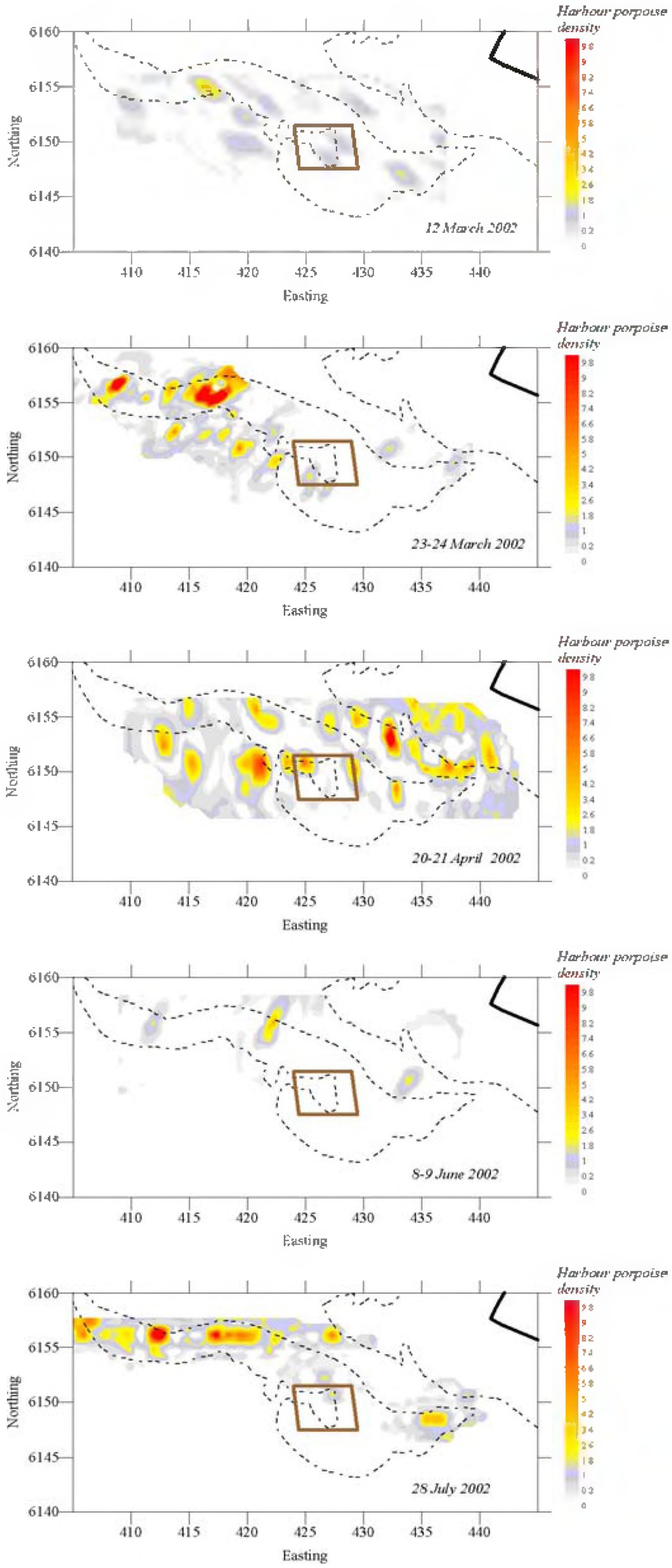


Figure 17. Spatial models (kriging) of the distribution of harbour porpoise during the 12 surveys on Horns Reef.

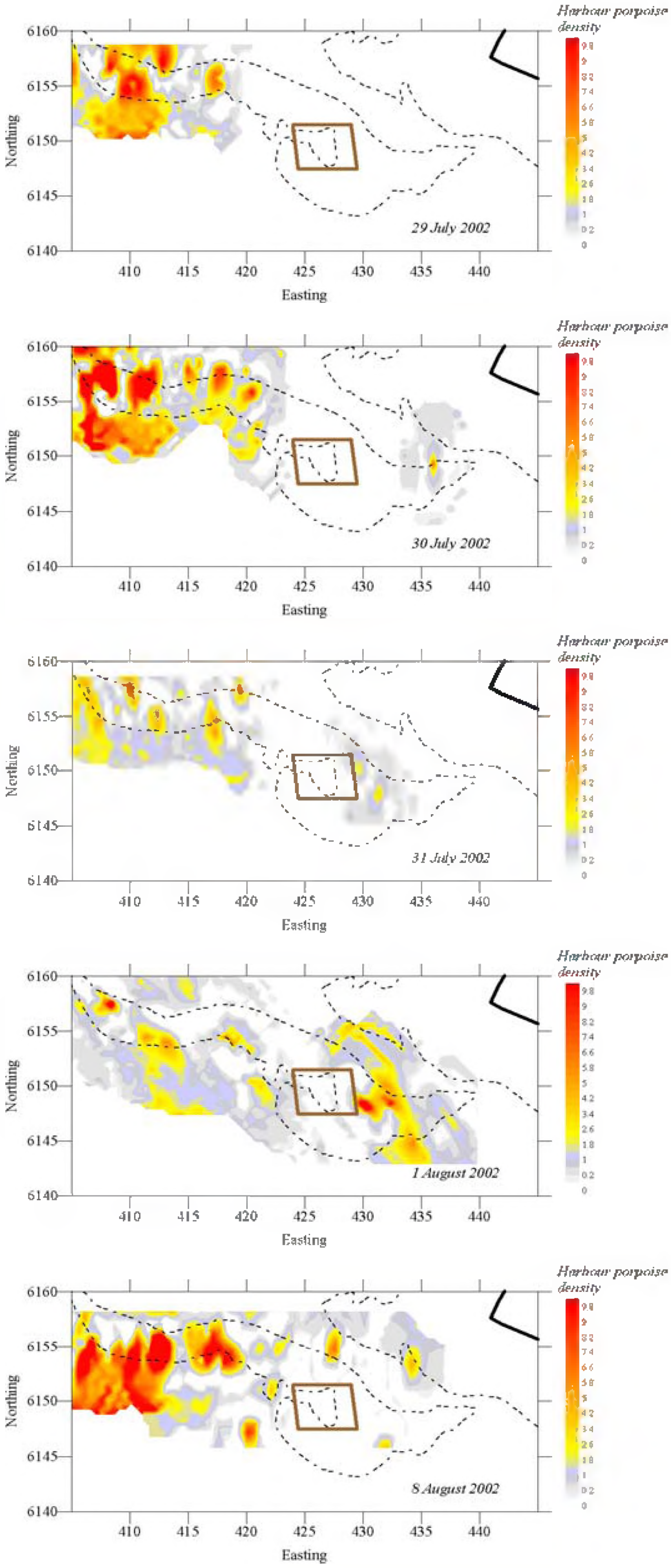


Figure 17 (cont.)

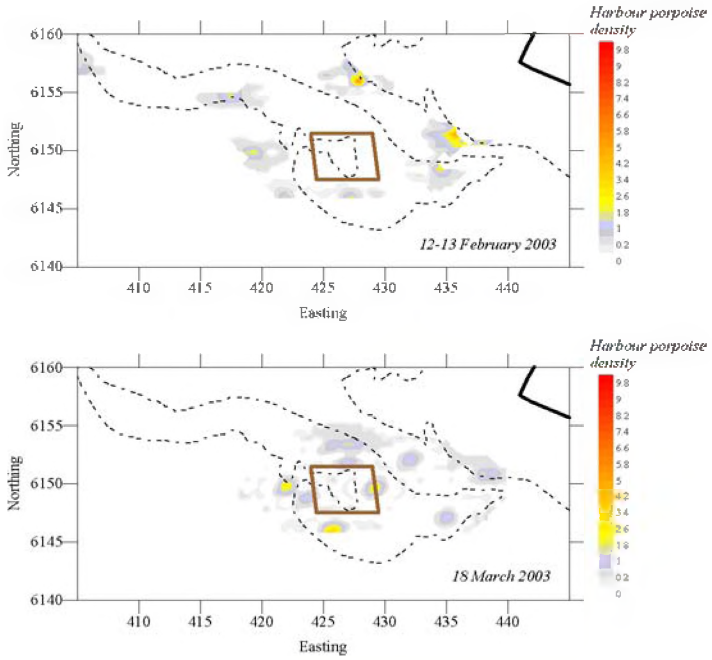


Figure 17 (cont.)

5.1.4 Density effects

The test for differences in the density of harbour porpoises in the entire study area on Horns Reef between the periods before and during the ramming phase show that when using salinity as a covariate the densities of the animals was significantly lower during the ramming phase as compared to the baseline period (F=26.25, p = 0.00000004, N = 680, Figure 18).

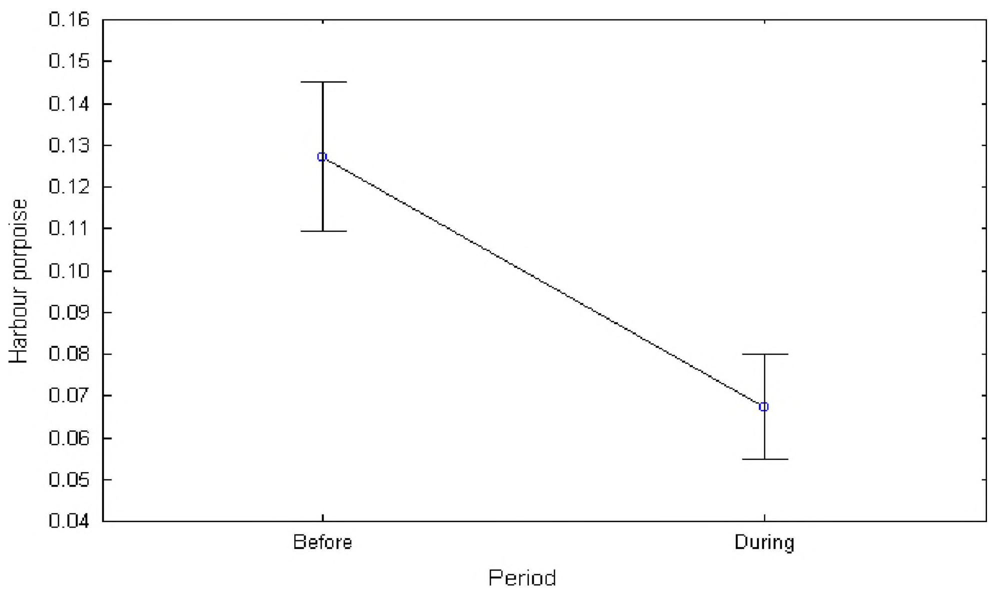


Figure 18. The log-transformed means of harbour porpoise densities in the whole Horns Reef area during and after the ramming phase (from ANOVA).

5.1.5 Behavioural observations

Distribution of observation classes is shown in Figure 19. About 90% of the observations consisted of directionally or non-directionally moving animals. Behaviours were significantly different between observations in ramming period and outside ($\chi^2 = 21.353$, $P < 0.001$). From Figure 19 it can be seen that directionally moving animals were highly overrepresented during ramming, compared to the three remaining behaviours.

Observations were separated into classes of distance from the wind farm (Figure 20 and 21). For observations outside ramming period there were no significant difference between distance classes ($\chi^2 = 9.93$, $P = 0.127$), whereas it was highly significant for the ramming observations ($\chi^2 = 24.729$, $P < 0.001$). From Figure 21 it can be seen that the behaviour non-directional movement (which is supposed to be associated with foraging) is underrepresented in the two inner distance zones, with the strongest effect in the innermost area. Directional movement is similarly overrepresented in these two inner areas.

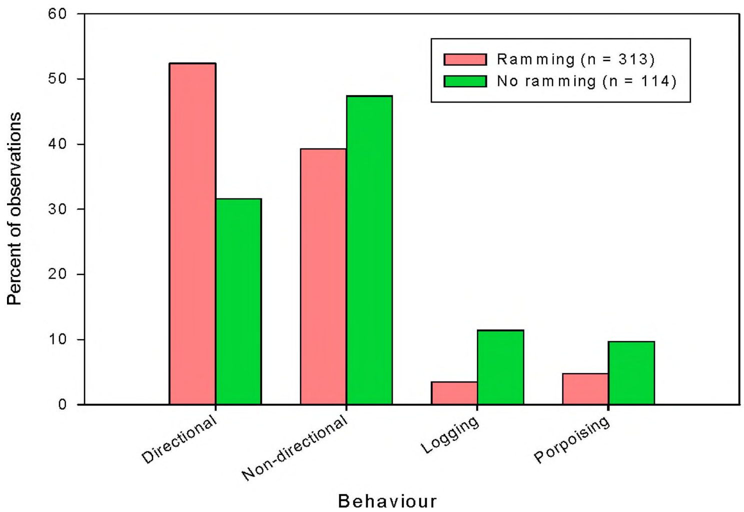


Figure 19. Behaviour of harbour porpoises on surveys in period with ramming operations (March 30th to August 1st) and on surveys before and after.

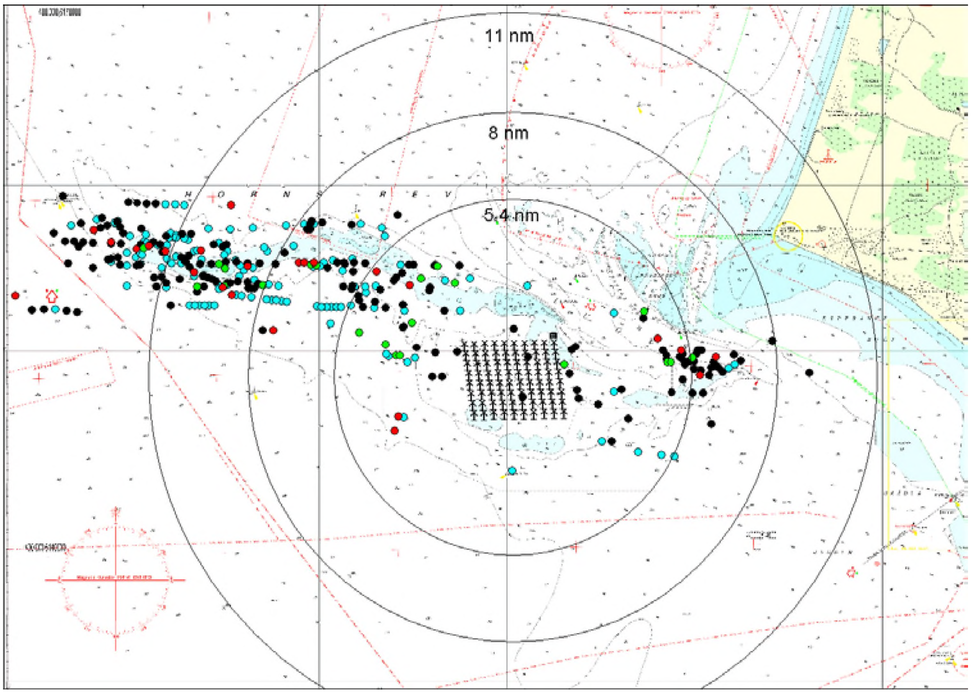


Figure 20. Behavioural observations on surveys conducted during ramming operations. Distance classes used in Figure 21 are shown as concentric circles. Behaviours: Black dots: directional, blue dots: non-directional, green dots: logging and red dots: porpoising.

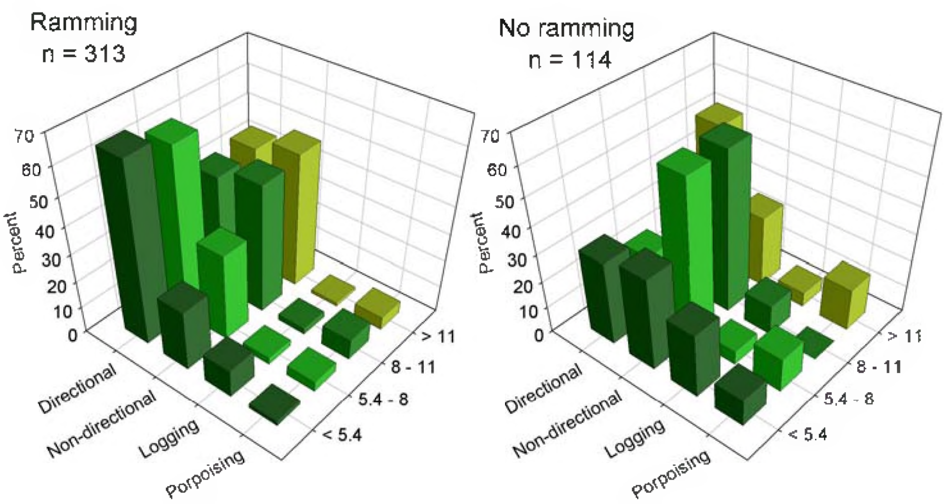


Figure 21. Behaviour of harbour porpoises at various distances from the wind farm, both during period with ramming operations (left) and before and after (right).

5.2 Human activities in construction period

Substantial amounts of human activities of various sorts were associated with construction of the wind farm. The general extent of the major activities is shown schematically in Figure 22, categorised into six types:

Filter: The first activity on all positions was deposition of a layer of pebbles on the seabed. This was done from the ship “Pompei”. This activity likely stirred up some bottom sediment as well as generated moderate levels of noise.

Ramming: Steel monopile foundations were rammed into the seabed with a hydraulic hammer and was done from the jack-up rig “Buzzard” (see Figure 3). Each ramming took between ½ hour and 2½ hours. This activity was very noisy and was probably the single most disturbing activity during construction.

Fitting: After foundations were rammed into the seabed, a fitting was mounted on top as base for subsequent mounting of the turbine.

Covering: A protective layer of boulders was layed out on the seabed around each foundation. This was also done with the ship “Pompeii” and is likely also to have generated some turbidity in the water as well as moderate levels of noise.

Turbine: The turbines were mounted by means of a jack-up ship with a large crane (“Ocean Hanne” and “Ocean Addy”, Figure 23). This activity probably created little underwater disturbance.

Cable: Subsea power cables were drawn between individual turbines and selected turbines and the transformer rig. Cables were buried in the sea bottom by means of a water jet operated by divers. This activity may have generated some noise.

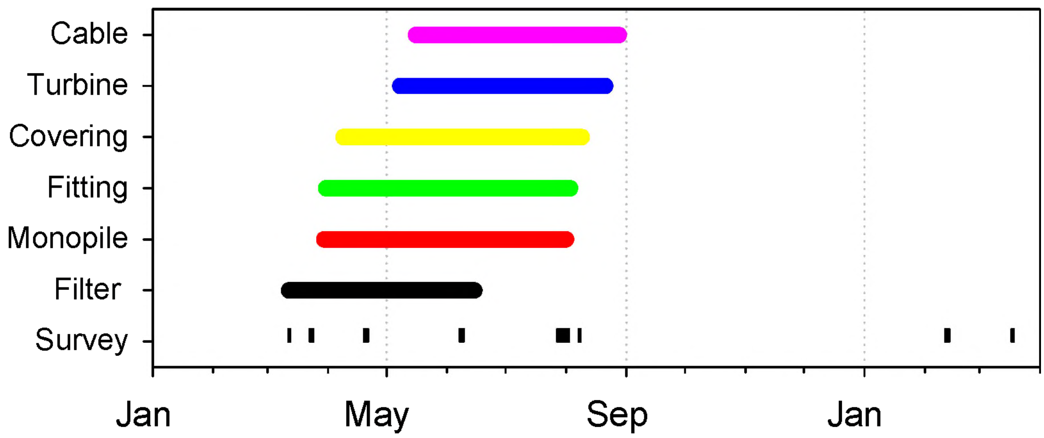


Figure 22. Construction activities in the wind farm and dates of surveys.

Figur 23 Mounting of wind turbine

In addition to the activities linked to the construction itself, a number of ships were in the area or sailing to and from with crew and materials to larger ships and turbines. Some of these smaller boats were fast sailing and thus capable of generating substantial levels of noise.

Some of these activities are very well documented, but this is unfortunately not the case for all. A detailed correlation between distribution and behaviour of harbour porpoises and the different types of activities is thus not possible. Instead an index of activity was calculated, shown in Figure 24. This index is an estimate of the number of turbines worked on and thus a rough measure of the level of activity. It should be noted however, that activities are unlikely to be equally disturbing to harbour porpoises.

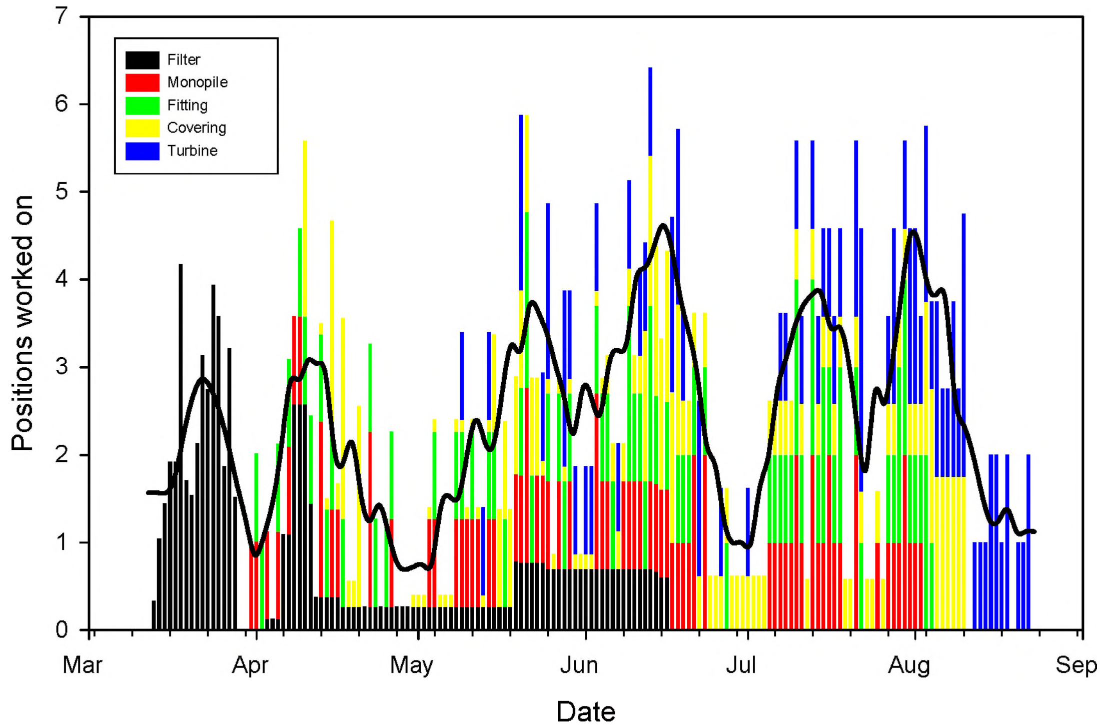


Figure 24. Activities in the wind farm. Some activities either streched over several days on the same position or activity could not be dated more accurate than an interval of several days, both resulting in figures below 1. Black line is running average of total number of positions worked on.

5.3 Stationary POD-data

The activity of harbour porpoises in the Horns Reef region has been assessed by means of porpoise detectors (PODs) described above. The first PODs were deployed at Horns Reef in July 2001 and the present report analyses data collected from the PODs up to mid October 2002 (no data are available for the period between November 2002 and March 2003). The time series obtained from the POD signals contain major gaps due to technical problems as described above. It should also be stressed that time series at the different positions within the investigation area are combined from different POD recordings, because gear has been lost and PODs have occasionally been shifted around from one position to another. All PODs are equipped with an internal hydrophone, in contrast to later models with external hydrophone (T-POD2 and T-POD3) meaning that the sensitivity of the different PODs should be of same order of magnitude. Recordings were combined from channels 2-6 (5 in total) giving measures of porpoise click activity for 45 seconds every minute.

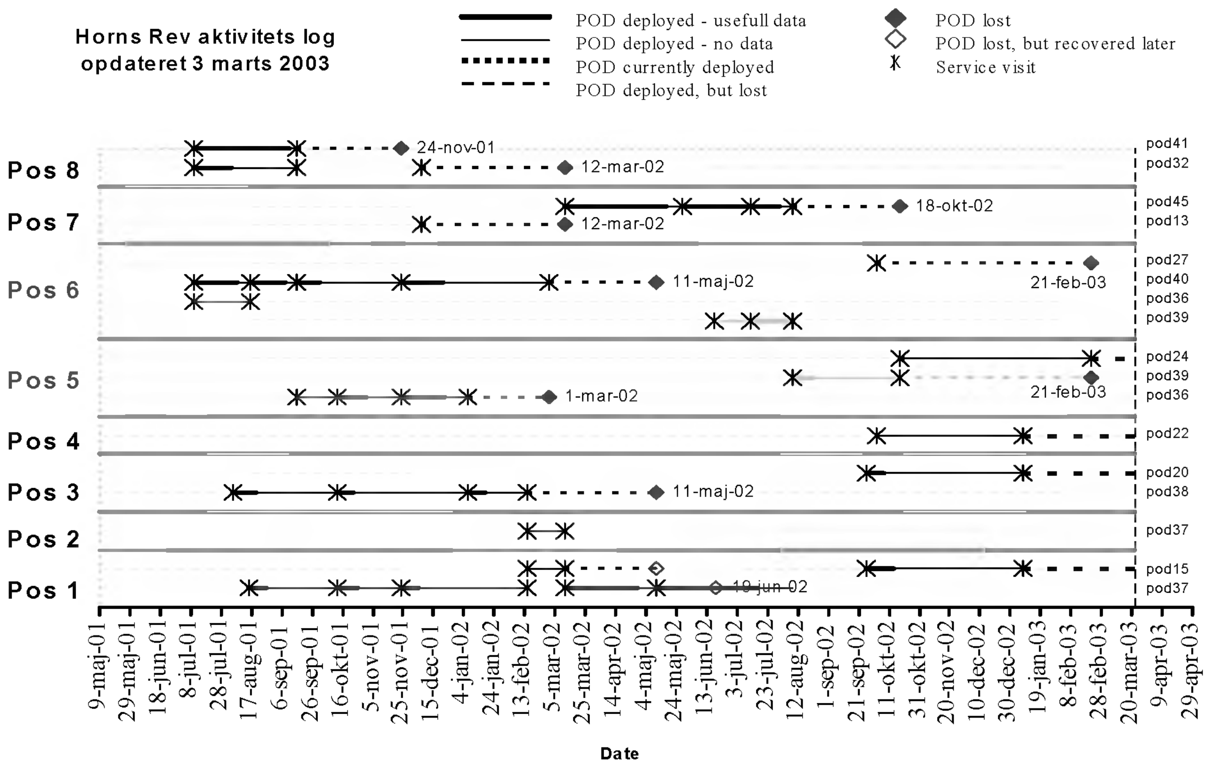


Figure 25 Schematic illustration of POD-deployments from onset of the monitoring program to last service visit in February 2003. Position 5 and 6 are impact area (wind farm).

POD37 was deployed on May 11th 2002, lost during deployment and later recovered on July 17th 2002. Thorough analysis of data from this deployment has shown that the POD was operating normally until June 19th, followed by suspect recordings. Thus, the recordings from the first part of this deployment are included in the analysis.

5.3.1 Daily statistics

Daily click frequency and intensity were calculated from the POD data (Figure 26). The temporal variations and variation between positions and PODs appear relatively smaller for intensities compared to frequencies. In order to test whether systematic temporal correlation was apparent autocorrelation functions for intensity and frequency were calculated for each sequence of a specific POD at a specific location. None of the 13 sequences were found to be temporally correllated (data not shown) and we thus assume that these daily indicators are independent observations.

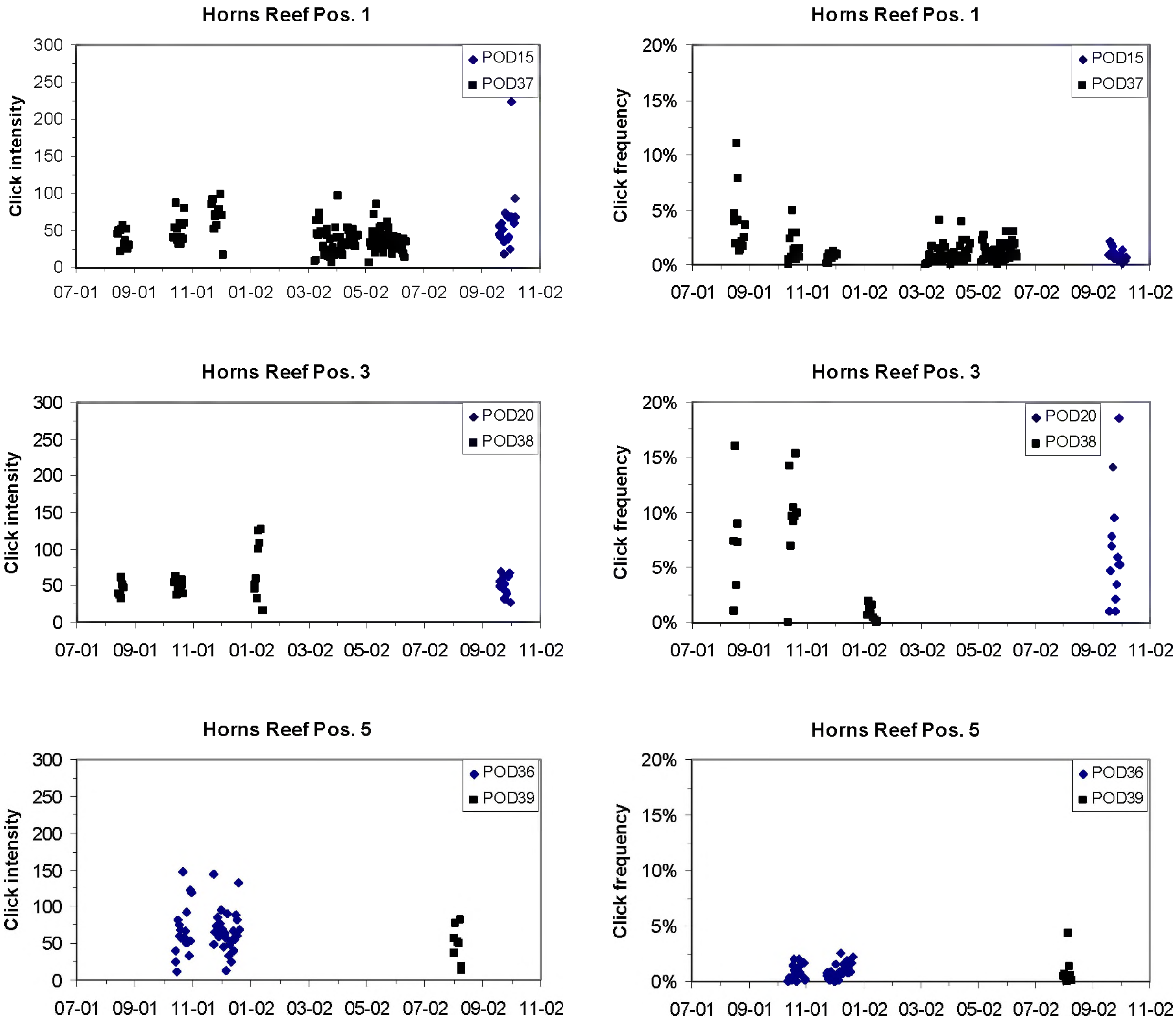


Figure 26: Daily click intensity (left panel) and click frequency (right panel) extracted from all POD data collected at Horns Reef from July 2001 to October 2002. Data from individual PODs are separated as indicated in the legends (top right corner). See map in Figure 1 for positions.

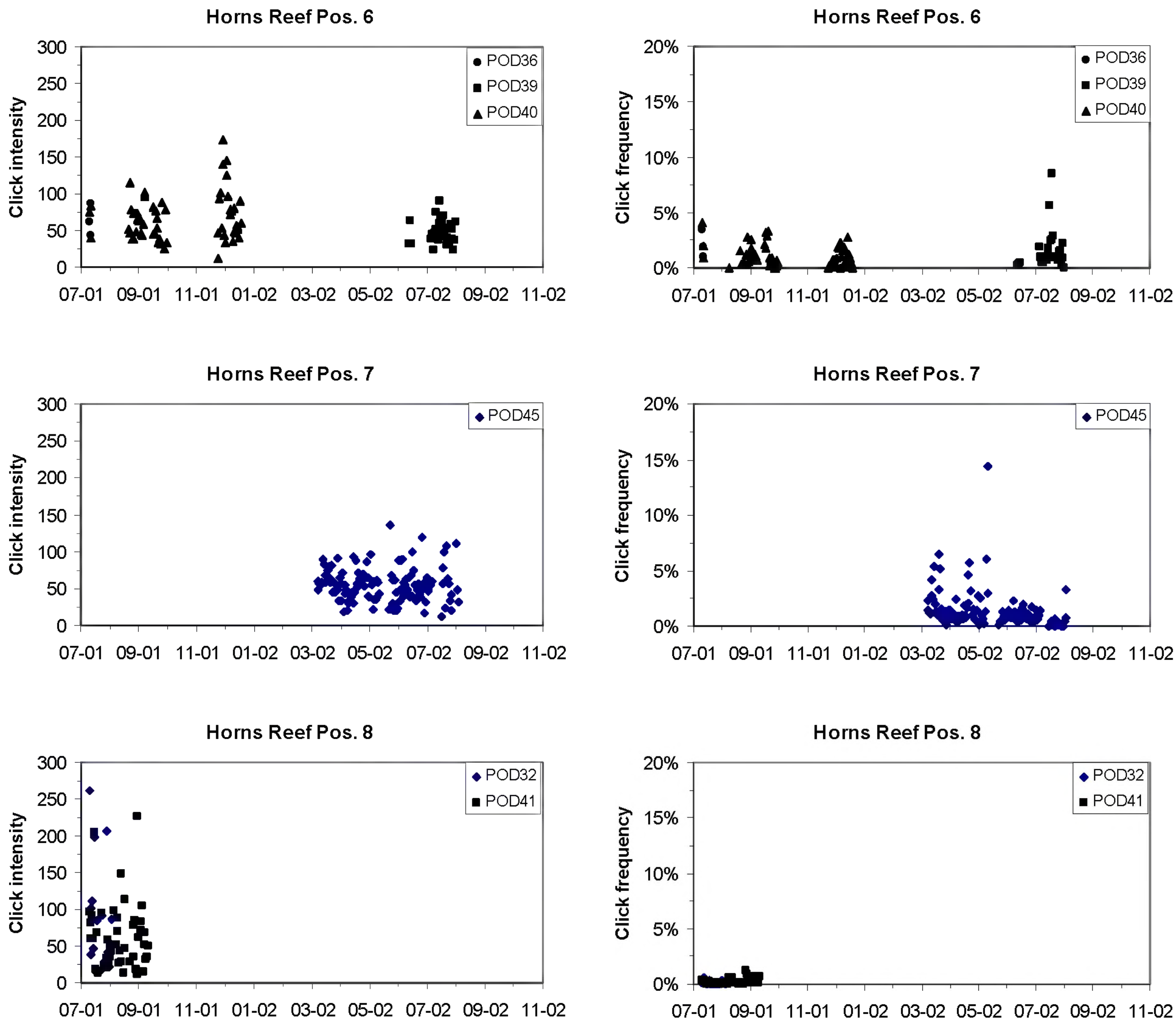


Figure 26 cont.

5.3.1.1 Variation in POD sensitivity

Due to the problems associated with unsupervised POD deployments for longer periods and switching of PODs between different locations, the variation attributed to seasons and variation between individual PODs are partially confounded. This implies that it cannot be determined exactly how much of the variation is seasonal and how much is due to substitution of PODs at specific locations. In order to determine the most likely source of temporal variation, the log-transformed daily click intensity and the arcsine-to-the-squareroot transformed click frequency was invesitigated. The analysis was carried out on baseline data as these comprise the largest part of the recordings and because the construction of the wind farm introduces a new source of variation.

Analysis of variance (ANOVA) showed that the variation attributable to substituting PODs at individual positions was insignificant for both frequency and intensity (Table 3). This implies that the variation in sensitivity between individual PODs is relatively small compared to other sources of variation. It should be acknowledged that the insignificant variation between PODs does not implicitly imply that the sensitivity of all PODs is the same, but that the variation between groups of PODs is small (i.e. POD15 and POD37 have the same sensitivity, POD20 and POD38 have the same sensitivity, etc.). Given that all these groups of PODs do not show any significant variation attributable to the specific POD, it is concluded that the variation in sensitivity between different PODs is generally negligible. Moreover, daily click intensity was found relatively constant as shown in Figure 27. The relatively small variation in click intensity suggests that porpoise group sizes do not vary systematically in time or space, provided that the click intensity can be interpreted as a measure of number of individuals during a POD recording.

Table 3: Analysis of Variance (ANOVA) for daily indicators (intensity and frequency) described by variation between area (Control versus Impact), stations within area, differences in PODs within specific station and area, seasonal variation described by monthly means and differences in seasonal variation between the two areas. For each indicator the least significant effect was discarded until all remaining effects were significant at a 5% significance level. P-values were determined by type III SS, i.e. the difference in variation described by the model including versus not including the considered effect. POD data from baseline period only.

Indicator	P-values for effects in model determined by type III SS (marginal variation)					
	Area	Station (area)	PODid (station area)	Month	Area *month	R^2
Daily intensity	0.2696	0.7677	0.8781	0.0170	0.6980	0.0919
	0.2130	0.3034	-	0.0140	0.6857	0.0909
	0.3279	0.2955	-	0.0074	-	0.0785
	-	0.3682	-	0.0074	-	0.0785
	-	-	-	0.0190	-	0.0615
Daily frequency	0.0590	<0.0001	0.9720	<0.0001	0.0262	0.6187
	0.0004	<0.0001		<0.0001	0.0056	0.6186

5.3.1.2 Variation between areas

The variation in click frequency could be attributed to both seasonal and spatial variation, and particularly, the seasonal variation was found to differ between the two types of areas. This implies that control and impact areas do not have similar temporal variations, which is the basic assumption for the BACI design. Therefore, it was investigated whether combinations of stations in the control area together with the two stations in the impact area (Pos. 5 and 6) could yield an insignificant cross-effect (area*month). It was found that the significance of area*month in Table 3 was linked to Pos. 8 in the control area. If analysis was carried out without including Pos. 8 in the control area there was no significant difference in the seasonal variation between control and impact areas (P=0.2687 for area*month), suggesting that Pos. 1, Pos. 3, Pos. 5 and Pos. 6 have similar temporal variations. The seasonal variation of click frequency based on baseline data from these four positions showed high frequency in July 2001 followed by medium frequencies throughout August-December 2001, whereas January 2002 had a very low frequency (Figure 27). Click frequencies were also generally higher at Pos. 3.

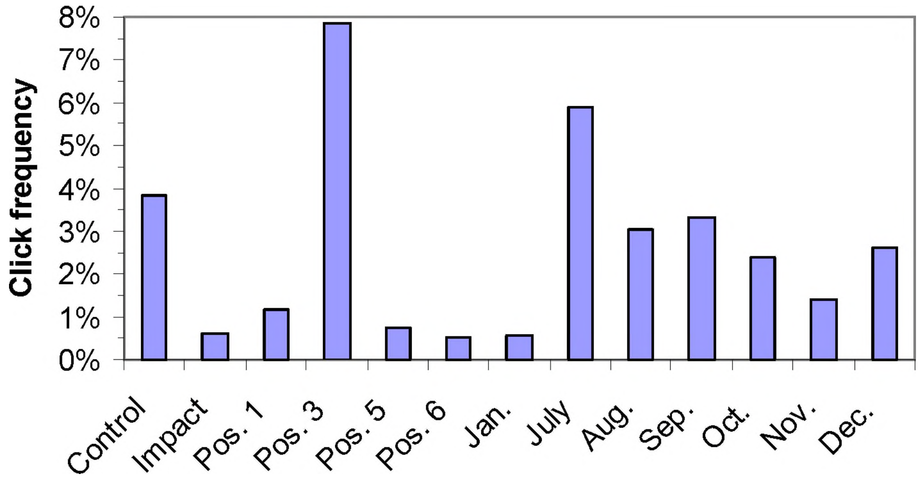


Figure 27: Median click frequencies derived from ANOVA analysis including baseline data from positions 1, 3, 5 and 6 (Control=Pos. 1+3; Impact=Pos. 5+6; individual months = all months with data from baseline). Median levels were obtained by applying the back-transform of the arcsine-to-the-squareroot transformation to marginal means from the ANOVA.

The difference in temporal variations between stations on Horns Reef (Pos. 1, 3, 5 and 6) versus Slugen (Pos. 8) may be explained either by differences in habitat use, which implies that the inner location is not comparable for the BACI analysis, or alternatively by variations in physical conditions that apply equally to all parts of the reef (e.g. variations in salinity). In the latter case, Pos. 8 can be used in the BACI analysis provided that the seasonal difference can be described by variations in physical variables. Whether temporal variation on Pos. 7 is identical to that of the impact area could not be determined, as PODs were not deployed on this position during the baseline study. This position hence cannot contribute to the BACI analysis. Because of deployment problems in Slugen (see above) pos. 8 was removed from the monitoring program after the baseline study. Thus, in the following we will use Pos. 1 and 3 as control and Pos. 5 and 6 as impact.

5.3.2 BACI analysis for baseline versus construction

Based on the analyses above a BACI analysis was conducted to determine a potential effect of the construction phase on daily activity statistics (Table 4). Both indicators showed significant variation between control and impact areas, although there was no significant difference when considering the baseline period only for daily intensity (Table 3). The daily intensity was not different for the two periods, before and after, whereas daily frequency decreased approximately 50% overall for all positions. The BACI effect (area*period) was significant for daily intensities, which declined in the impact area and increased in the control area.

Table 4: BACI analysis for daily indicators (intensity and frequency) described by variation between area (Control versus Impact), stations within area, seasonal variation described by monthly means, variation between periods (Before versus After) and differences in these periods between the two areas (BACI-effect). P-values, given in the first line, were determined by type III SS, i.e. the difference in variation described by the model including versus not including the considered effect. The coefficient of determination (R^2) was calculated on transformed data. Medians were found using back-transforms of marginal means from ANOVA in order to account for non-balance in data. The BACI effect was calculated as (IA-IB)-(CA-CB). Data from PODs deployed at Pos. 1, 3, 5 and 6 were used.

Indicator	BACI results					
	Area	Station (area)	Month	Period	Area *period	R^2
Daily intensity	<0.0001	0.6467	<0.0001	0.4798	0.0035	0.2208
Daily frequency	<0.0001	<0.0001	<0.0001	0.0001	0.2658	0.4801

Medians Intensity	**Control**	**Impact**	**Median Before/ after**	**BACI**	**Medians Frequency**	**Control**	**Impact**	**Median before/ after**	**BACI**
Before	28.2	26.1	27.1	-7.2	**Before**	4.12%	0.81%	2.16%	1.33%
After	31.4	22.1	26.3		**After**	2.38%	0.40%	1.19%	
Median Control/ impact	29.7	24.0			**Median Control/ impact**	3.19%	0.59%		

In summary, the daily intensity had a significant negative BACI effect that could be associated with the construction of the Horns Reef wind farm. The significant decline in daily frequency between periods could be due to differences in inter-annual variation as well (difference between 2001 and 2002) for the few overlapping months (July-October). Porpoise activity was generally higher in the control area, mainly Pos. 3.

5.3.3 BACI analysis for ramming days during construction

The construction period consisted of 80 short-term events of ramming foundations into the sediments, a process creating a very high noise level. It is hypothesised that these ramming activities could have an effect on the porpoise activity. The daily indicators during the construction period (After) were grouped into ramming days and ordinary construction days, and a BACI type analysis was carried out to determine if there was any effect on porpoise activity during ramming days in the construction period. In order to conduct this analysis it was necessary to include Pos. 7 as a reference station, as this was the only control position with data recorded simultaneously to the recordings within the impact area.

Table 5: BACI analysis for daily indicators (intensity and frequency) described by variation between area (Control versus Impact), stations within area, seasonal variation described by monthly means, variation between days with and without ramming activity and differences in these days of activity between the two areas (BACI-effect). P-values, given in the first line, were determined by type III SS, i.e. the difference in variation described by the model including versus not including the considered effect. The coefficient of determination (R^2) was calculated on transformed data. Medians were found using back-transforms of marginal means from ANOVA in order to account for non-balance in data. The BACI effect was calculated as (IA-IB)-(CA-CB). Data from PODs deployed at Pos. 1, 3, 5, 6 and 7 were used.

Indicator	BACI results					
	Area	Station (area)	Month	Ramming	Area *ramming	R^2
Daily intensity	0.3083	0.5885	0.0003	0.0162	0.9433	0.3213
Daily frequency	0.9827	<0.0001	0.0035	0.1082	0.6931	0.2731

Medians Intensity	**Control**	**Impact**	**Median No ram./ ram.**	**BACI**	**Medians Frequency**	**Control**	**Impact**	**Median no ram./ ram.**	**BACI**
No ramming (B)	26.7	29.2	28.0	-0.1	**No ramming (B)**	2.23%	2.39%	2.31%	-0.27%
Ramming (A)	23.7	26.1	24.9		**Ramming (A)**	1.80%	1.69%	1.74%	
Median Control/ impact	25.2	27.6			**Median Control/ impact**	2.01%	2.02%		

Days with ramming activity were found to have lower daily intensity (significant) and frequency (not significant) in both control and impact area. However, the decreases during ramming days in both of these indicators were of the same magnitude in both areas, indicating that 1) ramming activity had little effect on daily activity levels and the significance of the ramming factor is attributable to temporal variations or 2) the control area was affected by ramming activity in the same manor as the impact area. The first implies that ramming was generally carried out on days with lower activity over the entire Horns Reef, whereas the latter implies that Pos. 7 (control) and Pos. 6 (impact) are both affected by ramming activity, as these are the only two PODs providing simultaneous data from both control and impact area. It should also be recognised that the limited number of ramming days with POD recordings does not allow for detection of minor differences in daily frequencies.

Combining the daily indicators with ramming activity does not provide an ideal picture of the effect of ramming, because ramming is a short-term activity (typically 1-1.5 hour) that may take place at any time over the course of the day. However, by using daily indicators it is implicitly assumed that porpoise activity over the entire day, including the time from midnight to start of ramming, is affected by this activity. Hence, the analysis above can only provide weak indications for a potential effect of ramming activity. Applying the same type of analysis to encounter statistics during and after the ramming should provide a better approach to assess the potential effect of ramming.

5.3.4 Encounter statistics

Events were identified from the POD signals according to the definition (see above), and the mean duration of events and waiting time between events calculated (Table 6). The calculated waiting times presented in this section are 10 minutes shorter than the observed, corresponding to the "dead period" used for distinguishing encounters (see definition above). Autocorrelation functions for these two encounter indicators were calculated for each sequence of a specific POD at a specific location. Several of the 13 sequences were found to have systematic temporal correlation for waiting times between encounters whereas the autocorrelation for encounter length was less pronounced (data not shown). However, the pattern of autocorrelation was not consistent for all positions and the lag-1 correlations were generally small (<0.20) and hence, autocorrelation was not included in the models for encounter statistics. Pos. 3 has the shortest waiting times and longest duration of encounters, whereas Pos. 8 has the longest waiting times and shortest duration of encounters. In the impact area, porpoise encounters are recorded approximately every 1-2 hours with a median duration of 1-2 minutes, although some encounters are substantially longer.

Table 6: Median duration and time between porpoise encounters for PODs deployed at Horns Reef (unit=minutes). Periods listed may be combined of several deployments.

Station	POD id	Periods	Event duration	Waiting time
Pos. 1	15	117 events in 26/9 2002 - 14/10 2002	1	120
	37	1021 events in 15/8 2001 - 19/6 2002	1	85
Pos. 3	20	242 events in 26/9 2002 - 8/10 2002	3	30
	38	375 events in 15/8 2001 -17/1 2002	4	27
Pos. 5	36	313 events in 14/10 2001 -22/12 2001	2	99.5
	39	50 events in 8/8 2002 -17/8 2002	2	48
Pos. 6	36	27 events in 10/7 2001 -12/7 2002	1	58.5
	39	321 events in 19/6 2002 -7/8 2002	1	59
	40	474 events in 10/7 2001 -20/12 2001	2	86
Pos. 7	45	1225 events in 12/3 2002 -10/8 2002	2	66
Pos. 8	32	37 events in 10/7 2001 -3/8 2001	1	559.5
	41	125 events in 10/7 2001 -11/9 2001	1	376

The significance of changing PODs on encounter statistics was investigated by means of generalised linear models similar to the ANOVA carried out for daily indicators in Table 3. Both indicators were log-transformed prior to analysis and subsequently modelled by means of the Gamma distribution. The variation attributable to changing PODs at the different positions was also found to be insignificant for both duration and waiting times as was the variation between control and impact area (Table 7). For encounter duration variation between stations within the control and impact areas as well as seasonal variation were the only significant sources. For waiting times the seasonal variation was found to be different for the control and impact areas.

Difference in seasonal variations in the two considered areas poses a problem to the basic assumption of the BACI analysis, i.e. the two areas should have similar temporal variations during the baseline period. Including Pos. 8 in the control area contributes substantially to the significance of area*month for waiting times in Table 7. Hence, Pos. 8 was discarded from the control area and the analysis performed again, which resulted in a smaller but still significant interaction (P=0.0200 for area*month). This significant variation is due to data from Pos. 5 within the impact area, and the interaction term would only become insignificant if this position were removed from the analysis. Although the interaction (area*month) is significant on a 5% significance level, we decided to use data from all four positions (Pos. 1, 3, 5 and 6) in order to perform analyses consistent with those carried for the daily indicators and in order to obtain more observations in the sparse data set. Moreover, Pos. 5 is located in the middle of the Horns Reef between Pos. 3 and 6 such that there is little biological argument for this position to have a different temporal variation.

Table 7: Generalised linear models for encounter indicators (duration and waiting time) described by variation between area (Control versus Impact), stations within area, differences in PODs within specific station and area, seasonal variation described by monthly means and differences in seasonal variation between the two areas. Both indicators are assumed Gamma-distributed after log-transform. For each indicator the least significant effect was discarded until all remaining effects were significant at a 5% significance level. P-values were determined by type III SS, i.e. the difference in variation described by the model including versus not including the considered effect. POD data from baseline period only.

Indicator	P-values for effects in model determined by type III SS (marginal variation)					
	Area	Station (area)	PODid (station area)	Month	Area *month	Log-likelihood
Encounter duration	0.9277	<0.0001	0.9320	0.0077	0.1051	-1851.03
	0.3215	<0.0001	-	0.0063	0.0544	-1851.10
	-	<0.0001	-	0.0063	0.0544	-1851.10
	-	<0.0001	-	0.0017	-	-1856.52
Waiting times	0.3290	<0.0001	0.7264	<0.0001	0.0010	-3143.52
	0.1911	<0.0001	-	<0.0001	0.0005	-3143.84
	-	<0.0001	-	<0.0001	0.0005	-3143.84

Median waiting times showed most activity in the control area (Figure 28), particularly Pos. 3 with a median waiting time of less than 30 minutes, whereas median waiting times in the impact area were approximately 100 minutes. January and November had few encounters, whereas the other months had median waiting times between 30-60 minutes. The overall variations in waiting times are inversely related to the daily frequencies.

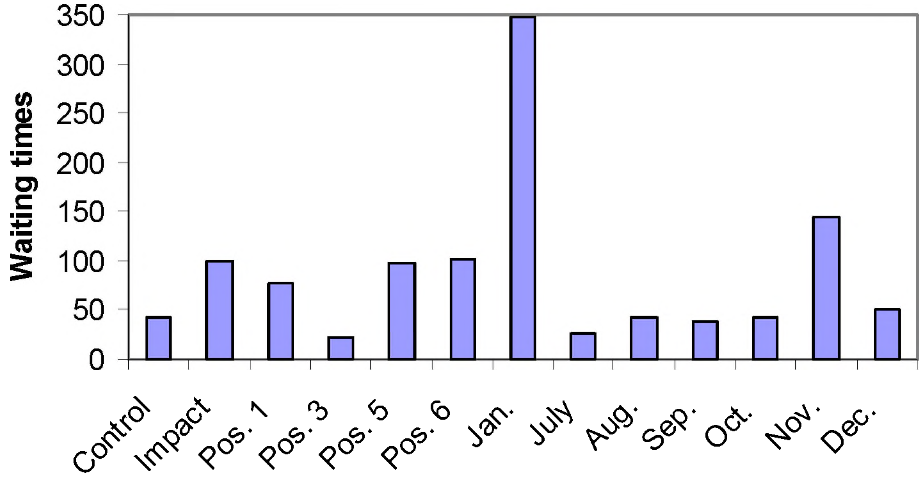


Figure 28: Median waiting times derived from generalised linear model analysis using baseline data from positions 1, 3, 5 and 6 (Control=Pos. 1+3, Impact=Pos. 5+6 and seasonal variation=all months with data from baseline). Median levels were obtained by applying the back-transform of the log, i.e. the exponential function, to marginal means from the generalised linear model.

5.3.5 BACI analysis for baseline versus construction

Duration of porpoise encounters and waiting times between encounters were grouped into periods before and after start of construction, and differences between control and impact areas were investigated for both of these periods by means of a BACI-analysis (Table 8). Both indicators showed significant variation between areas and for stations within areas, the latter most pronounced for the variation between Pos. 1 and 3 in the control area. For all positions combined the median duration of a porpoise encounter decreased significantly from the baseline to the construction period, whereas median waiting times between encounters were of same magnitude before and after. The BACI-effect (area*period) was significant for waiting times showing that these became relatively shorter in the impact area during construction. This indicates a positive effect on the porpoise activity during the construction phase, provided that the control area is unaffected by the construction.

Table 8: BACI analysis for encounter statistics (duration and waiting times) described by variation between area (Control versus Impact), stations within area, seasonal variation described by monthly means, variation between periods (Before versus After) and differences in these periods between the two areas (BACI-effect). Both indicators are assumed Gamma-distributed after log-transform. P-values, given in the first line, were determined by type III SS, i.e. the difference in variation described by the model including versus not including the considered effect. Medians were found using back-transforms of marginal means from the generalised linear model in order to account for non-balance in data. The BACI effect was calculated as (IA-IB)-(CA-CB). Data from PODs deployed at Pos. 1, 3, 5 and 6 were used.

Indicator	BACI results					
	Area	Station (area)	Month	Period	Area *period	No. of obs.
Encounter duration	<0.0001	<0.0001	0.0040	0.0020	0.0563	2940
Waiting times between encounters	<0.0001	<0.0001	<0.0001	0.19745	0.0090	2911

Medians Encounter duration	**Control**	**Impact**	**Median before/ after**	**BACI**	**Medians Waiting time**	**Control**	**Impact**	**Median before/ after**	**BACI**
Before	4.2	2.9	3.5	**0.8**	**Before**	34	84	53	**-28**
After	3.3	2.8	3.0		**After**	51	72	60	
Median control/ impact	3.7	2.9			**Median control/ impact**	42	77		

5.3.6 BACI analysis for ramming days during construction

In order to investigate the effect of ramming activity on porpoise activity focus were on the period from March 30th to August 1st 2002, when 80 foundations were rammed into the seabed. The ramming of one foundation lasts approximately 1 hour with deterring procedures carried out 0.5-1.5 hour before the actual ramming (see previous section). These short-term periods of ramming activity were identified by date and time (except for 12 foundations where the ramming was given by date only), and combined with the encounter indicators. Data were only available from Pos. 1, 6 and 7 during the ramming period. During the short periods with ramming activity 11 out of 584 encounters at Pos. 1, 4 out of 247 encounters at Pos. 6 and 23 out of 980 encounters at Pos. 7 were recorded. The number of encounters during ramming is somewhat lower than for periods without ramming, as ramming activity took place in only approx. 3% of the considered period. Porpoise encounters were thus recorded, also in the impact area, during the ramming periods, although activity appeared lower for all considered positions.

Table 9: BACI analysis for encounter statistics (duration and waiting times) described by variation between area (Control versus Impact), stations within area, seasonal variation described by monthly means, variation between periods with and without ramming influence and differences in these periods between the two areas (BACI-effect). Both indicators are assumed Gamma-distributed after log-transform. P-values, given in the first line, were determined by type III SS, i.e. the difference in variation described by the model including versus not including the considered effect. Medians were found using back-transforms of marginal means from the generalised linear model in order to account for non-balance in data. The BACI effect was calculated as (IA-IB)-(CA-CB). Data from PODs deployed at Pos. 1, 6 and 7 were used covering the period from March 30th to August 1st 2002. Resilience time after ramming was 8 hours.

Indicator	BACI results					
	Area	Station (area)	Month	Period	Area *period	Number of obs.
Encounter duration	0.0179	<0.0001	0.1559	0.9922	0.5672	1811
Waiting times between encounters	0.00279	0.1770	0.5512	0.4010	0.8127	1800

Medians Encounter duration	**Control**	**Impact**	**Median No infl. infl.**	**BACI**	**Medians Waiting time**	**Control**	**Impact**	**Median No infl./ infl.**	**BACI**
No influence	2.7	3.2	2.9	**0.2**	**No influence**	67.3	42.6	53.6	**1.1**
Influence	2.6	3.3	2.9		**Influence**	73.3	49.7	60.4	
Median control/ impact	2.6	3.2			**Median control/ impact**	70.3	46.0		

It is hypothesised that there is a potential impact of the ramming activity, both during ramming itself and during a resilience time after each ramming activity. This combined period will be denoted "ramming influence". Duration of encounters were categorised as influenced by ramming or alternatively not influenced by ramming, if the encounter was observed or not observed, respectively, within the period of ramming influence. Waiting times were similarly categorised if more than 50% of the waiting time was overlapping with the period of ramming influence. In order to include a reasonable amount of encounter observations and waiting times encounter indicators for the period from March 30th to August 1st 2002 using a resilience time of 8 hours were investigated (Table 9). The effect of ramming activity was not significant with a resilience time of 8 hours, although median durations generally decreased and waiting times generally increased during periods of ramming influence.

Changing the resilience time to lower values did not alter the significance of the different factors in the BACI-analysis, but it did have substantial effect on the calculated BACI-effect as well the uncertainty of this (Figure 29). The BACI-effect increased dramatically from 1.1 minutes to 122 minutes when changing the resilience time from 8 to 0 hours, whereas the uncertainty associated with estimates during periods of ramming influence increased dramatically as well. Reducing the resilience time had severe implications for the number of observed waiting times during periods of ramming influence. Thus, with this analysis there are strong indications that ramming affects the porpoise activity on time scales of a few hours, but this cannot be verified statistically due to data limitations. Changing the resilience time for duration of porpoise encounters did not have a similar effect.

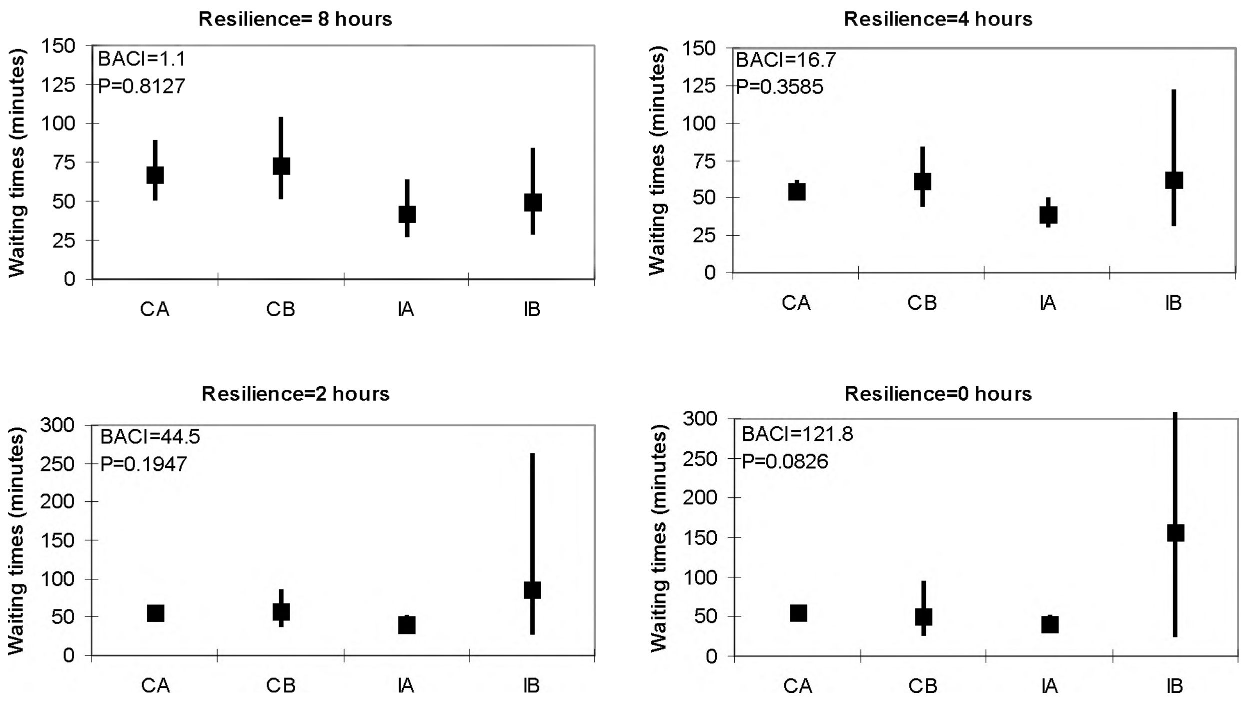


Figure 29: Median and 95% confidence limits for mean waiting times for combinations of control and impact area combined with periods of ramming influence. Resilience times from 0 to 8 hours are shown. The BACI effect was calculated as (IA-IB)-(CA-CB). Note the difference in scaling between top and bottom panels.

The potential impact of ramming can also be investigated by identifying the waiting time associated with each single ramming activity, i.e. the waiting time to the first reappearance of porpoises after ramming activity has ended. Such observations may provide a better means for assessing changes, because the first encounter after ramming may indicate the time of reappearance to normal activity, i.e. after the first reappearance the distribution of waiting times may become identical to the pre-ramming distribution again.

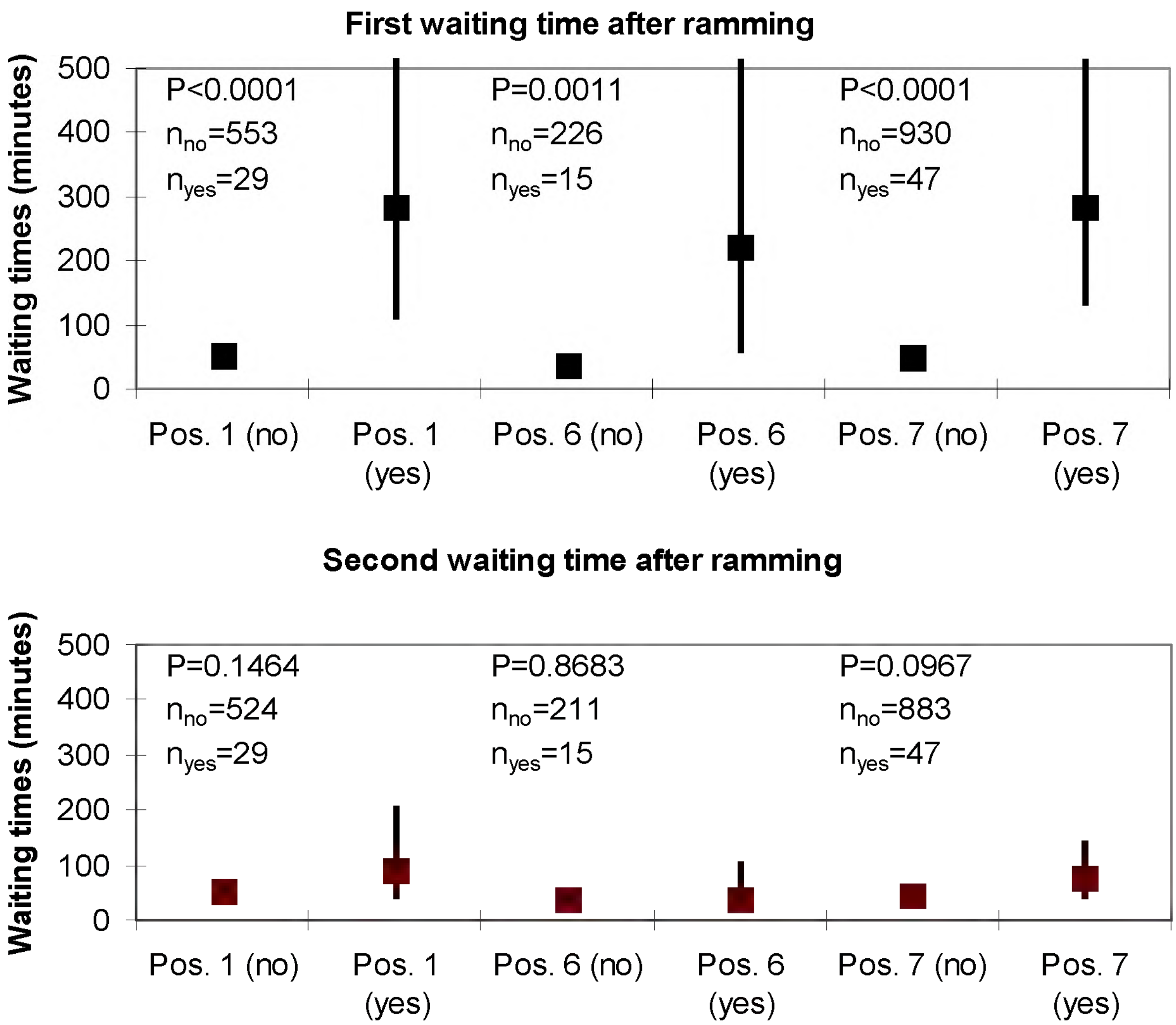


Figure 30: Median and 95% confidence limits for mean waiting times for the first (top graph) and second (lower graph) encounter of porpoises after ramming activity (denoted yes) compared to general distributions of waiting times for Pos. 1, 6 and 7 (denoted no) from March 30th to August 1st 2002. Test for differences in these distributions were carried out station-wise, and the significance of the test as well as the number of observations in each of the distributions is given in the graphs.

The number of observed waiting times associated with ramming activity is rather limited and provided too few data for a BACI-type analysis. However, the ramming activity was almost equally distributed over the period from March 30th to

August 1st 2002 it can therefore be investigated if the waiting times following ramming activity are longer disregarding temporal variation in porpoise activity. The latter assumption is valid if porpoise activity is not systematically related to the planned ramming activities, i.e. assuming that ramming activities are not planned to take place during such short-term periods that naturally have a lower porpoise activity. It was found that waiting times to the first encounter of porpoises after ramming were significantly different from the overall distribution of waiting times at Pos. 6 and 7, whereas waiting times for the second encounter after ramming were not significantly different at any of the stations (Figure 30).

Waiting times for the first encounter increased by factors of 5.3, 5.9 and 5.9 for Pos. 1, 6 and 7, respectively, corresponding to increases in waiting times of 3-4 hours. Small increases (less than doubling), although not significant, were observed for waiting times for the second encounter of porpoises following ramming activity. The median increases in waiting times were less than 40 minutes for all positions. Thus, the impact of ramming activity has had an apparent and short-lived effect on harbour porpoise activity in the Horns Reef area in general.

There were generally few porpoise encounters during ramming activity, and the prolonged first waiting time would therefore generally cover both the periods of ramming and post-ramming. With an average period of 1 hour for ramming, the porpoise activity returned to normal levels approximately 2-3 hours after ramming activity had ceased. The ramming activity also had an effect on positions both within the control and impact area, which for that matter means the entire Horns Reef. Hence, ramming activity has largely reduced the abundance of porpoises in the Horns Reef area for a short period after which the porpoise activity reached the normal level for the construction period.

5.3.7 Summary of stationary POD analysis

The monitoring efforts resulted in a rather small data set of POD recordings, which has to some extent limited the ability to obtain a coherent picture of all the variations affecting porpoise activity in the Horns Reef area. Fortunately, the density of porpoises in the area is high and this has resulted in a useful data set despite the relatively short periods of logging.

The baseline study showed that variation due to shifting of PODs is relatively small compared to all the other sources of variation. If the seasonal variation by monthly means is decribed, it was found that Pos. 1, 3 and 6, and to some extent Pos. 5 as well, showed similar temporal trends, whereas Pos. 8 was different. Pos. 1, 3, 5 and 6 were used for the general environmental impact assessment during the construction period, and Pos. 7 was included for assessing short term effects.

The daily click frequency level decreased over the entire Horns Reef from the baseline study to the construction period. This tendency was also reflected in shorter duration of porpoise encounters whereas waiting times remained unchanged. This general decrease from baseline to construction period could be associated with changes in seasonal densities or potentially also the construction activity as ramming was found to affect the entire Horns Reef. Due to the limited data set, little information is available on seasonal and interannual variation to determine the most likely cause of this general change in activity from the baseline to the construction period.

Ramming activities affected porpoise activity at all monitoring positions in the Horns Reef region with lower click intensities and increasing waiting times following ramming. Thus, there is an immediate, but short-lived response to ramming activities.

In conclusion, ramming activity has a short-term substantial effect on the porpoise activity over the entire reef. The generally lower acoustic activity level during the construction period could potentially be associated with construction activities. However, as this change was observed at all POD positions, it cannot be excluded that the lower activity could be due to general temporal variations in porpoise densities in this part of the North Sea as well.

5.4 Towed POD

A total of 10 harbour porpoise click trains were found during all surveys, corresponding to 11.5 percent of a total of 87 visual sightings of porpoise groups on the same surveys. Hit rates for individual surveys are shown in Table 10.

Table 10. List of surveys where both acoustic and visual observations were made. The number acoustic observations as well as the number of porpoise groups (and number of animals) observed visually is shown. The hit rate is calculated on basis of acoustic observations in relation to the number of porpoise groups seen.

Date	Acoustic records from towed POD	Visual observations of groups (no. of animals)	**Hitrate between acoustic records and visual obs. (groups)**
20. April 2002	0	0 (0)	-
21. April 2002	3	29 (67)	**10.3%**
8. June 2002	1	1 (1)	**100%**
9. June 2002	0	4 (5)	**0%**
29. July 2002	1	29 (89)	**3.4%**
12. Feb 2003	0	8 (13)	**0%**
13. Feb 2003	0	5 (10)	**0%**
18. March 2003	5	11 (15)	**45.5%**
Mean	10	87 (200)	**11.5%**

The maximum cruising speed was 10 knots or approximately 300 meters per minute. The maximum visual detection range in front of the boat is 500 m and the POD is towed 200 meters behind, which means that the POD will pass the position of a visual sighting within approximately 2 minutes. Four of 10 acoustical sighting were found within 2 minutes after a visual sighting and 6 of 10 were found within 5 minutes.

Likely harbour porpoise encounters were plotted on survey maps. An example from the survey conducted on 29th of July 2002 is shown in Figure 31. Maps for the remaining surveys are found in appendix B.

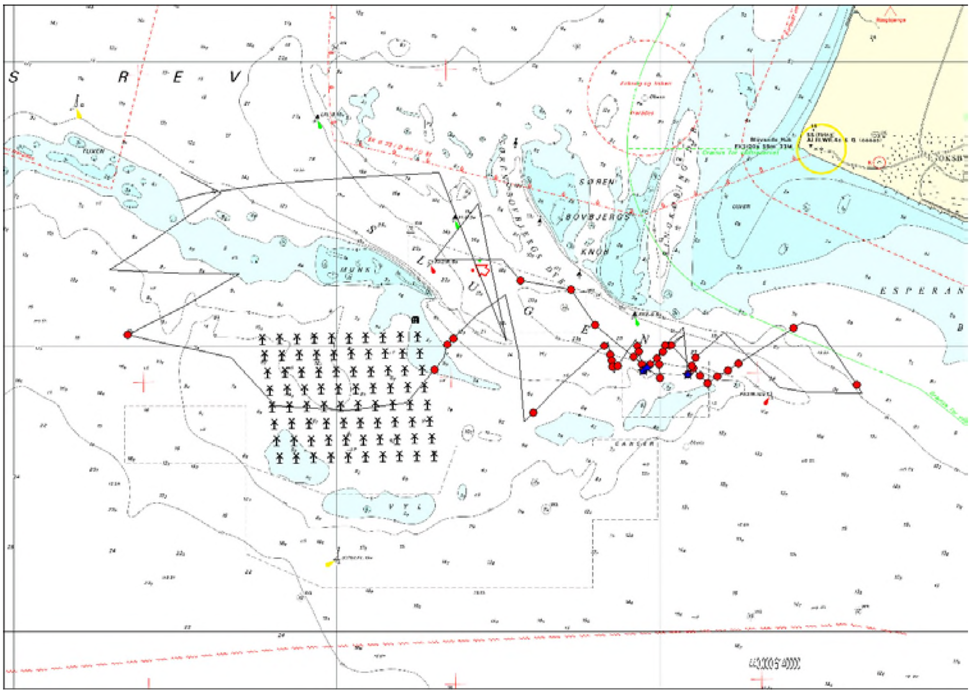


Figure 31. Survey record from the 21 April 2002. The acoustic POD observations are shown with blue stars and visual observations with red dots. The survey effort is shown with the grey line. 29 groups (69 animals) were seen and three acoustic detections obtained. Most observations were situated on the eastern part of Horns Reef (Slugen).

6 Discussion and Conclusion

6.1 Effects of construction phase

This study has provided considerable new knowledge on the possible short-term effects on harbour porpoises from the construction of offshore wind farms. This is despite the fact that data collection during this effect study was affected negatively by extensive loss of acoustic data loggers and the long pause in investigations between September 2002 and January 2003.

In the environmental impact assessment it was envisaged that harbour porpoises would leave the area of the Horns Reef wind farm during the construction phase due to the high noise levels generated by ramming of monopiles (Skov et al. 2000). It was further assessed that animals would return to the wind farm area after the construction phase. The data now collected, indicate that harbour porpoises have been affected by the ramming operations both in terms of behaviour and abundance over a range of temporal and spatial scales, thus expanding the potential effects beyond what was suggested in the EIA.

Data from the deployed PODs provided strong indications that ramming affects the porpoise acoustic activity on time scales of a few hours, although smaller long-term changes could not be assessed due to data limitations. The impact of ramming activity seemed to have a short-lived effect on harbour porpoise acoustic activity in the Horns Reef area in general, as the activity returned to normal levels approximately 3-4 hours after ramming activity had ceased. The ramming activity had an effect both within impact and control areas. The porpoises thus either left the area during ramming operations or changed their behaviour in ways which resulted in fewer porpoise signals being picked up by the PODs. Hence, ramming activity reduced the activity of harbour porpoises in the entire Horns Reef area for a short period after which the activity resumed.

It should be emphazised that the fact that porpoises left the area during ramming operations was not only expected but also intended, as deterring devices (pingers) were deployed prior to ramming operations in order to protect the porpoises from the ramming noises. It is unlikely however, that all the effects observed can be attributed to the deterring sounds alone, as they were of comparatively low intensity relative to the ramming noises. Pingers produce sounds with source levels of approximately 150 dB re. 1 μP at 1 m and are known to deter porpoises out to distances of 100-200 m. Seal scares operate at higher source levels (16 kHz, 195 dB re. 1 mPa at 1 m; Magnus Wahlberg; pers. comm.), but still significantly below the levels from ramming sounds.

The statistics on daily intensities indicated a significant negative BACI effect over the entire period, indicating that the resumed level of activity in the wind farm area was lower during the construction period as compared to the baseline. This is expected, as a large number of other construction activities were continuously ongoing in the period as well as a large number of service vessels continuously present in the area.

At a larger temporal and spatial scale the acoustic statistics on daily intensity and frequency showed that the ramming activity had affected the activity of the animals in both control and impact area, and that the decreases during ramming in both of these indicators were of the same magnitude. On this basis and on the basis of the behavioural observations and sampled densities it is evident that both the impact and the control areas on Horns Reef were affected over larger time scales by the ramming activity. The test of differences in observed behaviours indicated an impact on the proportion of potentially feeding animals (judged from their non-directional behaviour) within a distance of 10-15 km from the wind farm. This was further corroborated by the comparison of sampled densities of porpoises between the baseline and the ramming period, which indicated a general decline in the abundance of animals during the intensive part of the construction.

In summary it is concluded that individual rammings had an effect on the acoustic behaviour of harbour porpoises on the reef, lasting up to 3-4 hours after end of each ramming operation. Furthermore there were more general effects on abundance and behaviour of the animals in the construction period. It is not clear, however, whether this change in behaviour is truly attributtable to the construction or whether it is related to overall temporal variation. Collection of data in the coming summer months should help to clarify this issue.

6.2 Towed POD - Methodological considerations

The performance of the towed pod was not impressive. Hit rates realised (comparing with visual sightings) indicate that the sensitivity of the POD is not sufficient to be used for towing. The highest hit-rate was obtained on a survey with only one visual observations where also one acoustic recording was made. The remaining hit rates were between 0% and 45.5 %. Two surveys encountered high numbers of visual observations (29 groups each) but the hit rates for these were no more than 3.4 and 10.3 %.

There is some degree of temporal agreement between acoustic and visual observations, as 40 % of the acoustic events were found within 2.4 minutes after a visual sighting and 60 % were found within 5 minutes

It can be concluded that towed PODs does not give the expected outcome in form of data sufficient enough to consolidate or replace data from normal visual surveys as they have been carried out during the monitoring programme.

We do not find that using towed PODs for acoustic surveys add to the information gathered by visual observation, for the above mentioned reasons. We thus recommend that a towed POD is not deployed on furture surveys.

Nevertheless, we are confident, that acoustic surveying techniques can be improved and add substantial information to ship based surveys. This is especially true at seastates above 2, where visual surveys cannot be conducted reliably. Acoustic surveys however, should be conducted with equipment designed for towing. The T-POD used in 2002 was never designed to be towed after a ship at 10 knots and instead a genuine towed array of hydrophones should be employed.

One such system, the IFAW array has been developed and used with success on surveys for porpoises during several years in British waters (Pierpoint, 2001; Gillespie and Chappell, 2002) and is now commercially available.

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8 Dansk resumé

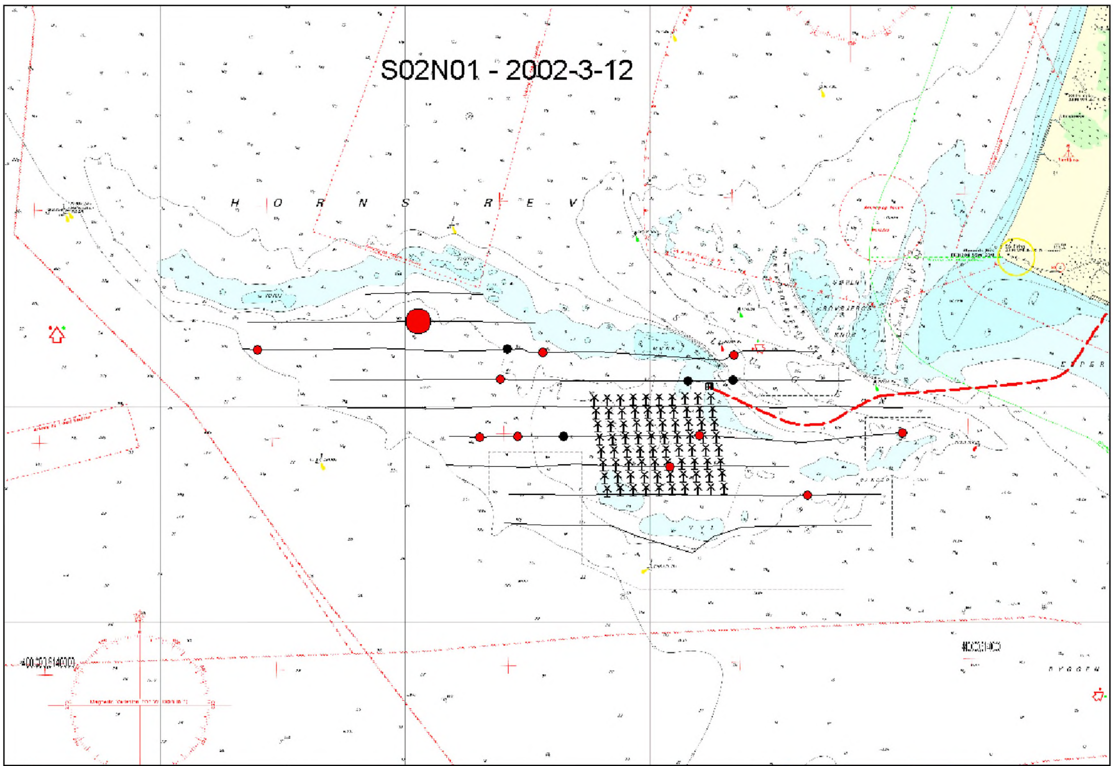
I løbet af sommeren 2002 blev verdens hidtil største vindmøllepark, bestående af 80 2MW møller, opført på Horns Rev ud for Blåvandshuk. I forbindelse med opførselen blev det undersøgt i hvilket omfang byggeaktiviteterne påvirkede tilstedeværelsen og adfærd af marsvin (*Phocoena phocoena*). Specielt fokus blev lagt på nedramningen af møllefundamenterne, der består af en stålcylinder, der bankes ned i havbunden med en hydraulisk hammer. Det er velkendt at denne type operationer kan resultere i meget høje lydtryk under vandet.

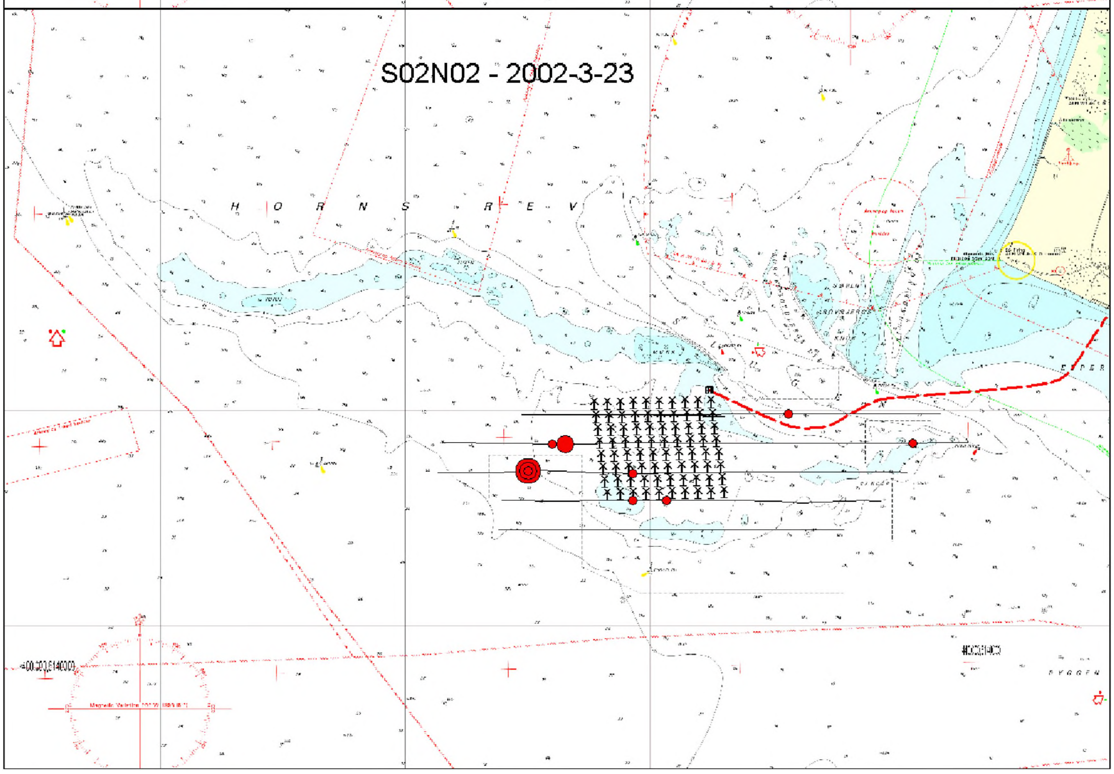
De samlede resultater fra optællinger fra skib, adfærdsobservationer fra skib og måling af akustisk aktivitet inde i og udenfor mølleområdet viste at byggefasen påvirkede marsvinene både over korte tidsrum (timer) og lange tidsrum (hele byggeperioden). Ved starten af de enkelte nedramninger gik dyrenes aktivitet ned både inde i og uden for mølleområdet og returnerede først til normale niveauer igen 3-4 timer efter at ramningen var overstået. Denne adfærd var forventet på forhånd men også ønsket, idet skræmmelyde (fra pingere og sælskræmmere) blev udsendt umiddelbart før hver ramning begyndte og under hele ramningen med det formål at få sæler og marsvin til at forlade området og dermed undgå eksponering til de store lydtryk genereret under ramningsoperationen. Ændringerne i udbredelse og adfærd over større afstande kan ikke forklares alene ved skræmmelydene, af forholdsvis mindre lydtryk end ramningslydene og effekterne må tilskrives de sidstnævnte.

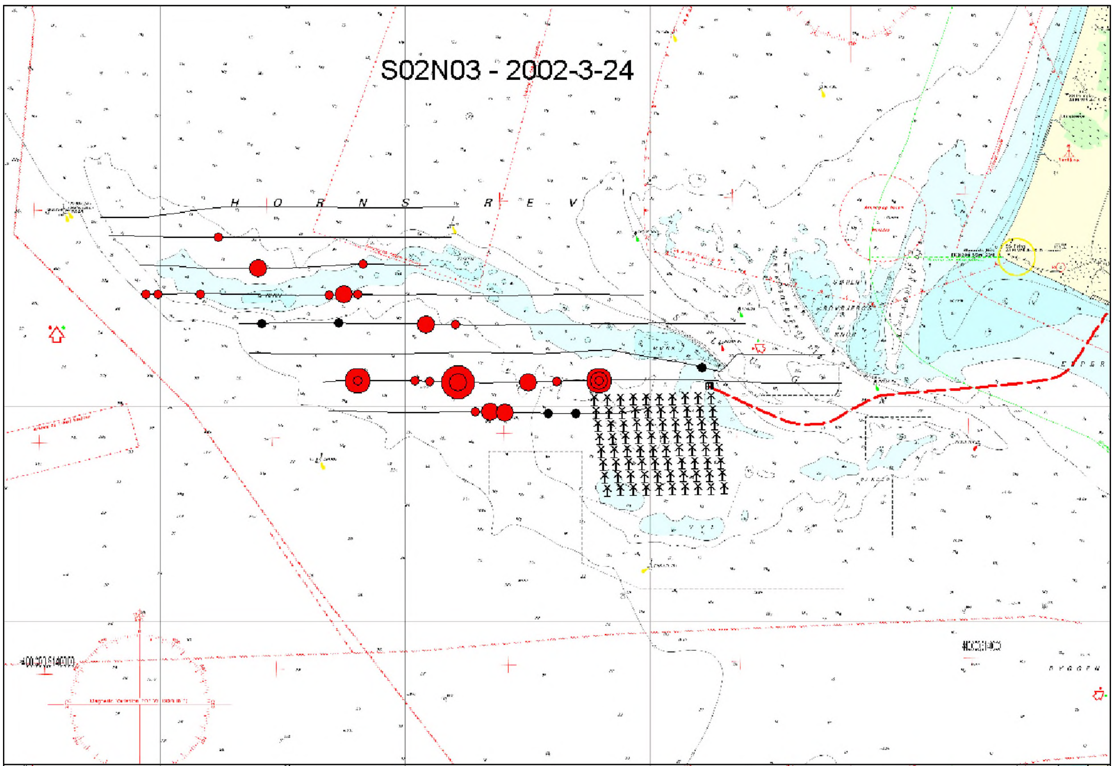
Under hele byggefasen kunne ses en generel påvirkning af dyrenes adfærd i en afstand af op til 10-15 km fra mølleområdet. I forhold til før og efter byggeperioden blev der observeret en nedgang i adfærd, der hos marsvin normalt forbindes med fouragering. Tællinger før, under og efter byggeperioden indikerede ligeledes at der generelt var færre marsvin tilstede på Horns Rev i byggeperioden. Det kan imidlertid ikke på nuværende tidspunkt afgøres om disse effekter skyldes byggeriet eller er et udtryk for generelle tidsmæssige variationer.

9 Appendix A - Individual surveys

The following maps present data from individuel surveys. Red dots indicate harbour porpoise sightings, graduated in size with number of animals per sightings. Black dots indicate seals.



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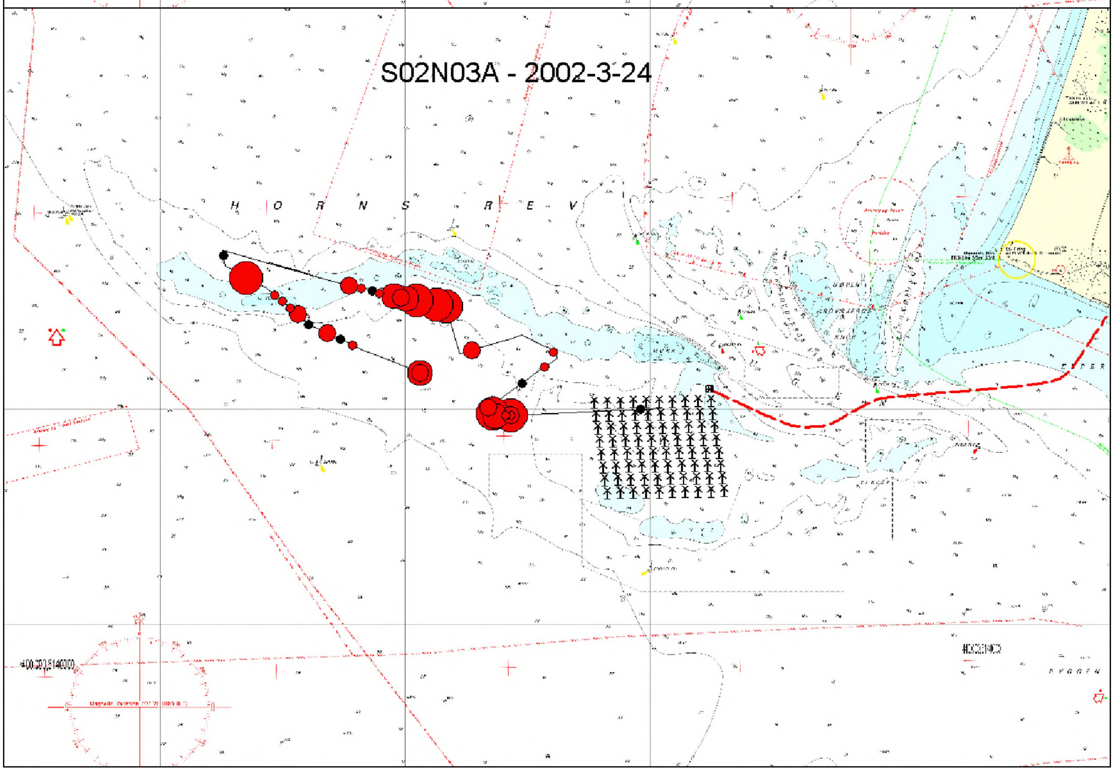
H O R N S R E V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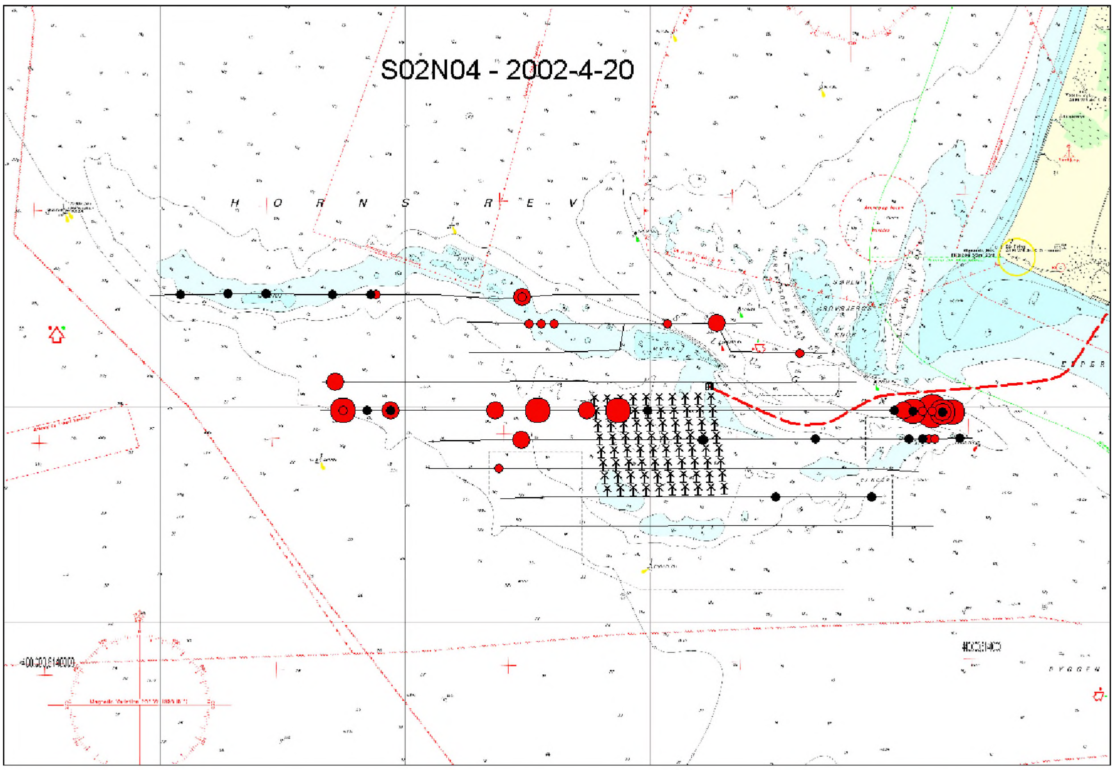
H O R N S R E V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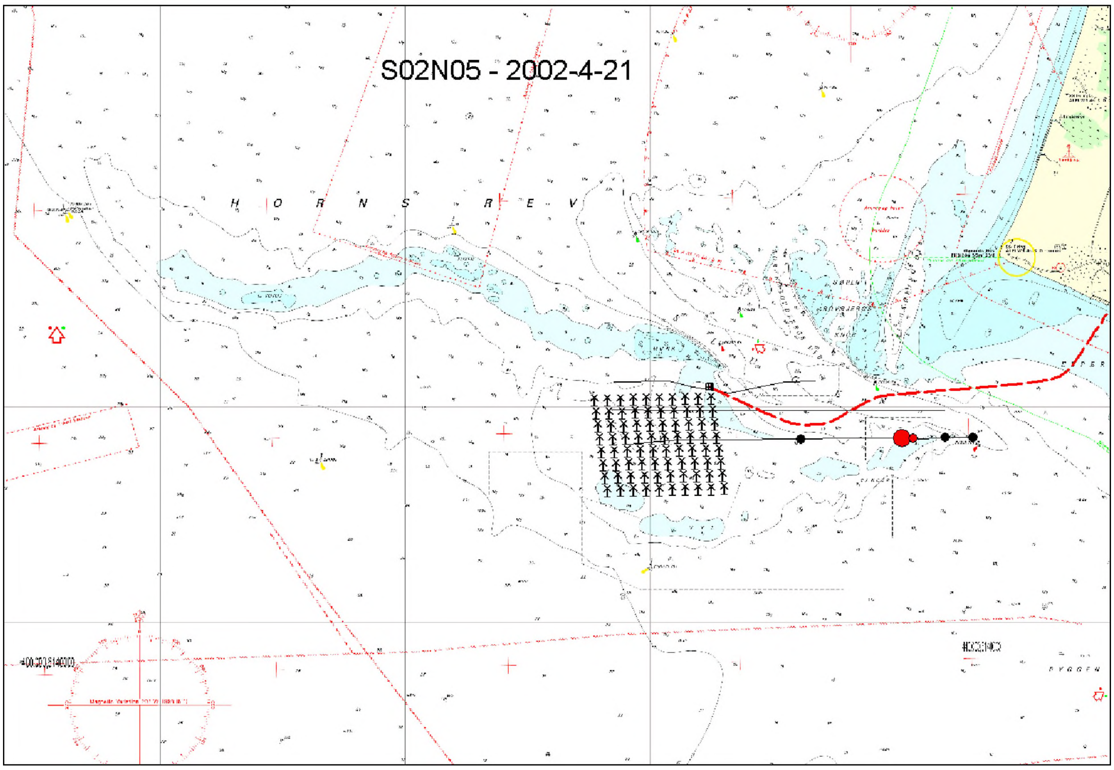
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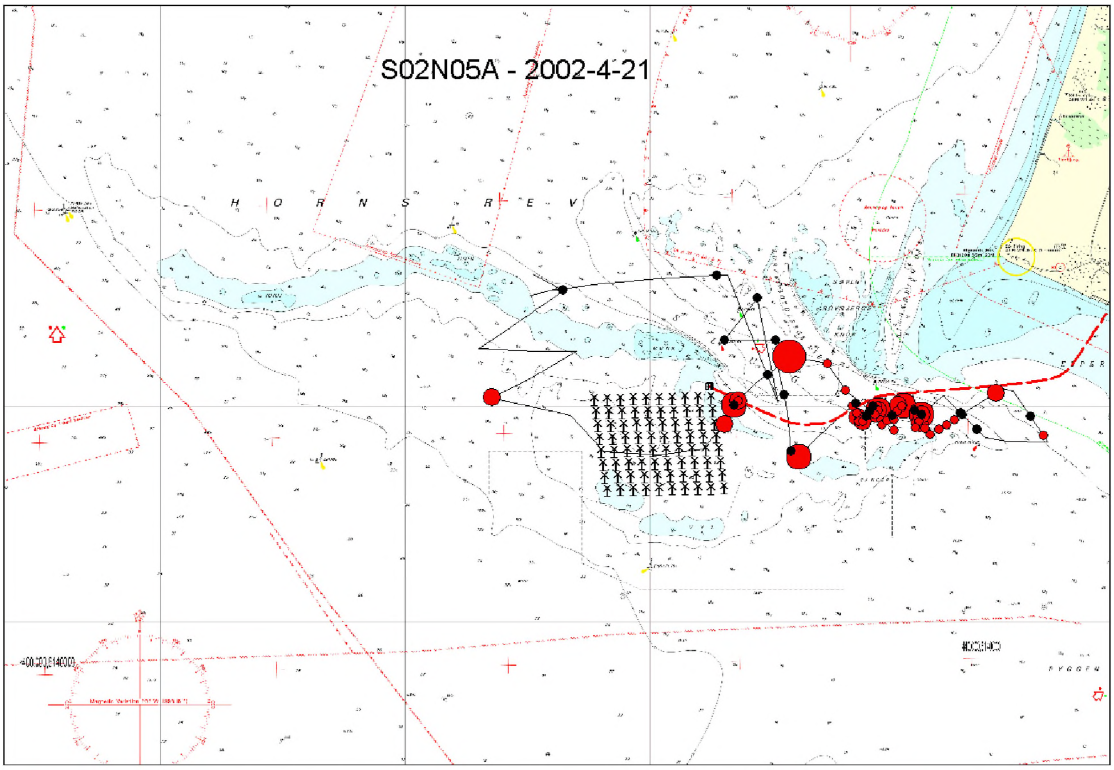
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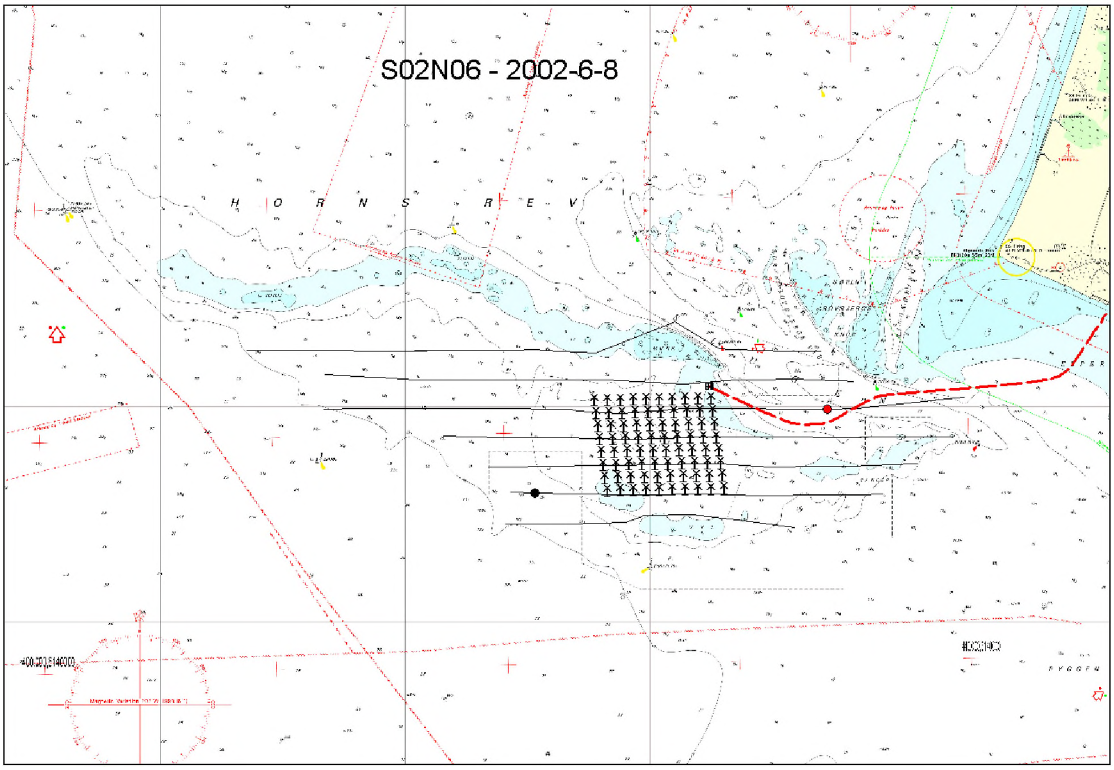
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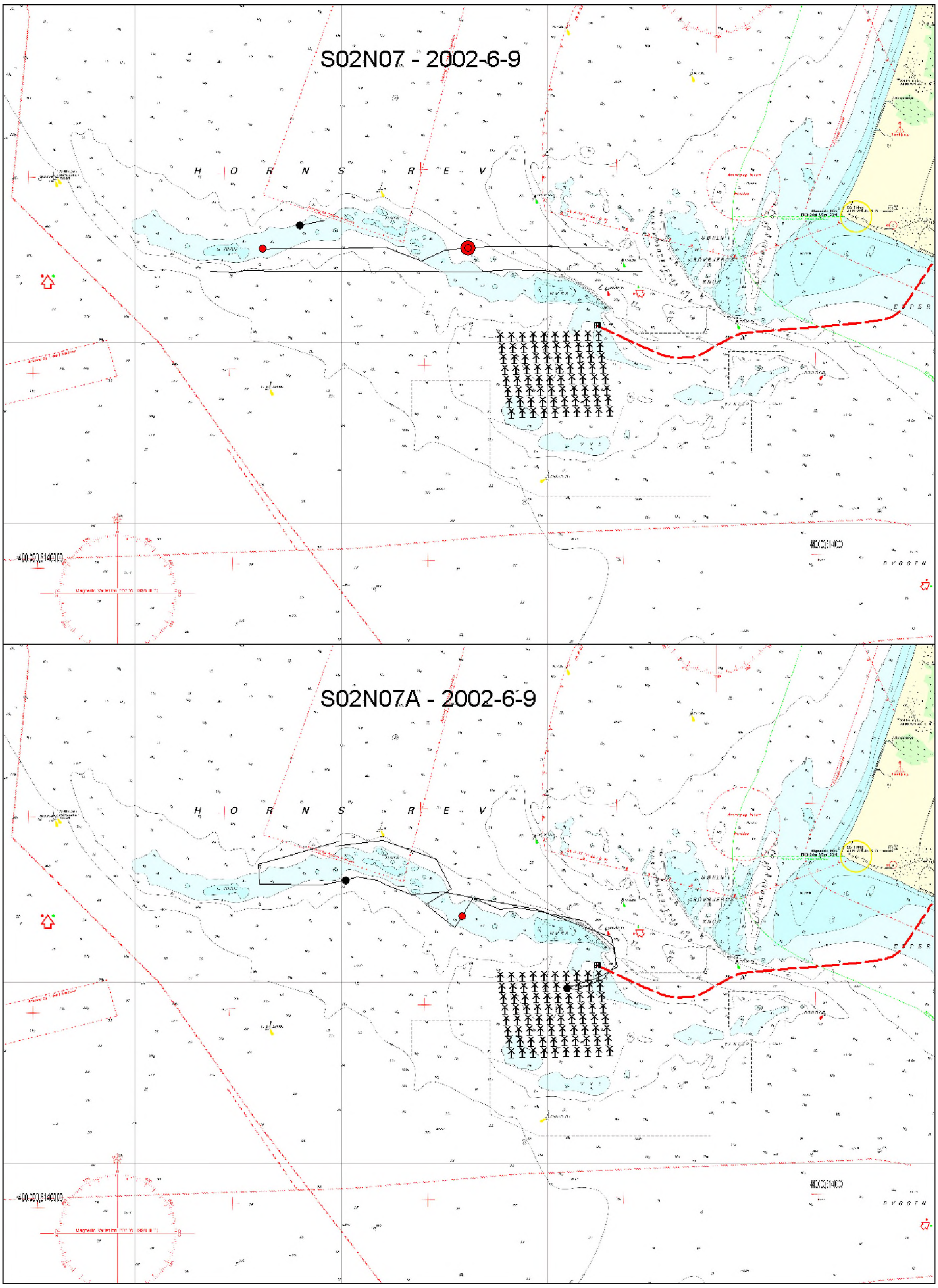
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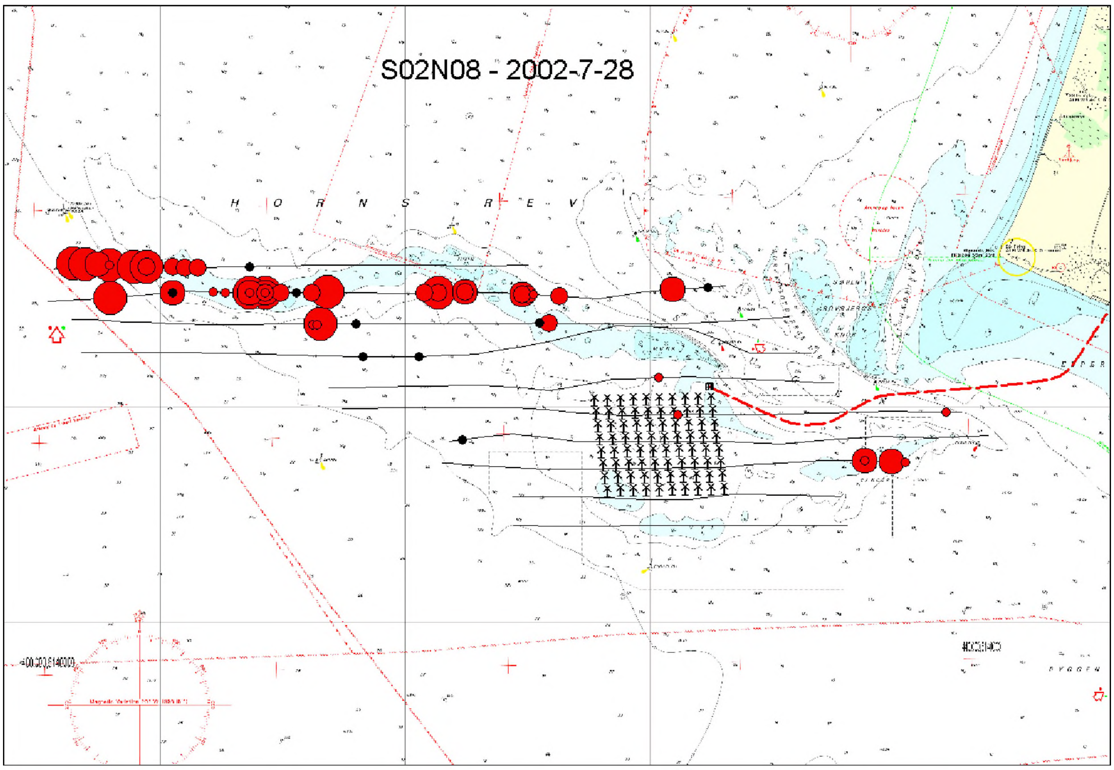
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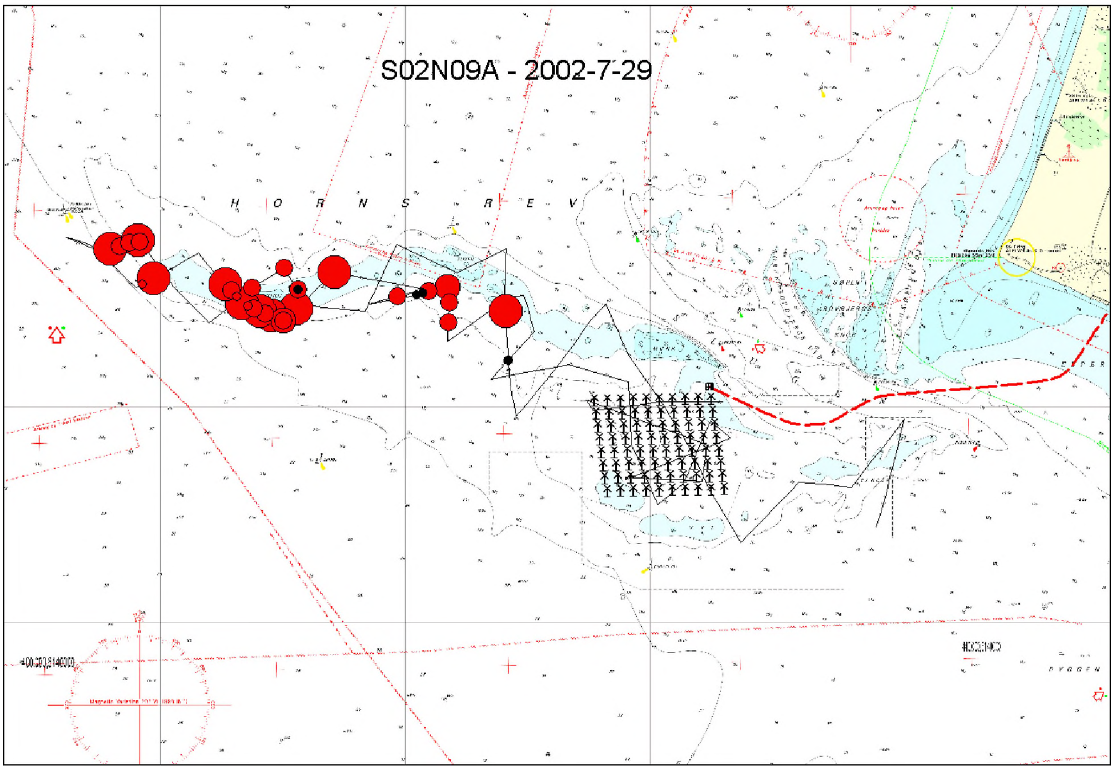
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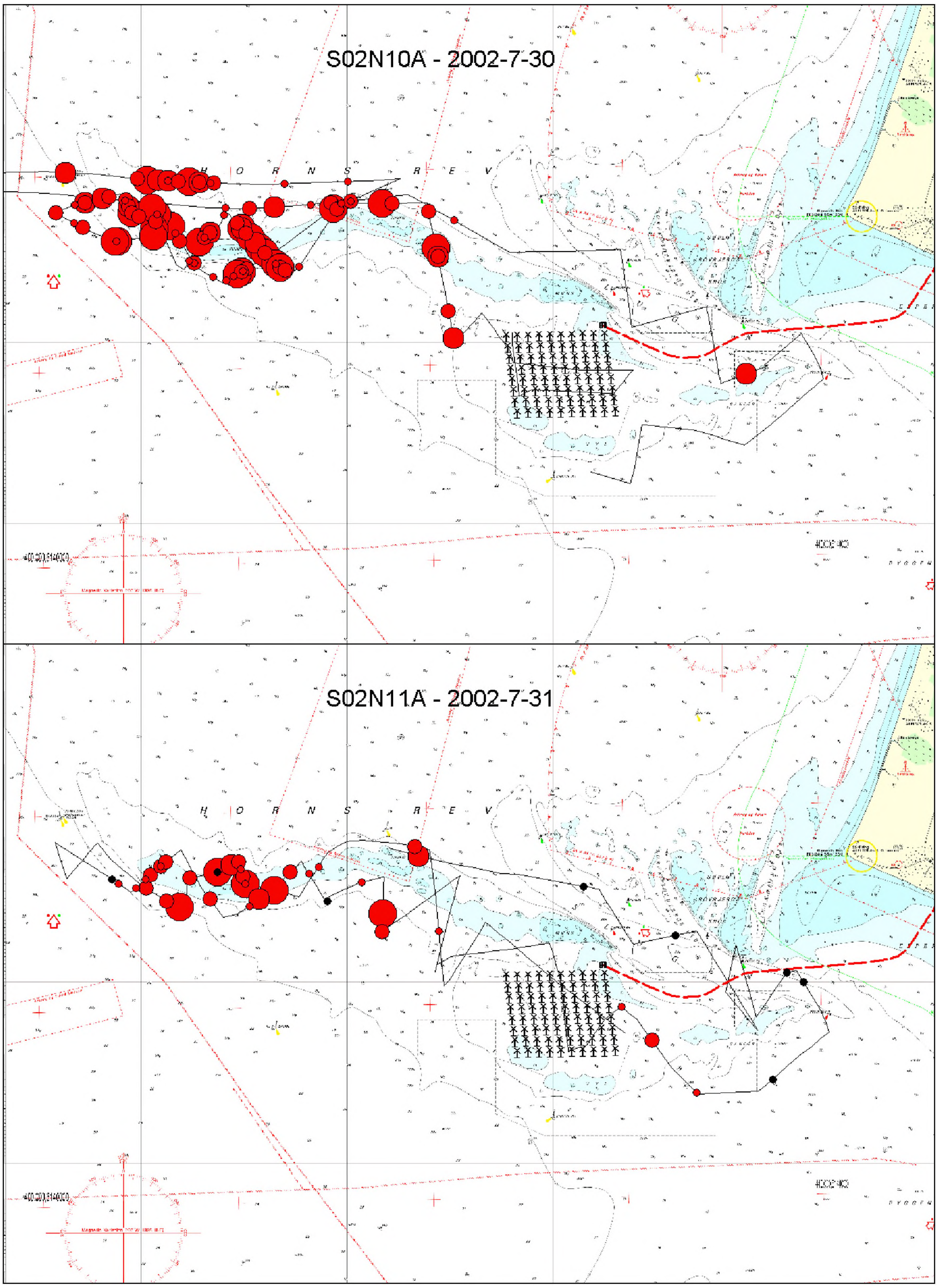
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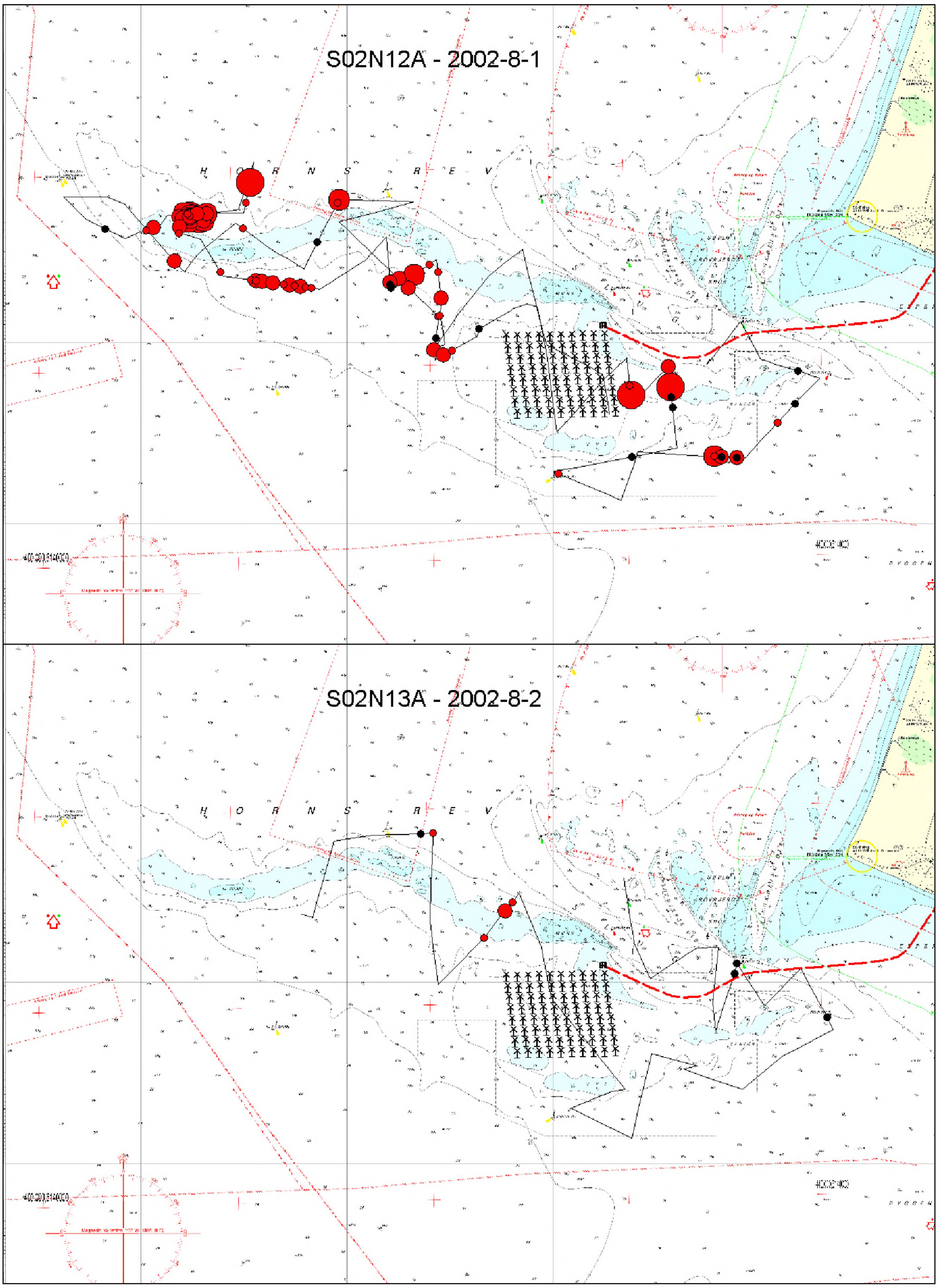
H O R N S R E V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H O R N S R E V
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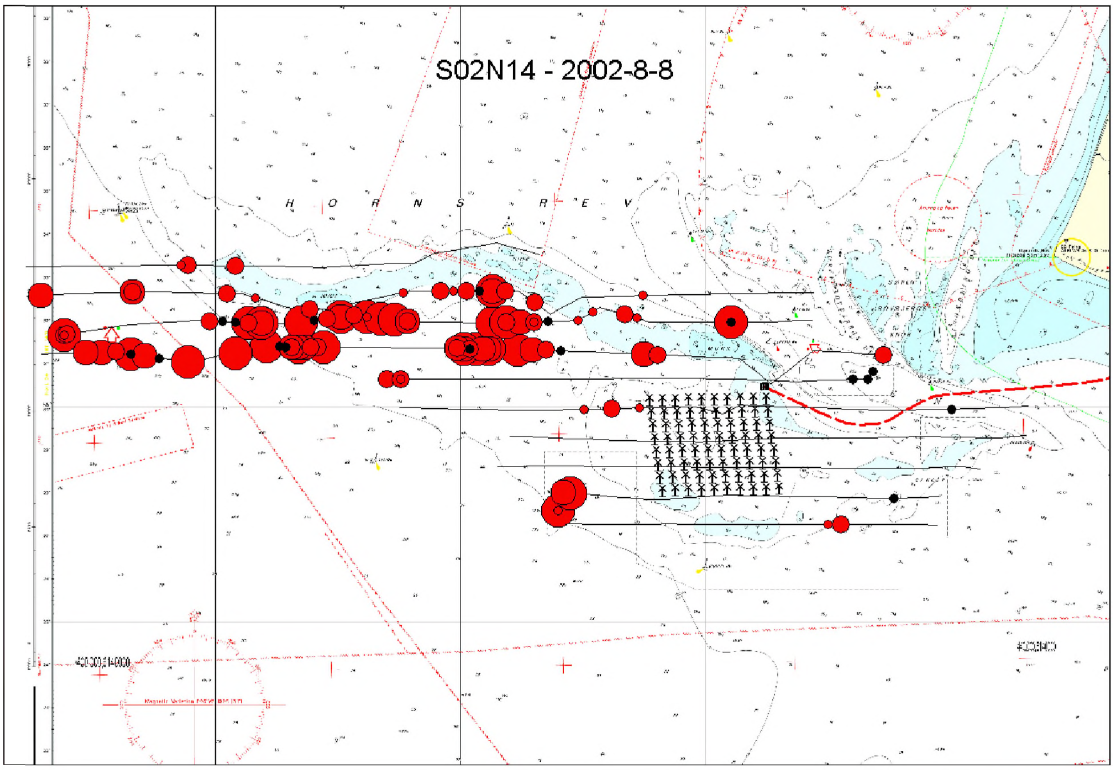
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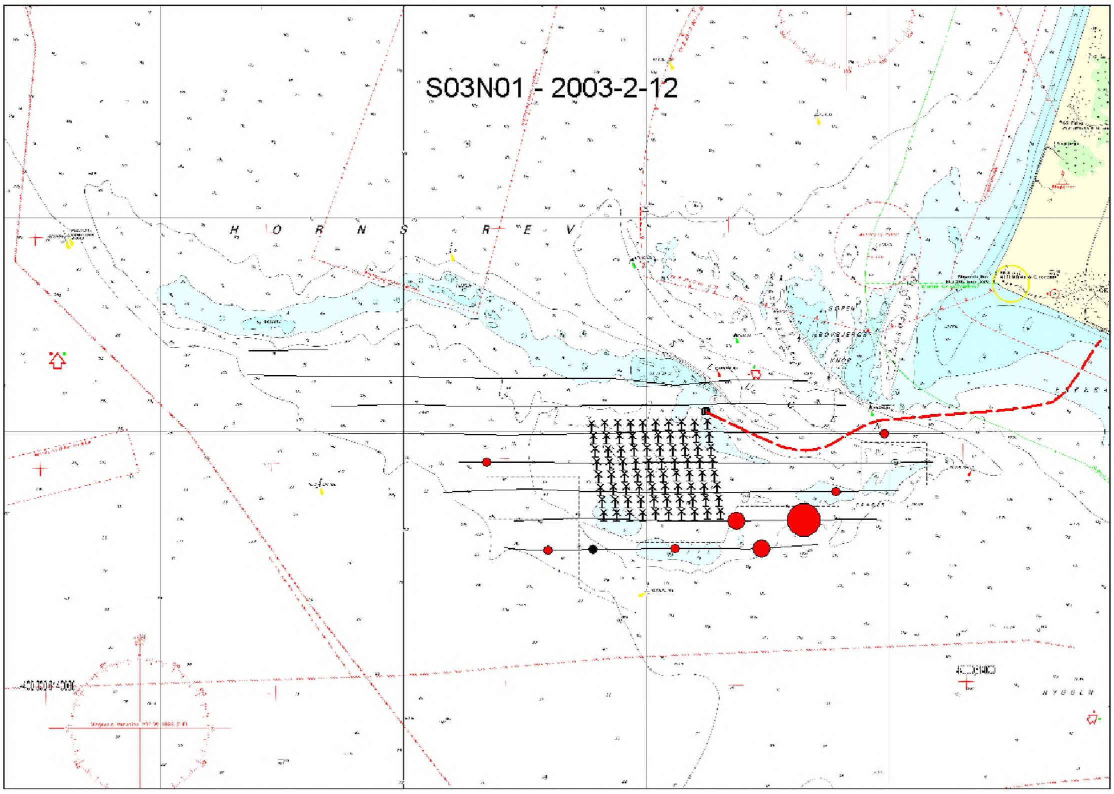
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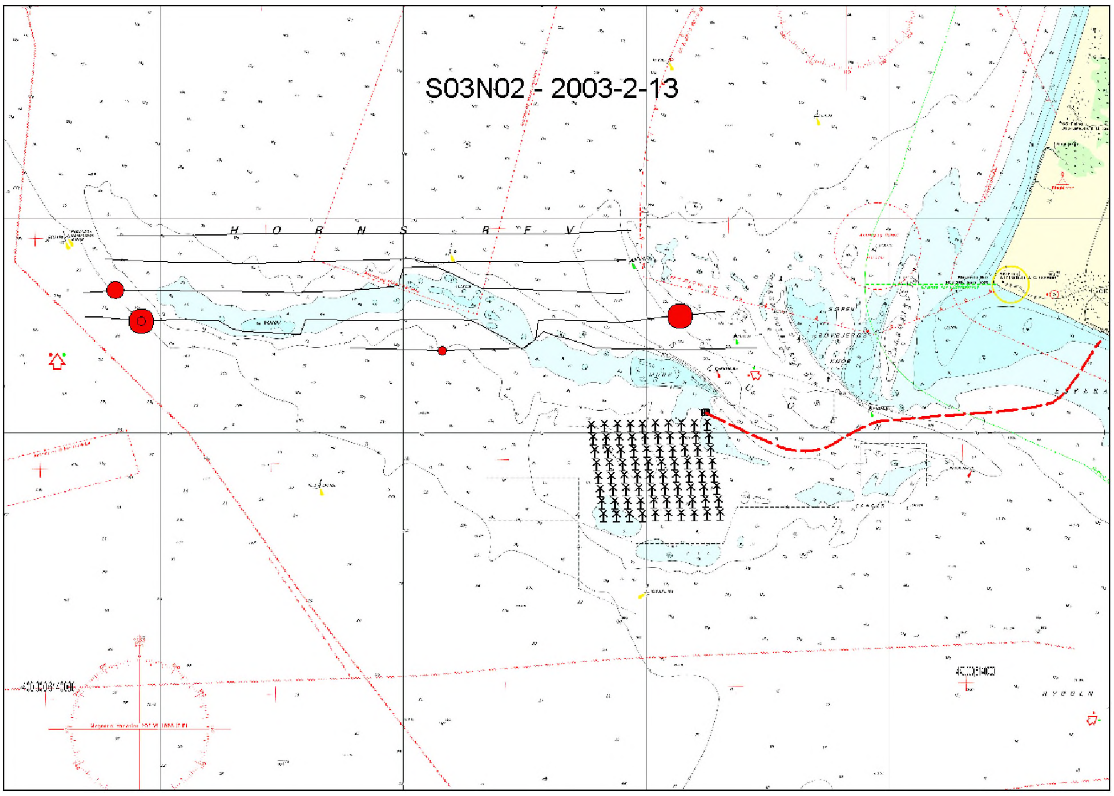
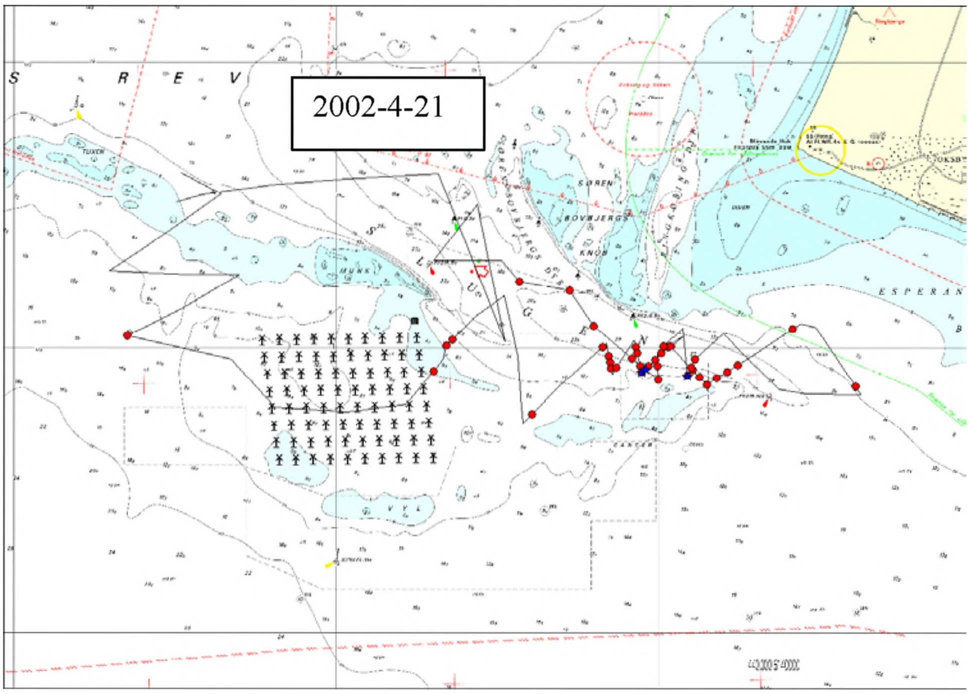
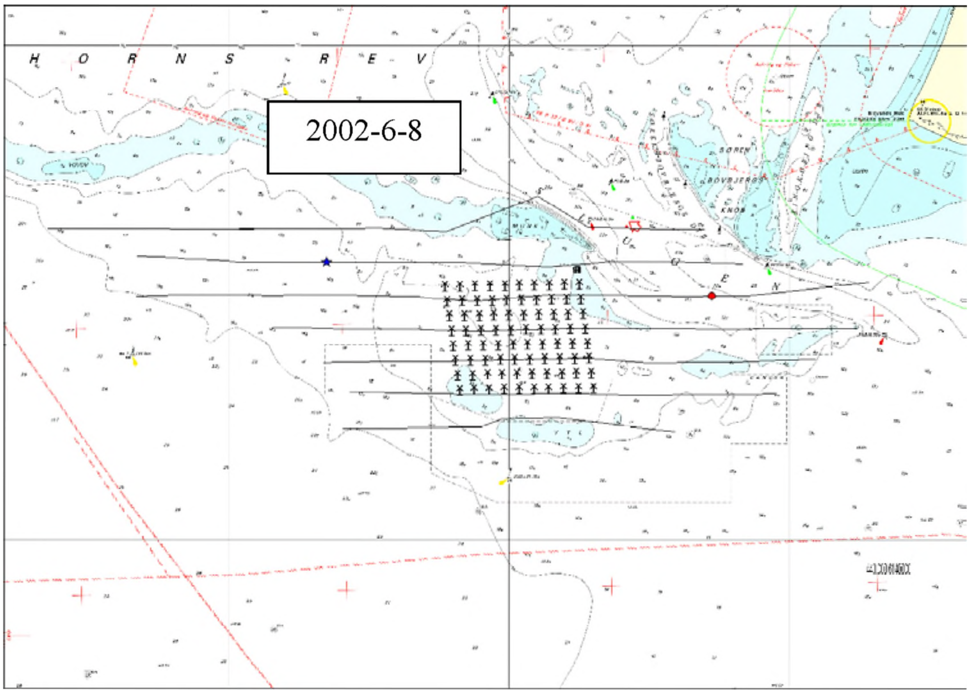
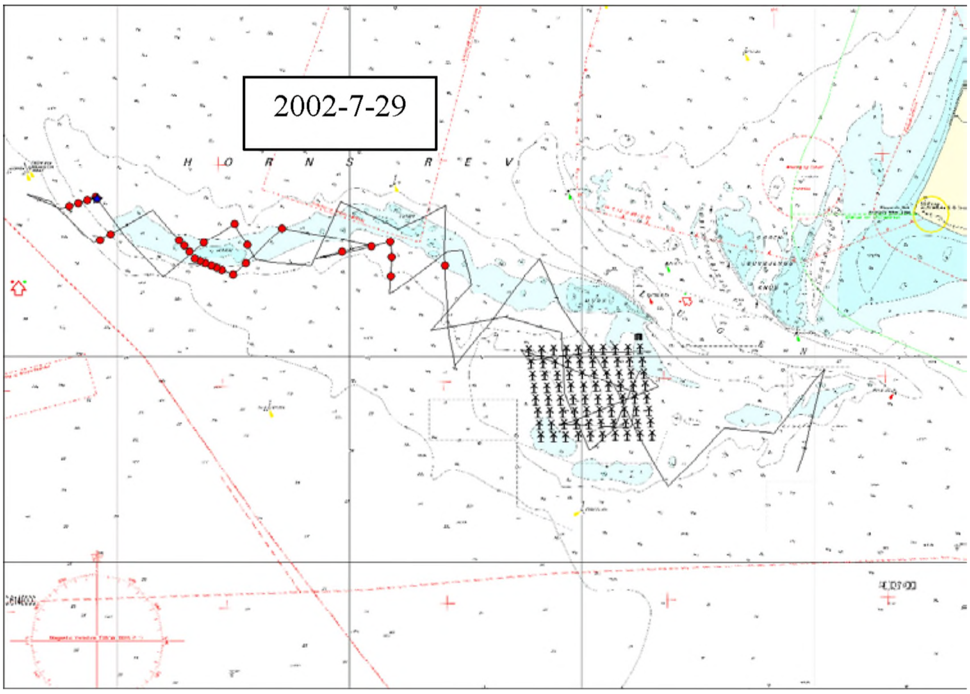

S03N02 - 2003-2-13
H O R N S R E V

10 Appendix B - Towed POD data

The following maps show data from ship surveys where a towed POD was employed and porpoise sonar signals recorded (see section 5.5. for details). Red dots indicate visual observations of harbour porpoises, blue stars indicate click trains registered on the POD as porpoise signals. Survey dates were acoustic monitoring were made are 21.4.2002 (this side, top), 8.6.2002 (this side bottom), 29.7.2002 (next side, top) and 18.3.2003 (next side, bottom).



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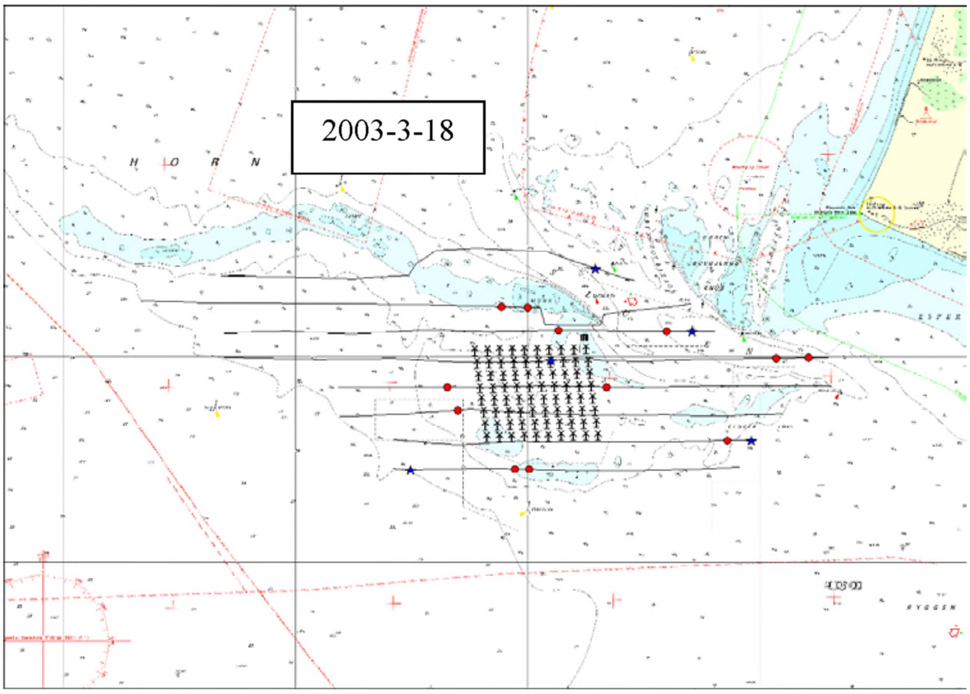
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