Tidal influences on the distribution of the harbour porpoise *Phocoena phocoena* in the Marsdiep area, The Netherlands

L. L. IJsseldijk

Integrated Coastal zone Management
BSc Thesis

Imares/NIOZ
Texel, The Netherlands
G. Aarts & C. J. Camphuysen

Hogeschool Van Hall Larenstein
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Acknowledgement

After many experiences around the world, I don't think I ever realised that such a beautiful piece of nature was just 35 kilometres away from home. Neither did I expect any possibilities of whale watching in the Netherlands which turned out to be so successful and fun. I experienced the sea, dunes, beaches and countryside of Texel as a peaceful, but cold environment to live and work in and I enjoyed every minute.

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Lonneke

Den Hoorn, Texel
29-05-2013

Summary

Harbour porpoises (*Phocoena phocoena*) are the smallest cetaceans in the North Sea (Gaskin, 1974). They have recovered from being rare to nowadays being present throughout the year in numbers reaching to 80 000 in the Dutch sector or the North Sea (Camphuysen & Siemensma, 2011). The only area where studies were conducted prior to the disappearance of the harbour porpoise from Dutch waters was in the Marsdiep by Verwey between 1931-1973. The Marsdiep area is a tidal inlet between the mainland of Noord-Holland and the Wadden Sea island Texel.

The historical research by Verwey (1975ab) was conducted along the shores of the Marsdiep between Huisduinen and the harbour of Den Helder. He noted harbour porpoises visiting the harbour entrance at high tide and movements influenced by ebb and flood tides were documented (Verwey ,1975a). Verwey questioned if "*Phocoena has special reactions on the tides*?".

With the harbour porpoise nowadays being present in high numbers in the early spring months (Camphuysen & Siemensma, 2011), this resulted in the hypothesis of this research: harbour porpoises move into the Marsdiep area with upcoming tides and out during ebb. The main question raised is: 'Is there an association between the presence of harbour porpoises and the tidal cycle in the Marsdiep area?'.

The ferry crossing the Marsdiep area daily on a 30 minute interval is used as an observation platform. The ferry offers a unique opportunity as it covers the entire Texel – Den Helder gradient. Besides, compared to land-based observations, there is a lower risk of repetitive counting due to high vessel speed and relative short observation duration. A single observer during this study results in no observer biases. Both environmental as sighting data is collected from 20 February until 2 April 2013.

A total of 134 sightings in approximately 82 hours of dedicated fieldwork during all times of the tidal cycle were conducted. A strong association between the tidal cycle and the presence of harbour porpoises in the Marsdiep area was present, which is supported in the literature. It seems that the tides influence the porpoise presence within the entire area. By dividing the tidal cycle in four tidal stages (high tide, descending tide, low tide and rising tide) a significant difference of harbour porpoise presence is detected. Most porpoises are detected during high tide (n= 56) and at the Texel side (n=38) of the Marsdiep area. A smaller amount of porpoises are detected during descending tide (n=50) and also at the Texel side (n=36). The fewest porpoises are detected during low tide (n=9) and again mostly on the Texel side (n=6). More porpoises are observed again during rising tide (n=19) but here mostly on the Den Helder side (n=10). This means that harbour porpoises in the Marsdiep area show a statistically significant preference for high tide.

Swimming direction does not associate with the tidal cycle. Potential feeding against the tides, the influence of the ferry and the speed of the ferry makes it difficult to determine swimming direction properly and this is often a snapshot. However, no sign of any behavior that indicated foraging is observed in this study.

The harbour porpoises observed tends to choose places of higher water velocities and warmer water temperature as these both associate with the tidal stage. Water velocity does associate with sightings, but is not a better measure than dividing the tidal stages based on water height.

Tide dependent patterns in occurrence of harbour porpoises is also detected in other places in the Netherlands and abroad. Research on harbour porpoises in the Bay of Fundy, Canada, also showed a significantly higher density of porpoises during flood than ebb phases (Johnston et al. 2005). Goodwin (2008) in her study to diurnal and tidal variation of harbour porpoises in Southwest Britain noted no tidal difference in one area (Morte Point), while in another area (Lee Bay) a tidal difference in behavior, group size and distance from shore was detected. Stevick et al. (2002) writes that diurnal movements are likely the result of vertical migration of prey species, but names foraging movements associating with the tides less common in Cetacean species.

Some points of discussions are raised considering the effect of weather conditions and behavioral aspects of the harbour porpoises on the data gathering. The effect of the ferry on the sightings is also unknown. Recommended is more data collection for the following years in order to detect any seasonal patterns in the Marsdiep area, and, with that, in the North Sea. This might help in understanding exactly why porpoises enter the Marsdiep area.

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1. Introduction

1.1 Study species

With a maximum length of 1.86m, harbour porpoises (*Phocoena phocoena*) are the smallest cetaceans in the North Sea (Gaskin, 1974; Figure 1). There are six species of porpoises in the world, and they belong to the family Phocoenidae (Read, 1999; Shirihai & Jarrett, 2006). The harbour porpoise is the only of these species that inhabits the cold waters of the North Sea. They are also found in coastal waters of the North Atlantic, North Pacific and Black Sea (Read, 1999). Harbour porpoises differ from other odontoceti (toothed-whales) by their small size, small triangular dorsal fin, lack of rostrum or beak, and spade-shaped rather than conical teeth (Read, 1999; Shirihai & Jarrett, 2006).

Porpoises have a life span of about 15-20 years and reach sexual maturity at three (males) or four (females) years of age (Gaskin & Blair, 1977; Rogan, 2010). Pregnancy lasts 11 months and one calf is born every one or two years. In the North Sea, birth takes place in spring and early summer in June and early July (Gaskin et al., 1984; Camphuysen & Siemensma, 2011). Porpoises suckle for their first few months of life, but shortly after their teeth emerge they begin to take solid food (Read, 1999; Camphuysen & Krop, 2011).

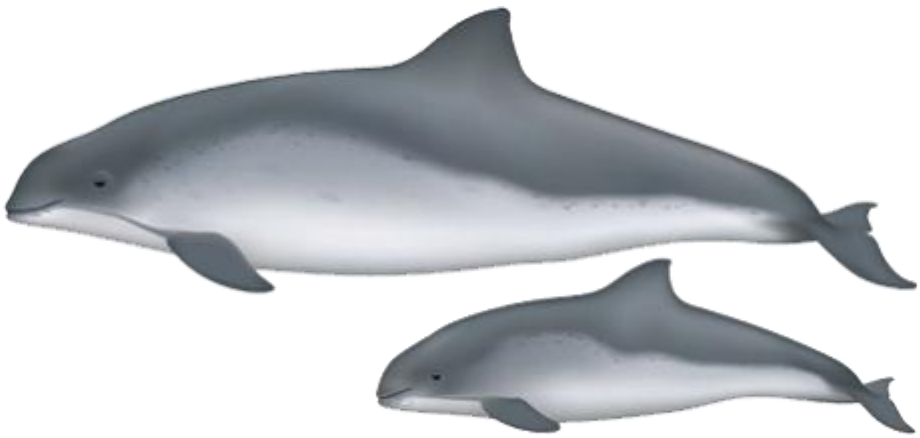

Figure 1: Harbour porpoises (www.thewhaletrail.org)

1.2 Study area

In the North Sea, harbour porpoises are present throughout the year and are seen along the whole Dutch coast (Camphuysen, 2011). Population numbers today reach around 250 000 in the entire North Sea (SCANS II, 2008). Currently, up to 80 000 may live in the Dutch sector of the North Sea (Camphuysen & Siemensma 2011; Scheidat *et al*. 2011). This has not always been the case (Camphuysen, 2004; Rebel, 2010). The only area where studies were conducted prior to the disappearance of cetaceans from Dutch waters was in the Marsdiep (Verwey, 1975ab; Boonstra et al. *in press*). Research was done by Verwey between 1931-1973. He observed bottlenose dolphins (*Tursiops truncatus*) and harbour porpoises.

The Marsdiep area is a tidal inlet between the mainland of Noord-Holland and the Wadden Sea island Texel (Figure 2). This sea strait connects the North Sea with the shallower basin of the Wadden Sea. The area is 4.5 km wide, has an average depth of 4.5 metres and a maximum depth of 53 metres. Tidal currents keep the inlet open (Buijsman, 2007). The mainland is connected with the island by a regular ferry service. At the ferry transect, the area is maximally 27 metres deep. Tidal currents are strongest at the south side of the inlet and the average tidal range at Den Helder is *c.* 1.4m (Buijsman, 2007; Buijsman & Ridderinkhof, 2007).

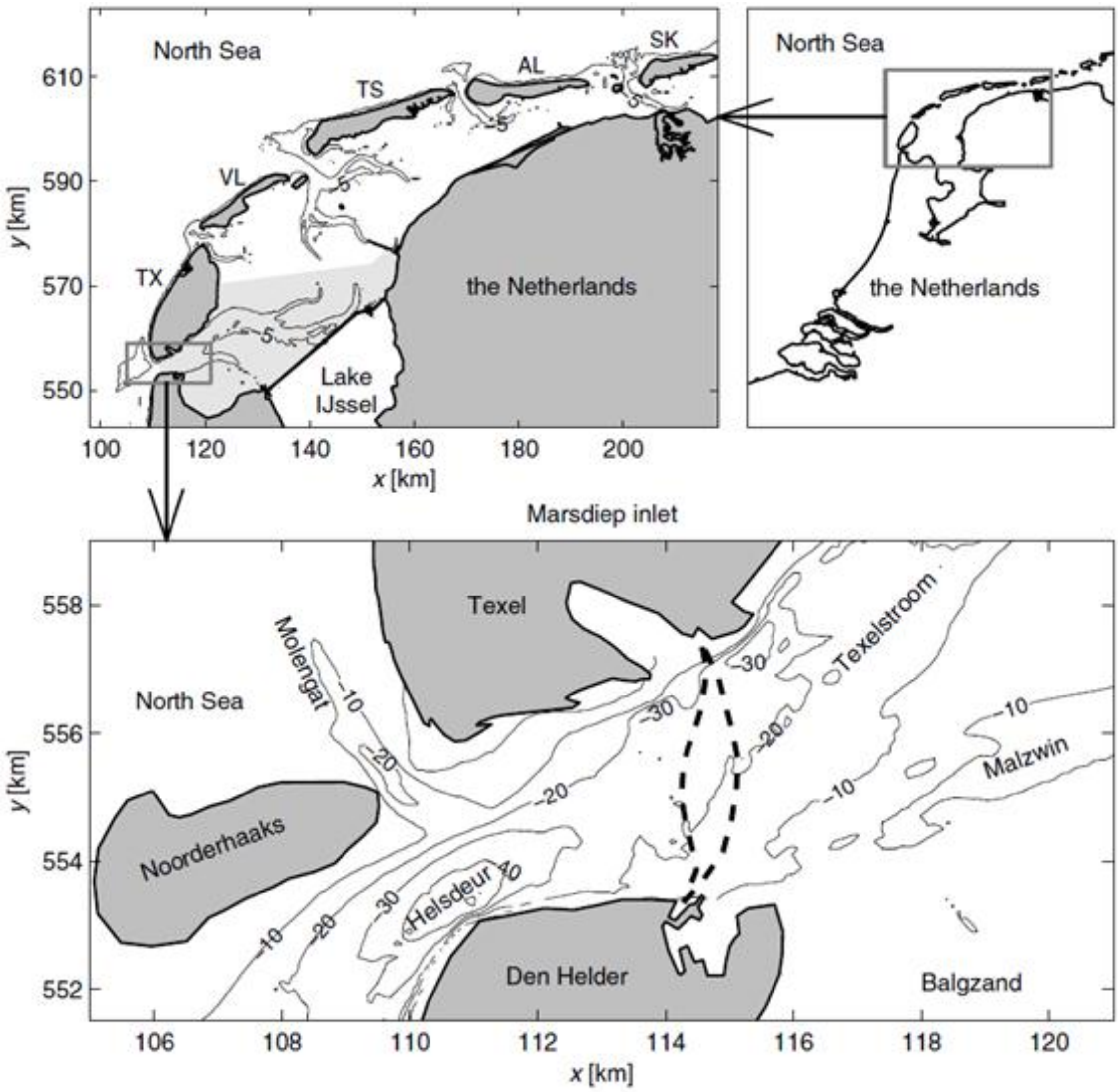

Figure 2: Buijsman's (2007) figure of the Marsdiep area

1.3 Problem description

Verwey noted an absence of harbour porpoises in the Marsdiep area in March and April, but otherwise recorded small numbers of animals around the year. Verwey suspected that the porpoises spent their time further offshore, where whiting was presumably present in high numbers (Verwey, 1975a). Apart from harbour porpoises, bottlenose dolphins were regular visitors in the Marsdiep area in spring (Wolff, 2000) in the early 20th century. Along with porpoises and dolphins, Zuiderzee-herring, were present in the Marsdiep area starting in February with its peak numbers being reached in April (Wolff, 2000).

The Zuiderzee was closed by a dike in May 1932 for the protection of the mainland. This resulted in the disappearance of the Zuiderzee herring in the area (Verwey, 1975a; Lotze, 2005). A decrease in the number of Tursiops in the Marsdiep area was soon detected and it seemed to be linked to the absence of herring (de Wolf, 1983). During World War II, no reliable records or observations on cetaceans were kept, likely because entering beaches during those years was prohibited (Camphuysen & Peet, 2006). After World War II, harbour porpoise sightings progressively declined (Camphuysen & Peet, 2006; Rebel, 2010). Recordings of both bottlenose dolphins and harbour porpoises became extremely rare (de Wolf, 1983).

The disappearing of the bottlenose dolphin can be related to the disappearing of the Zuiderzee-herring, but this is not likely to account for the disappearance of the harbour porpoise (Verwey, 1975a; Lotze, 2005). Porpoises during these years entered the Marsdiep two to three months later than the herring and were still present when herring had left the area. Together with a decrease in the Marsdiep, harbour porpoise numbers in Belgium, Germany and Denmark also decreased in the same years (Koschinski, 2001; Camphuysen & Peet, 2006). It is still largely unknown what caused harbour porpoises to decrease in numbers (Verwey, 1975a; de Wolff, 2000).

In the 1980’s, cetaceans in Dutch waters were rare. Since the mid -1980s the number of harbour porpoise sightings has gradually increased (Camphuysen, 2004). This population return cannot be seen as a local population recovery, however, because the numbers were too high to be caused by reproduction (Camphuysen & Peet, 2006). These increasing numbers are more likely caused by a shift in distribution from the Northern parts of the North Sea into the Southern North Sea. A reduction in the number of prey species in the North Sea may have caused this shift (Camphuysen, 2004).

Dutch coastal waters currently represent an important habitat for the harbour porpoises during most of the year. Harbour porpoises are opportunistic feeders who respond to changes in the food web (Jansen, 2012) and therefore can be seen as sentinel species for the ecosystem in which they live (Bossart, 2012). Due to their small size, harbour porpoises need a high energy demand but are unable to carry large energy stores (Johnston et al., 2005; Koopman, 1998). Availability in prey is therefore often correlated to the distribution of harbour porpoises (Goodwin, 2008; Johnston et al., 2005). Kastelein *et al.* (1997) documented that harbour porpoises cannot survive for more than a few days without food.

The historical research by Verwey (1975ab) was conducted along the shores of the Marsdiep between Huisduinen and the harbour of Den Helder. Harbour porpoises visited the harbour entrance at high tide and movements influenced by ebb and flood tides were documented (Verwey,1975a). Verwey hypothesized if ”*Phocoena has special reactions on the tides*?”.

Boonstra *et al.* (in press) found a strong influence of tidal currents on sightings frequencies around the Marsdiep, with most sightings during late flood and early ebb. Sightings were conducted from four sites on Texel and near Den Helder. Boonstra *et al.* (in press) showed that porpoises were most numerous near Texel. However, no correction was made for differences in observer effects. The observations were made from vantage points on the shore, but a large patch of water between Texel and Den Helder could not be overseen reliably.

The results from both Boonstra *et al.* (in press) and Verwey (1975ab) suggested that harbour porpoises move into the Marsdiep area with upcoming tides and out during ebb. Moving with the tides could save energy. Alternatively, currents may also be used for foraging since harbour porpoises fish against the current (Verwey, 1975a).In the western Wadden Sea, the rise of the water level is faster than the descent. This results in relatively strong flood currents, although ebb duration is longer (Buijsman, 2007). Tidal currents could also provide foraging opportunities (Pierpoint, 2008).

1.4 Conservation status

Marine mammals in general have long life spans, are long-term coastal residents and feed at high trophic levels (Bossart, 2012). As marine mammals, such as harbour porpoises, are mega fauna which are mostly of interest for humans to observe, it is likely that health concerns that affect this species may be detected sooner than other ocean health issues (Bossart, 2012). Knowing when and where harbour porpoises are present in an area may contribute in the protection of this species.

Due to the rapid decline in the population in the 20th century, the status of the harbour porpoise in the North Sea and adjacent waters became a concern (Hammond et al. 2002). Growing concerns about conservation status of small cetaceans in the North and Baltic Seas led to the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) (Read 1999, Koschinski 2001, Hammond et al. 2002; Camphuysen & Siemensma, 2011). This agreement has been signed by most European countries and aims to promote collaboration between countries to achieve and maintain a favorable conservation status for small cetaceans (Hammond et al. 2002). The problems cetaceans in European waters deal with are also recognized in the Commission Directive on the Conservation of Natural Habitats and of the Wild Fauna and Flora. All cetaceans are also listed in Annex IV (species of Community interest in need of strict protection) and the harbour porpoise and bottlenose dolphin are both also listed in Annex II (species of Community interest whose conservation requires the designation of Special Areas of Conservation) (Hammond et al. 2002; Camphuysen & Siemensma, 2011). Information on distribution and abundance of small cetaceans in the North Sea are also included in plans of other international organizations, such as in United Nations Environmental Programme (UNEP) in its global plan of action for cetaceans, in the International Council for the Exploration of the Sea (ICES) through its marine mammals committee and its working group on seals and small cetaceans in European Seas, and in the North Sea Ministerial Conference of 1990 (Hammond et al. 2002).

Economic and social relevance of knowing when and where harbour porpoises are present will give humans the opportunity to adapt the planning of certain activities, such as Navy exercises, in the nearby area. Harbour porpoises are highly dependent on sound to navigate, socialize and detect prey. For that reason, anthropogenic sound may negatively impact the behaviour and distribution of porpoises (Camphuysen & Siemensma, 2011). Those conflicts are particularly lilely to occur in coastal regions, like the Marsdiep area with its harbour and two naval bases. Those conflicts only occur when porpoises are indeed present, and therefore information on this aspect of their life cycle is essential. This is valuable information for conservation and management. Besides, knowing these potential tidal patterns will give investigators the opportunity to adapt their protocols when planning airplane and/or seismic surveys. Biological relevance of this study is to expand the current knowledge about distribution patterns and tidal use of harbour porpoises in the Marsdiep area. This study could contribute to the knowledge of the presence of this species in the entire North Sea and help in better understanding their distribution and feeding behavior.

1.5 Research aim

Due to the elusive nature of porpoises, studying their behaviour and ecology in the North Sea is challenging. In contrast, the Marsdiep area is unique in the sense that the entire area can be overseen from land. Its complex bathymetry and oceanography offers a rare opportunity to study wild cetaceans (Boonstra *et al*. in press).

The overall aim of this curiosity-driven study is to find out more about harbour porpoises in the western Wadden Sea in order to find ecological interesting aspects from their occurrence. In this we move forward in understanding the way the harbour porpoise enter the Marsdiep area in early spring and how they use this area. This will contribute in gaining more knowledge about this species and therefore can contribute in protection of this species and the habitat it occurs in. Aim of understanding tidal movements of harbour porpoises will help in better understanding the feeding, distribution and energy aspects of this species. The small and clear area of the Marsdiep provided unique opportunities for observing porpoises in the wild.

1.6 Research questions

The main question of this research is:

<u>Is there an association between the presence of harbour porpoises and the tidal cycle in the Marsdiep area?</u>

This is investigated by answering sub questions addressing both the potential associations as well as potential explanations:

Is there an association between water height and harbour porpoises presence?

Is there an association between swimming direction of harbour porpoises and the tidal cycle?

Is there an association between local water velocities and the presence of harbour porpoises?

Is there an association between local water temperature and presence of harbour porpoises?

2. Methodology

2.1 Data collection

Monitoring harbour porpoises has been done by land-based observations by Rebel (2010) from the location Huisduinen close to Den Helder. Rebel noted that harbour porpoises used to be known as summer visitors of the area, but more currently, they **seem to be present** more during the winter months. Rebel (2010) noted in his study that harbour porpoises in the Marsdiep are present from the end of February and during the whole month of March. Also Boonstra *et al.* (in press) found a strong influence of tidal currents on sightings frequencies around the Marsdiep. This is confirmed by Camphuysen and Siemensma (2011) in the harbour porpoise conservation plan.

Camphuysen & Peet (2006) noted that harbour porpoises can be observed early spring from the ferry between Texel and Den Helder. Sightings of harbour porpoises in the entire area of the Marsdiep are conducted in order to determine the effort-corrected abundance in relation to tidal phases. For doing this, the ferry crossing the area daily on a 30 minute interval seemed to be the useful observation platform needed.

Observations in the Marsdiep area were done from the ferry “Dokter Wagemaker” of the TESO (Texels Eigen Stoomboot Onderneming) (figure 3), leaving Texel every hour. It’s the type Double-ended Ro-Ro Ferry, built in 2004 and 2005. It is 130.40m long and 22.70m wide. The capacity of the Dokter Wagemaker is 300 cars and 1750 passengers. The draught is 4.4m (Teso, n.d.). The speed of the ferry is 17km per hour (10 Knt) (Buijsman & Ridderinkhof, 2007). The vessel contains two bridges, located in the front and rear of the vessel. The observer was located on the bridge wing, approximately 17.5 meters above the sea surface. The ferry offers a unique opportunity for using it as an observation platform as it covers the entire Texel – Den Helder gradient. Besides, compared to land-based observations, there is a lower risk of repetitive counting due to high vessel speed and relative short observation duration.

Figure 3: Dokter Wagemaker; observation platform (www.teso.nl)

Observations were done by one observer. A single observer results in no observer biases. The position changed every half an hour, so every passage, as observations are always done looking in the same direction the ferry navigates. Starboard and port were also switches every half hour. This resulted in observation of the total area every two hours when weather conditions were optimal. Every half hour, 90 degrees was surveyed. When wind and/or sun had a major effect on the sighting ability, the best side was chosen. The materials used during the fieldwork were; binoculars, a voice recorder, an angle board, a GPS, a measuring stick and a camera. Observations were done by using the naked eye and a pair of binoculars. Data was always recorded using a voice recorder to minimize accidently missing porpoises when writing.

The data collected is formulated below. This was put together with the use of SCANS-II handbook: Small Cetacean in the European Atlantic and North Sea Information for observer's handbook.

First a **waypoint** was made using the GPS, so later on the position of the observer could be determined by looking up the exact coordinates in the program *Mapsource*. These coordinates were stored in the GPS when making a waypoint. Then the **angle** of the sighting relative to the ship is measured, using the pointer on an angle board. Next, the **distance** of the observed porpoise from the observers point of view is estimated using a measuring stick and divided into six classes: A: 0-50 metre, B: 51-100 metre, C: 101-200 metre, D: 201-300 metre, E: 301-500 metre and F: > 501 metre. The **group size** is recorded. Porpoises are placed as a group whenever they were observed within 100m of each other and swam in the same direction. Due to the speed of the ferry (approximately 10 knots), time to observe group bonding is not included in this study so group size determination is a snapshot for each sighting and probably an underestimation. The **swim direction** is recorded using a compass. Swimming direction in association to tides might reveal information about feeding strategies. Lastly, the most dominant **behaviour** detected was recorded, options: wheeling or swimming slow (70), escape from ship (rooster tail) (71), swimming fast; not avoiding ship (72), apparently feeding; herding behaviour (75), apparently feeding; other behaviour (76), calf at tail of adult (77), basking; afloat (79), spyhopping (80) and approaching ship (83). These behaviours are from the European Seabirds at Sea (ESAS) surveys which include cetacean sightings. The total list of cetacean behaviour is added in appendix 1.

Besides information about the sighting, environmental information was also recorded during each start of a track and during a five minute interval during a track. Environmental data was collected using the voice recorder. Data collected:

- **Sea state**: using sea state 0-5. Appendix 2 consists of a description of each sea state, copied from SCANSII: shipboard observer field handbook.
- **Glare**: record sun glare present in the 90 degrees that needed to be observed, from 0-4. Score description again can be found in appendix 2.
- **Visibility**: record visibility using scores 0-3. Appendix 2 consists of a description of these scores.
- **Cloud cover**: ranged from 1-8, with 1= no clouds and 8= fully cloudy.
- **Precipitation**: of which was chosen between none (N), rain (R) and fog (F). Also needed to be noted it the precipitation is intermittent (I) or continuous (C).
- **Wind direction**: record from which direction the wind blew relative to the ship, using 0 = ahead, 90 = right angle, 180 = behind.
- **Wind speed**: in Beaufort scale.
- **Comment**: again comments were given.

After the ferry crossed the area, the data recorded was written onto printed datasheets. Two datasheets were used in this research; one consisting of the environmental data (Appendix 3) and one consisting of the sighting data (Appendix 4). These datasheets were put together with the use of the SCANS-II: Small Cetacean in the European Atlantic and North Sea Information for observers and from the European Seabirds at Sea (ESAS) database.

Several a-biotic factors may have limited the success rate of observations. First of all, fieldwork can only be done when weather circumstances allow this. Sea state and wind speed/direction are closely related. The more wind, the higher the sea state. Sightings can be blocked by waves which makes observations difficult. A sea state of score three or below will only be good enough for fieldwork.

Besides sea state, visibility is an important factor for observations. Visibility of at least 500-1000m is necessary as good observation conditions. Decisions for starting fieldwork were done based on scanning the area from the land and by using online webcams available to get a good view of the other side of the area. Deteriorated conditions during fieldwork meant the end of data collection for that day.

After fieldwork was completed, the data was imported into an Excel spread sheet. This spread sheet played a critical role when the data was analysed.

Since 1998, a vessel mounted Acoustic Doppler Current Profiler (ADCP) has been installed under the ferry (Buijsman, 2007). This device is used to measure current velocities. The downward hanging ADCP is attached to the hull of the ferry, at 4.3m below the water surface, near the horizontal centre of the ferry (Buijsman & Ridderinkhof, 2007). Data has been collected by the Royal Netherlands Institute for Sea Research (NIOZ) since 1998 (Buijsman & Ridderinkhof, 2007). Simultaneous sampling of local water velocity and local water temperature measurements are recorded by the ADCP. This data is used for this research by linking the measurements, which are averaged for each passage, with the sightings. Presence of harbour porpoises in the Marsdiep area might associate with water temperature and local water velocities. This study could contribute in the knowledge of adaptions for saving energy by swimming together with the tides and in warmer waters, so more warmth and energy is saved. The variation in water velocities, which are tidal related, will be used to determine if porpoises do use tidal currents when they make use of the area.

Water height data is provided by Rijkswaterstaat for the entire period of the fieldwork. It is measured on the Den Helder side of the Marsdiep area.

2.2 Data pre-processing

All data is stored in Excel and transported to SPSS version 19. Sighting and environmental data is combined into one database so analyses could be done using only this sheet. This database consists of the following data:

- Date (dd/mm/yy);
- Start time;
- End time;
- Duration (h);
- Logarithm of duration;
- Sightings (n);
- Tidal stages in classes;
- Oriëntation (East or West);
- Sea state (units);

- Water velocity (units);
- Water temperature (average per passage);
- Sun glare (units);
- Visibility (units);
- Cloud cover (units);
- Precipitation (units);
- Wind direction (units);
- Wind speed (units);
- Damage threshold ;
- Waterlevel (units);
- Time to high water and (units);
- Time to low water (units).

This resulted in 1106 rows of data. With 134 sightings, this means that the row for sightings consists of mostly zero's.

A few corrections in the database had to be made. The distances classes are not equally divided. To correct for this, the porpoises per distance class are divided by the size of each distance class. To correct for the difference in time observed per tidal stage, the amount of sightings per tidal stage are divided by the total hours observed during that tidal stage.

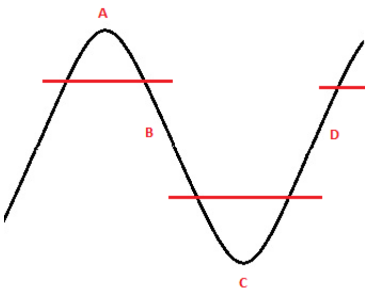

Figure 4: Tidal stages (1)

The tidal stages are divided in three different ways. First, four tidal stages are determined; high tide (approximately 1.5 hours before the highest water height and 1.5 hours after the highest water height), descending tide (approximately 1.5 hours after the highest water height until 1.5 hours before the lowest water height), low tide (approximately 1.5 hours before the lowest water height until 1.5 hours after the lowest water height) and rising tide (approximately 1.5 hours after the lowest water height until 1.5 hours before the highest water height) (see figure 4). The duration of a tidal cycle varies but often covers six hours; the number used in determining the tidal stages. When the cycle was longer, this was corrected and the cycle was equally divided for the four tidal stages.

The four tidal stages are also divided into three stages each resulting in twelve stages (high tide 1, high tide 2, high tide 3, descending tide 1, descending tide 2, descending tide 3, low tide 1, low tide 2, low tide 3, rising tide1, rising tide 2 and rising tide 3). The amount of sightings for each of these tidal stages is divided by the total time observed during these twelve tidal stages.

A third division in the tidal stages is done as well, to detect any changes using different classes. For this third tidal stages analyses, the stage high tide starts at the highest water height until approximately 3 hours after that, tidal stage ebb starts approximately 3 hours after the highest water height until the lowest water height, tidal stage low tide starts at the lowest water height until approximately three hours after that and tidal stage flood starts approximately three hours after the lowest water height until the highest water height.

For determining side preferences, the Marsdiep area is divided through the exact middle in 'Mapsource'.This is done by determine the total track (4.5 kilometres; distance between Den Helder and Texel) by two. The middle, and so the time, for every track is determined.

Water velocity is divided in ten classes; <-0.80, -0.79999 to -0.60, -0.59999 to -0.40, -0.39999 to -0.20, -0.19999 to 0, 0.10001 to 0.2, 0.20001 to 0.4, 0.40001 to 0.6, 0.60001 to 0.8, >0.8.
Water temperature is divided into 6 classes with increasing 0.5 degrees Celsius per class (1.5° to 2°, 2.0001° to 2.5°, 2.50001° to 3°, 3.0001° to 3.5°, 3.50001° to 4°, >4°).

2.3 Data analyses

After processing the data into SPSS, the analyses were done. First, some graphs using the basic data (sighting and environmental data collected during the fieldwork) are created. This summarizes the conditions during the fieldwork. In SPSS version 19, the statistical tests are done for analysis.

All excel data is imported into SPSS and the type and measure of each data row is categorized. The type of data is analysed in order to choose the right test. The data is discreet, binomial, with >2 groups and unpaired. The test that fits the best is 'Chi-Square'. In 'analyse' a `Generalized Linear Model' (GLM) is chosen to work with, as the 'Chi-Square' is also tested here. The number of sightings was defined as the response or dependent variable and the log of the observation duration (in hours) was included as the offset. This essentially amounts to modelling the number of porpoises per hour. However, it takes into account difference in sampling effort. The log is used in order to prevent the sighting rate from getting negative. The response variable was assumed to follow a 'Negative binomial distribution with log link'. This distribution allows for over-dispersion (i.e. many zeros and occasional extreme high counts). Several explanatory variables were included in the analysis. All variables were included as main terms, however when modelling tide-dependent differences in sighting rate between Den Helder, an interaction between tidal state and location (i.e. Texel or Den Helder) was included. The scale parameter method is set to 'deviance' to allow for the estimation of dispersion parameter.

To select the best model, the 'Akaike's Information Criterion' (AIC) was used. 'AIC' is a measure of 'the goodness of fit', but penalizes for the number of parameters included in the model. The lower the 'AIC', the better the model. To test whether a particular variable significantly explains variations in the sighting rate a likelihood ratio test based on the 'Chi-Square' (referred to as X2 in the results) statistics was used. The outcome of these tests were considered significant when the p-value was <0.05. Finally the model output produces 'Parameters Estimates' and corresponding standard errors. This output can be used to test whether a particular reference class (e.g. tidal state 'rising tide') is different from other classes (e.g. tidal state high tide, descending tide or/and low tide). By changing the reference class, different tests can be carried out. This is known as post-hoc testing. The following models were fitted:

- The effect of Sea State (0,1, 2, 3, 4 or 5) on sightings;
- The effect of Tidal stages 1 (A, B, C, D) on sightings;
- The effect of Tidal stages 2 (A1, A2, A3, B1, B2 etc.) on sightings;
- The effect of Sides (Texel versus Den-Helder) on sightings;
- The effect of Swim Direction (compass) on Tidal Stages 1 (A, B, C, D);
- The effect of Velocity stages 1 (1, 2, 3, 4) on sightings;
- The effect of Velocity stages 2 (1 to 10) on sightings;

- The effect of Temperature stages (1 to 6) on sightings;
- Interaction between Sides (Texel versus Den-Helder) and Tidal stages 1 and the effect on sightings.

3. Results

This chapter contains the results of this study. The first subchapter will give an overview of the analysed basic data collected during the fieldwork. The second subchapter contains analyses on occurrences of harbour porpoises in the Marsdiep area in relation to tidal stages and other environmental factors together with their swimming direction. The last subchapter will give the analyses of the local water velocity and local water temperatures each sighting was recorded.

3.1 Basic data

A total of 21 days of fieldwork accounted for a total of 156 hours and 30 minutes was carried out. All fieldwork occurred between 20 February and 2 April 2013. Of these 156.5 hours, 81 hours and 39 minutes were spent observing outside of the harbour on the navigating ferry. The remaining 74 hours and 51 minutes were observed on the ferry within the harbour of either Texel or Den Helder. In the outside of the harbour observations a total of 134 harbour porpoise sightings were recorded.

Observations always started from Texel. The east side observing the Wadden Sea side of the ferry channel was observed for 34% of time, the west side observing the North Sea side for 66% of time.

3.1.1 Sighting data

Group size

In a total of 134 sightings, 173 harbour porpoises were recorded. Group size varied from one to three individuals at a time. The average group size was 1.3 porpoise(s) with a standard deviation of 0.472151. The most common group size was one harbour porpoise (96 sightings; 71.6%), followed by 37 sightings of two harbour porpoises (27.6%), and one sighting of three porpoises (0.7%).

Distance

Observations per class are visible in Figure 5. Observation distance ranged between 20 metres and 700 metres. The average distance of observed harbour porpoises observed was 190 metres with a standard deviation of 120.68. Figure 5 shows that most observations are made between 101 and 200 metres.

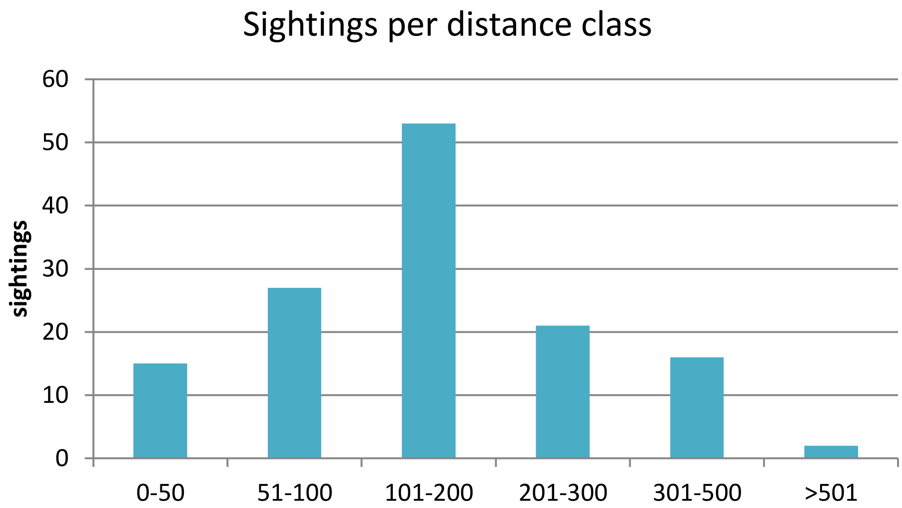

Figure 5: Sightings per distance class

The distances classes are not equally distributed; class A counts 50 metres while class B counts 49 metres, class C 99 metres etc. To correct for this, the number of porpoises per distance class were divided by the size of each distance class. This results in Figure 6 and shows most porpoises were detected between 51 and 100 metres away, as well as a lot of porpoises detected between 101 and 200 metres. This indicates that harbour porpoises further than 200 metres away from the observation platform are less likely to be observed than harbour porpoises that appear closer.

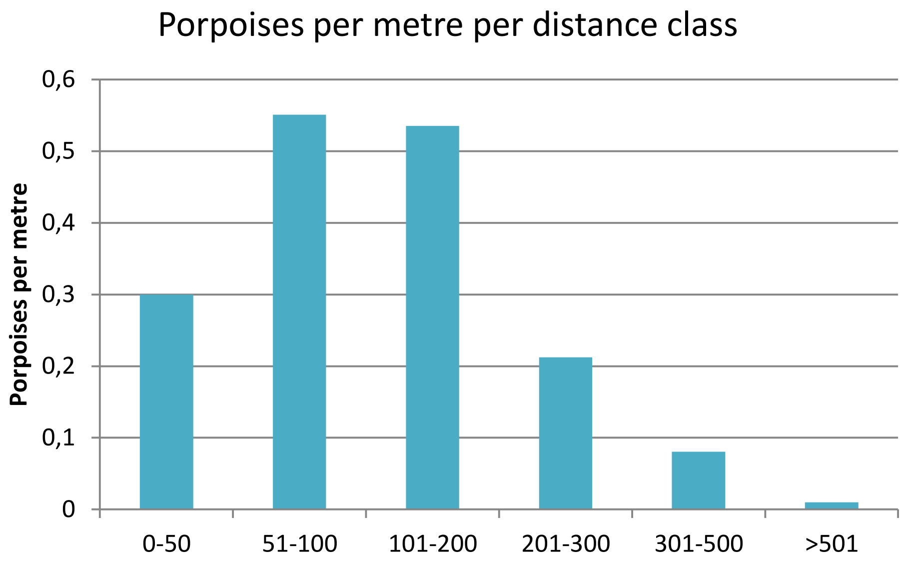

Figure 6: Porpoises per metre per distance class

Behaviour

Some behavioural parameters were also recorded during the sightings. This is a snapshot at each sighting; due to the speed of the ferry this cannot be measured extensively. Behaviour options were: wheeling/swimming slow, escape from ship, swimming fast without avoiding ship, apparently feeding with herding behaviour, apparently feeding with other behaviour, calf at the tail of adult, basking/afloat, and/or approaching ship (see also appendix 1).

During most of the sightings wheeling was observed (81%). Besides wheeling, the porpoises were observed swimming fast without any sign of avoiding the boat for 13% of the sightings. Escaping from the ship and basking were both observed in 2% (escape from ship) and 4% (basking) of time. Feeding with herding behaviour, feeding with other behaviour and calf at the tail of adult were never observed. This pattern suggests that only little reaction towards the ferry is detected.

3.1.2 Environmental data

Sea state

Different amount of time was observed during each sea state. Most observations were done during sea state 1 (28% of total observation time), 2 (36%) and 3 (26%). Less observations were done at sea state 0 (5%), sea state 4 (5%), and sea state 5 (<1%).

14 Sightings were made at sea state 0, 58 sightings were made at sea state 1, 32 sightings were made at sea state 2, 25 sightings were made at sea state 3, and 5 sightings were made at sea state 4. In sea state 5 no porpoises were detected.

The amount of sightings per sea state was divided by the time observed per sea state to correct for the difference in observation time. Figure 7 shows that sea state 0 had the highest amounts of observations per time, followed by sea states 1, 2, 3 and 4, where sea states 2, 3, and 4 were considerably lower. This suggests that sea state affects the sighting probability.

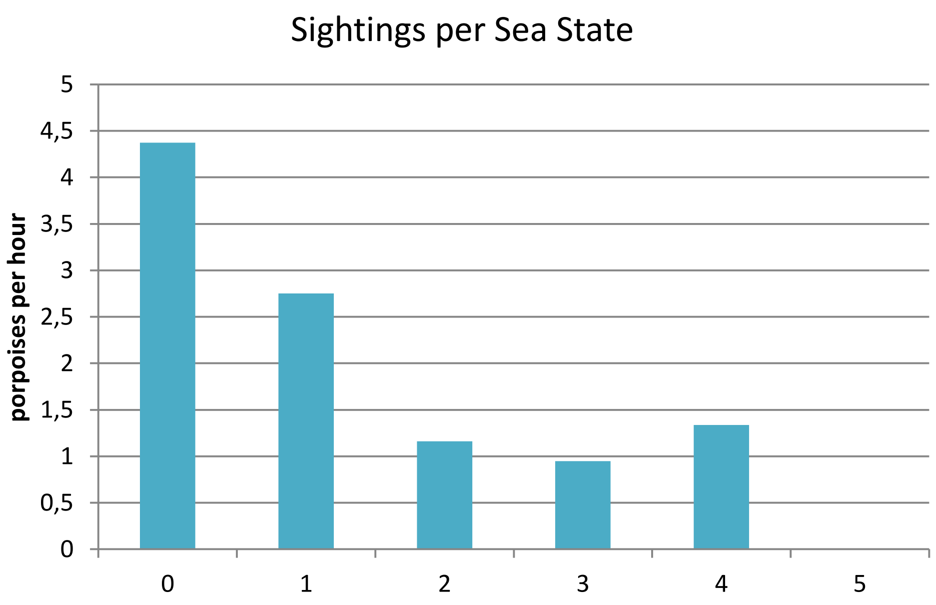

Figure 7: Sea state during sightings

The effect of Sea State on sightings is tested with GLM (see data analysis for detailed explanation). The model for the 'Goodness of the fit' shows an Akaike's Information Criterion (AIC) of 763.318, and the likelihood Chi-Square shows high significance ($p<0.001$). A post hoc test shows that not all sea state are significant different from each other. Table 1 shows the significances between the sea states.

Sea state	0	1	2	3	4	5
0	X	0.960	<0.001	<0.001	<0.001	<0.001
1	0.960	X	<0.001	<0.001	<0.001	<0.001
2	<0.001	<0.001	X	<0.001	0.929	<0.001
3	<0.001	<0.001	<0.001	X	<0.001	<0.001
4	<0.001	<0.001	0.929	<0.001	X	<0.001
5	<0.001	<0.001	<0.001	<0.001	<0.001	X

Table 1: Significances between sea states

Wind

Wind force varied between Beaufort 0 and Beaufort 5, but the average wind speed was Beaufort 3 and the modus Beaufort 2 (36%). Wind direction was predominantly North-east, during 50% of all fieldwork. Besides Northeast, also Southwest, West and North-western winds (<5% of the time) was recorded during all fieldwork. The remaining time, wind direction was south (19%) or north (19%).

Associations

Sea state associates with wind speed (Palka, 1996), so when wind speed (Beaufort) increases, sea state also increases. Sea state also associated with distances of sightings. Figure 8 shows the average sea state (y-axis) per distance class (x-axis). This reveals that during higher sea state, porpoises are detected closer to the observation station more often than further away. Two observations in class F were made; in sea state 0 and 1.

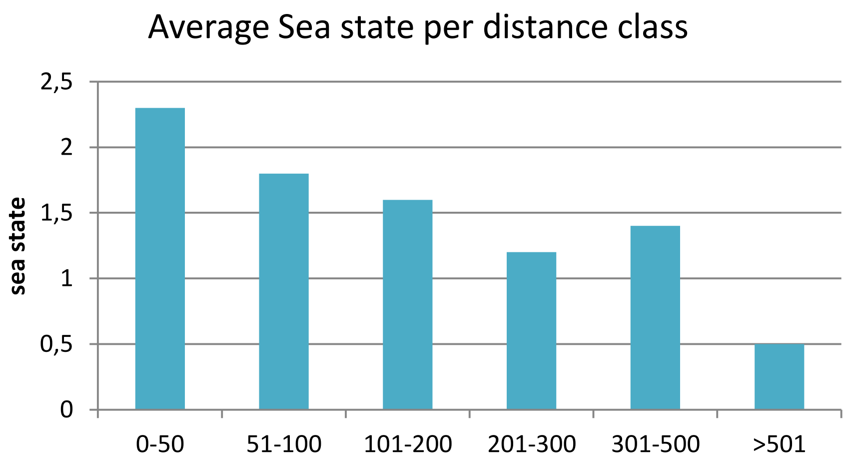

Figure 8: Sea state per distance class

Mostly glare was not present (83%). Visibility was most of the time good; more than 4 kilometres which is the distance between Texel and Den Helder. The average cloud cover over all fieldwork days was 5.4 (out of 8) and apart from some moments of snow and days of fog, mostly there was no precipitation. No other association between environmental factors and behaviour types were found.

3.2 Occurrence of porpoises in the Marsdiep

Figure 9 shows all harbour porpoise sightings in the study area. Each yellow dot refers to a sighting.

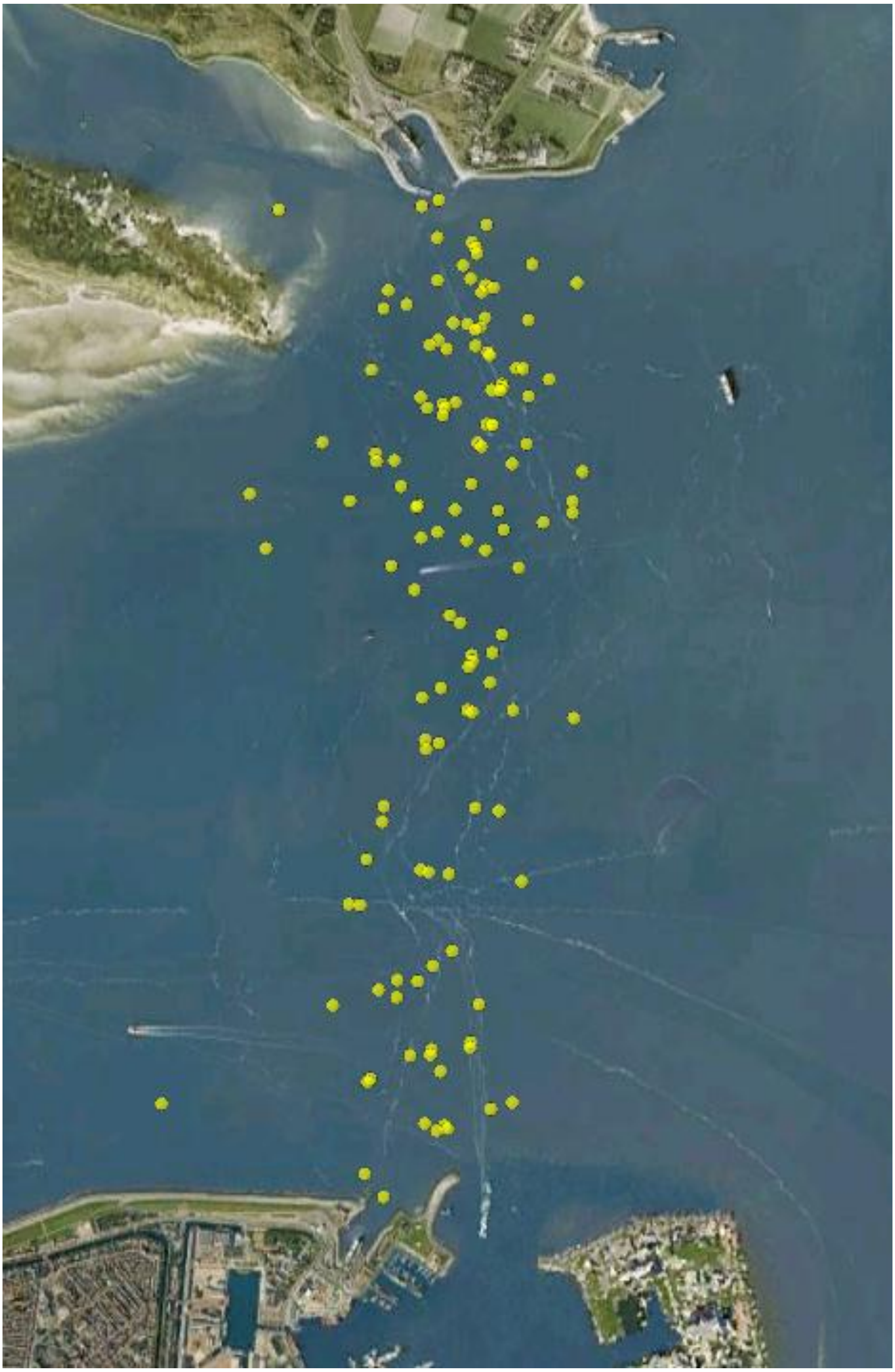

Figure 9: Sightings in the study area

3.2.1 Tidal differences

The data is also analysed per tidal stage. Four tidal stages are determined as mentioned in the methodology. The duration of a tidal cycle varies but often covers six hours; if this was different a correction was made in order to divide the duration of the cycle equally for all stages. Figure 10 shows the sighting per tidal stage.

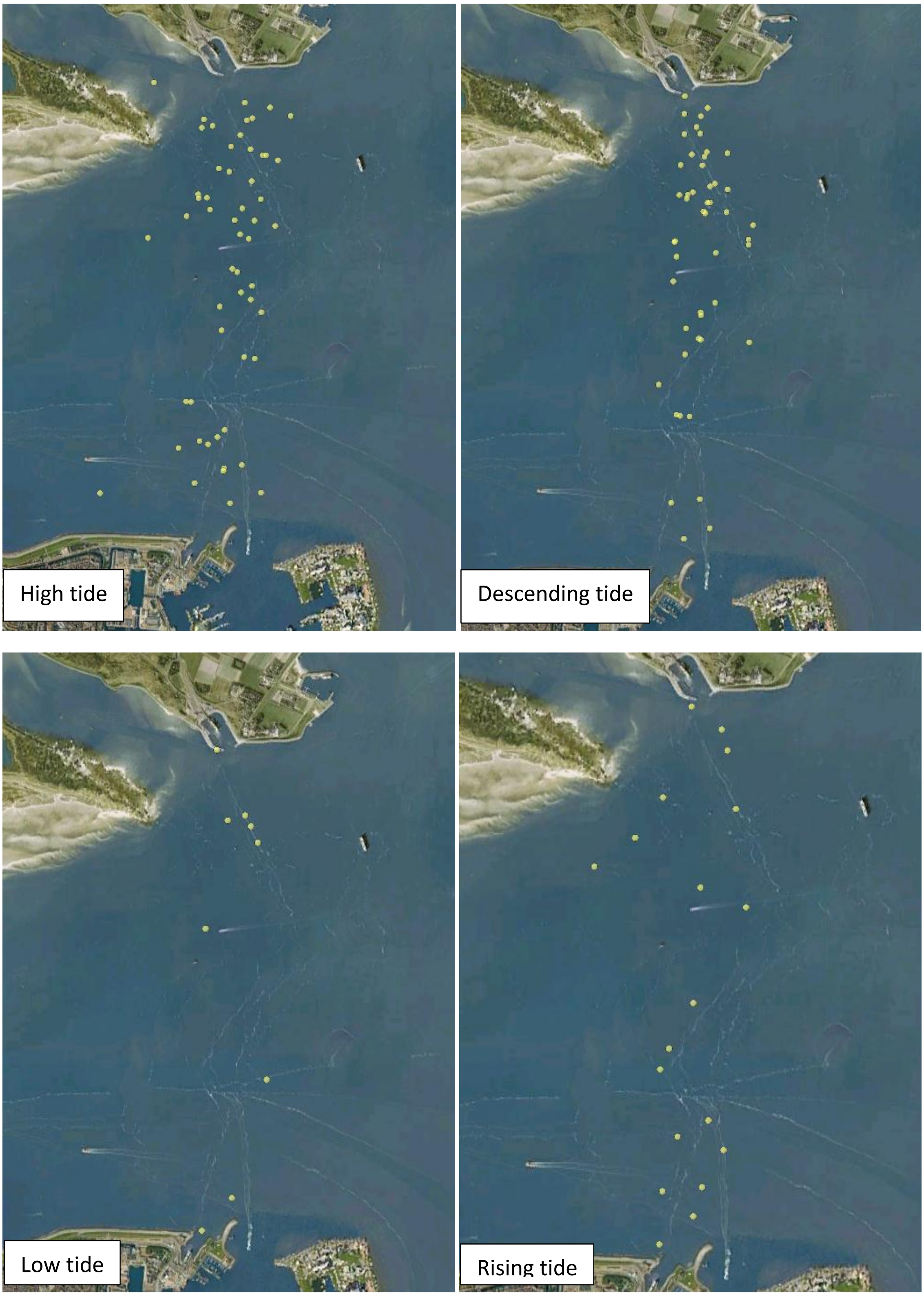

Figure 10: Sightings per tidal stages in the study area

Each tidal stage was sampled for a different amount of hours, depending on chance of effort. Low tide and rising tide in the period when observations were done were shorter than high tide and descending tide. In the western Wadden Sea, the rise of the water level is faster than the descent which results in stronger flood than ebb currents, although ebb duration is longer (Buijsman, 2007). As well as the longer ebb duration due to the difference in water level throughout the area, the strong easterly winds that were present during the fieldwork period contributed to the results of less time in low tide and in rising tide. This resulted in more observation hours spent during stage high tide and descending tide; high tide counted 24 hours and 45 minutes of observation, descending tide counted 29 hours and 20 minutes observation time, low tide counted 15 hours and 27 minutes observation time, and rising tide counted 12 hours and 7 minutes observation time.

To correct for the difference in time observed per tidal stage, the amount of sightings per tidal stage were divided by the total hours observed during that tidal stage. This resulted in Figure 11, showing the number of porpoises per hour for the different tidal stages.

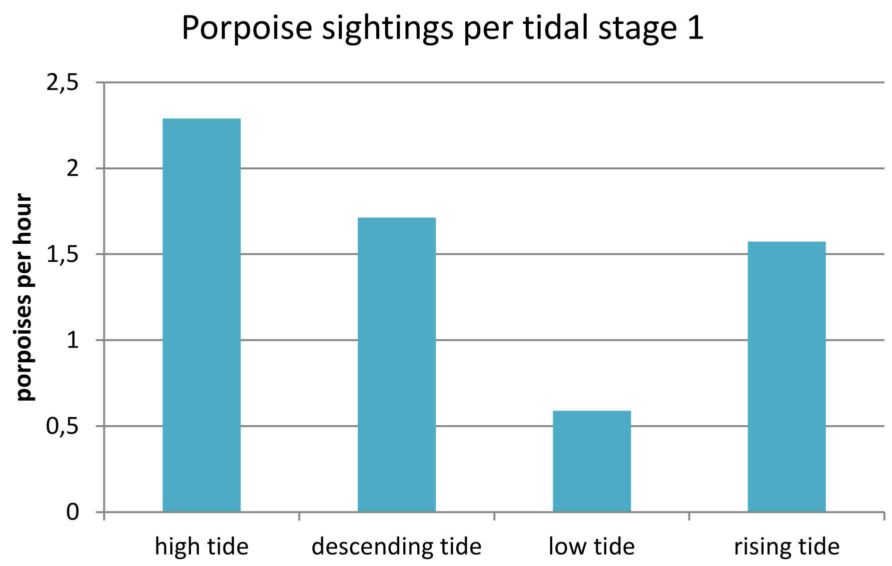

Figure 11: Harbour porpoise sightings per hour per tidal stage (1)

Figure 11 indicates that porpoises were mostly observed during high tide. During low tide, almost no porpoises were observed. Descending and rising tide showed similar amounts of porpoise observations in between the amounts during high and low tide.

The effect of the tidal stages on the sightings is tested with GLM. The model for the 'Goodness of the fit' showed an Akaike's Information Criterion (AIC) of 765.651. The likelihood Chi-Square (X2=40.753) showed significance of difference between tides ($p<0.001$).

As mentioned in the analyses of the basic data the sea state had an effect on the sighting probability. Adding sea state to the GLM together with tidal stages, the AIC increased to 805.605, higher than testing the effect of tidal stages alone, indicating that addition of sea state did not improve the model.

To get a more detailed look at effects of the tidal stage timing, the four tidal stages were each divided into three sub-stages of equal duration within the stage, resulting in twelve stages as mentioned in the methodology. The amount of sightings for each of these tidal stages was divided by the total time observed during these twelve tidal stages to correct for observation bias. Figure 12 shows the results of the number of porpoises per hour found in these 12 tidal stages. The pattern indicates that most harbour porpoises were equally present during all high tide stages with slightly more porpoises central and at the end of high tide. A decrease of harbour porpoises observed halfway during descending tide was visible, and this continued until the end of descending tide. Some harbour porpoises were observed in het beginning of low tide, but in the last part of low tide no porpoises were seen. Some harbour porpoises were present at the beginning and middle parts of the rising tide, and an obvious increase of harbour porpoises at the end of the rising tide was observed. This pattern suggests that porpoises enter the area at the last hour when the tide is rising, that they stay in the area during high tide, that they leave after approximately one hour after the tide is descending and that they are not present during most time at low tide.

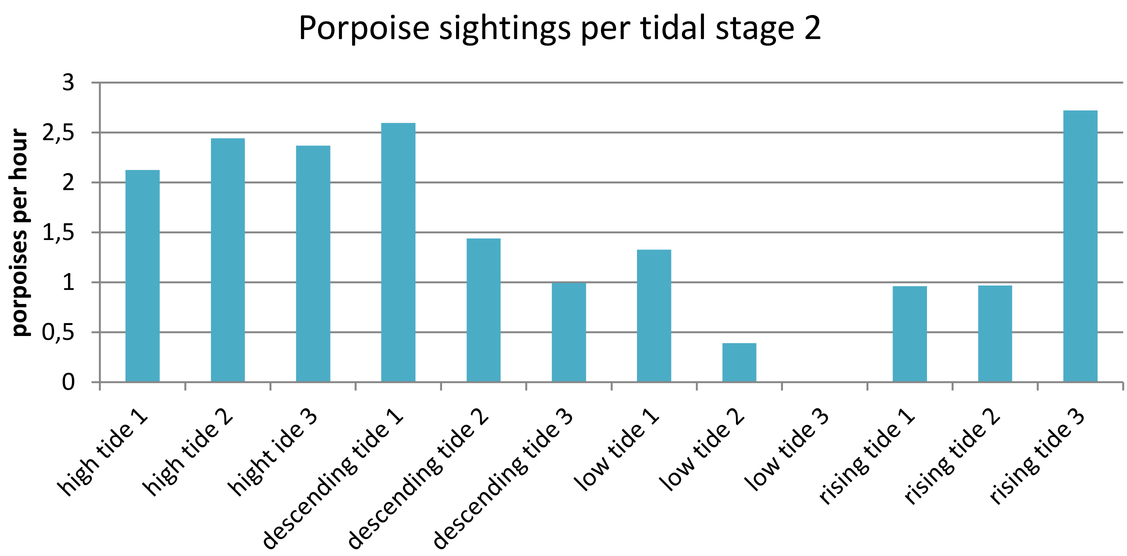

Figure 12: Harbour porpoises per hour per tidal stage (2)

The effect of tidal stage when sub-divided in twelve classes was also tested with a GLM. The model 'Goodness of the fit' showed an Akaike's Information Criterion (AIC) of 764.708. The likelihood Chi-Square showed significance of tidal stage (X2=40.753, $p<0.001$).

Since the detailed analysis suggested large changes in the amount of sighting within a stage, also a shift grouping was performed: the stage high tide was redefined to between the highest water height until approximately 3 hours after that, tidal stage ebb to start approximately 3 hours after the highest water height until the lowest water height, tidal stage low tide to start at the lowest water height until approximately three hours after, and tidal stage flood to start approximately three hours after the lowest water height until the highest water height. This dividing is also based on a tidal cycle of six hours and whenever the amount of hours of a cycle was different, this is corrected and the cycle is equally divided for the four stages. This resulted in Figure 13 with the x-axis being the tidal stages and the y-axis being the number of porpoises per hour. The difference between stages is significant ($p<0.001$). However, with an AIC of 771.270 this did not result in a better model than the model using the earlier definitions of 4 stages. The Figure appears to indicate a stronger difference of stage high tide compared to the three other stages.

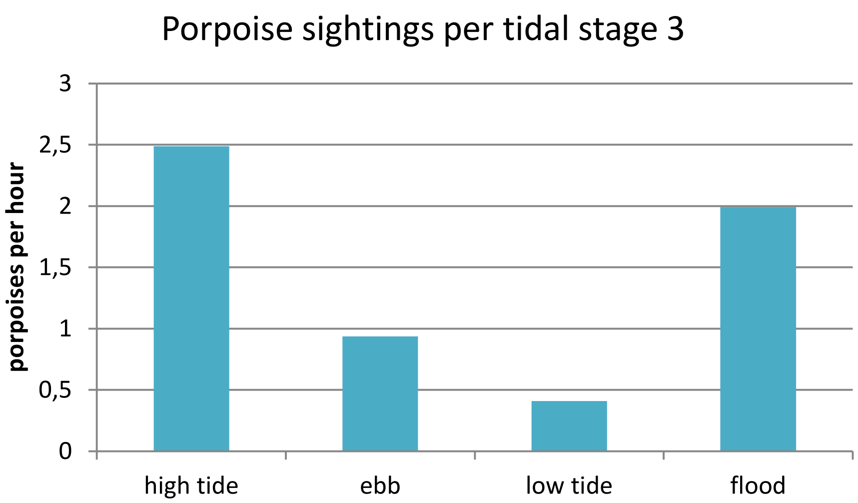

Figure 13: Harbour porpoise sightings per tidal stage (3)

3.2.2 Location preferences

Besides an effect in tidal stage, also a difference in location was detected. Dividing the Marsdiep area through the exact middle resulted in 89 sightings (63%) at the Texel side and 45 sightings (32%) at the Den Helder side. This difference is significant (GLM: X2=26.225, p<0.0001) with an AIC of 788.005.

In addition, there appears to be also a difference in occurrence of porpoise sightings on each side depending on tidal stage (Figure 14). For this analyse the first tidal stage definitions of 'high tide, descending tide, low tide and rising tide' were used.

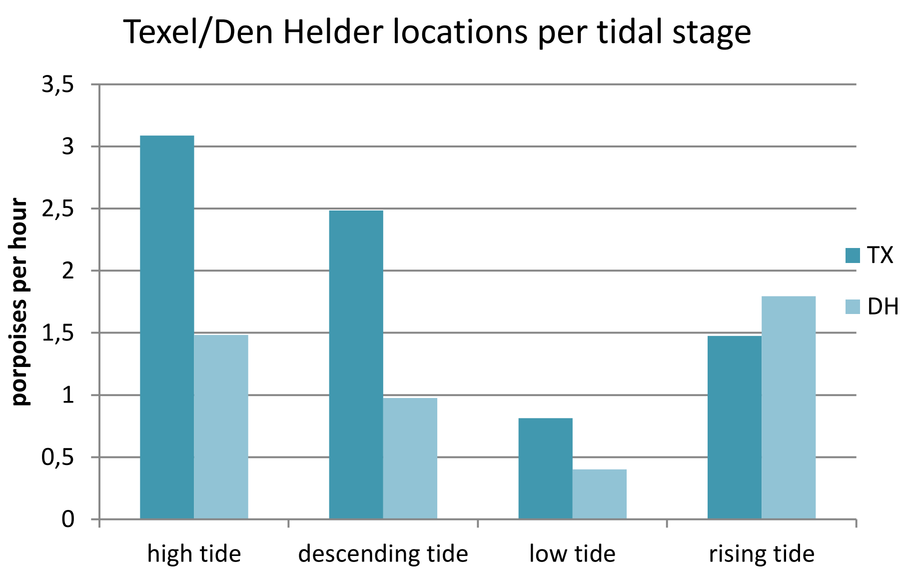

Figure 14: Difference in harbour porpoise occurrence per tidal stage per side

Figure 14 indicates that porpoises were present on the Texel side approximately twice as often during high tide, descending tide and low tide. Only at rising tide, porpoises were more frequently seen at the Den Helder side. This interaction effect between the tidal stages and location on the sightings was tested with GLM. The interaction was significant (GLM: X2=79.405, p<0.001) with an

AIC of 779.740. This indicates that the model with the interaction is better than taking only the location into account.

3.2.3 Swimming directions

Figure 15 shows the swim direction during each tidal stage. A pattern emerges that during all stages, most porpoises are found swimming in Westerly or North-westerly direction. This was not expected during rising tide, where a movement towards the Wadden Sea (easterly direction) was anticipated. Low tide appears to favour a westerly direction, so it may be assumed that these animals were on their way to the North Sea when observed. However, this is based on a low number of sightings (n = 9) during this tidal stage. Descending tide shows an expected movement; mostly animals recorded swimming westerly or north-westerly. High tide shows a broad variation of porpoise swimming direction with a peak for swimming both in easterly and westerly directions.

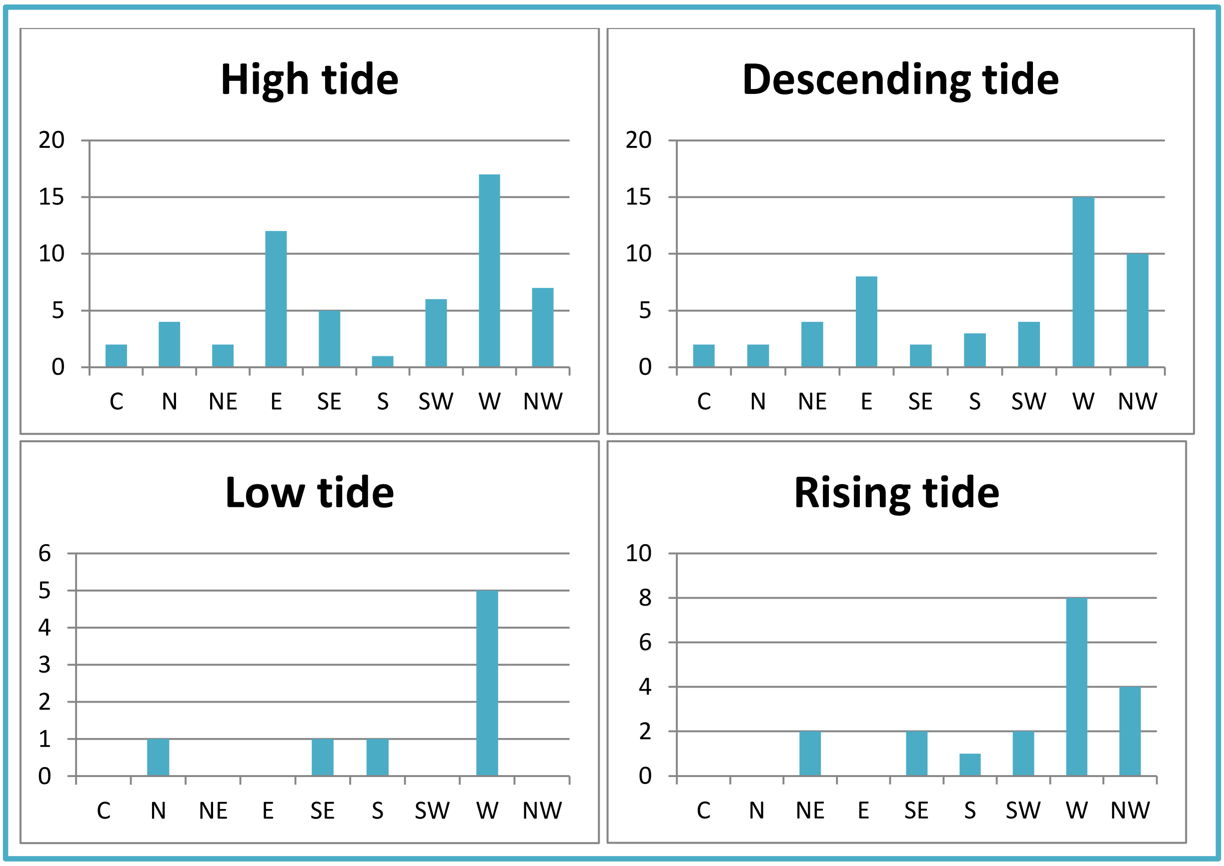

Figure 15: Swimming direction per tidal stage

The different swimming direction classes were reduced to four classes for analysis. (Figure 16). Figure 16 also shows a variation is swimming direction during all tidal stages.

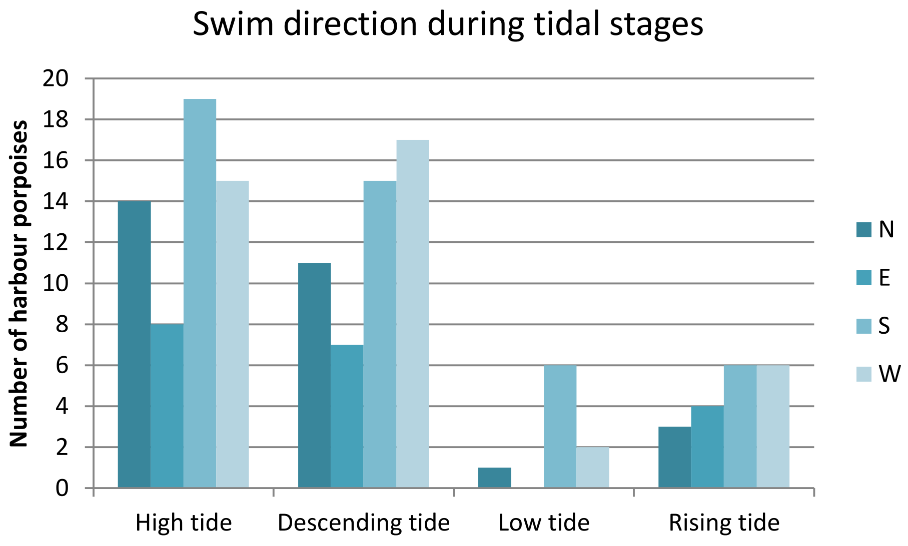

Figure 16: Swimming direction per tidal stages

3.3 Acoustic Doppler Current Profiler data

3.3.1 Local water velocity

Local water velocities during the entire period ranged in value from an average (per passage) of 0.626 m/s eastward velocity, to an average of -0.456480291 m/s westward velocity with a standard deviation of 0.3172. Table 2 shows the averages as well as the standard deviation and the standard error of mean for each tidal stage 1.

The average water velocity for the sightings during the high tide stage was positive (meaning an eastward positive velocity) of 0.373m/s. The descending tidal stage had an average water velocity of -0.454 m/s meaning an outward westward velocity. The low tide stage had the highest average outward velocity of -0.663 m/s. The rising tide stage showed the highest incoming velocity of 0.664 m/s.

	Standard Deviation	Average	Standard error of mean
High tide	0.196616016	0.373327642	0.02627392
Descending tide	0.265409021	-0.453980331	0.037534504
Low tide	0.058383288	-0.663484655	0.019461096
Rising tide	0.243421036	0.663573651	0.055844616

Table 2: Statistical measurements of local water velocity for each tidal stage

Figure 17 shows all water velocity measurements with the time before high water indicating highest inward velocity at two hours before high tide (indicated with the most left arrow in Figure 17), a turning point at two hours after high tide (indicated with the middle arrow in Figure 17) and the fastest outward velocity at four hours after high tide (indicated with the most right arrow in Figure 17).

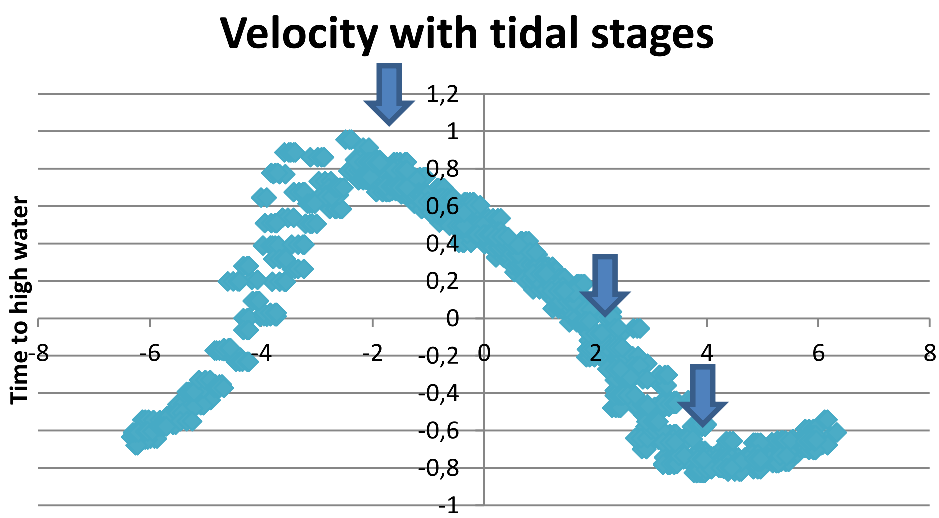

Figure 17: Local water velocity in association with time to high water

To investigate the effect of water velocity on harbour porpoise sightings, the overall water velocities were divided into four classes (-0.9 to -0.5, -0.4999 to 0, 0.00001 to 0.5 and 0.50001 to 1). Figure 18 indicates the effect of water velocity (in four classes) on the sightings of harbour porpoises. The Ratio Chi-Square was 0.001 (p) with an X2 of 15.848, meaning significant differences. The AIC is 796.140.

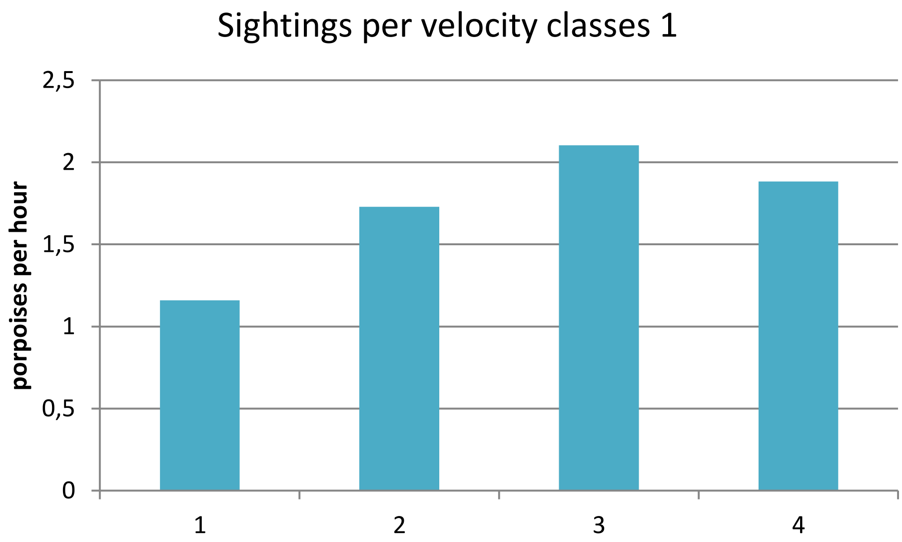

Figure 18: Harbour porpoise sightings per velocity classes (1)

The overall water velocities possible were divided into ten classes; <-0.80, -0.79999 to -0.60, -0.59999 to -0.40, -0.39999 to -0.20, -0.19999 to 0, 0.10001 to 0.2, 0.20001 to 0.4, 0.40001 to 0.6, 0.60001 to 0.8, >0.8 m/s. The negative numbers represent a westward velocity; the positive numbers represent an eastward velocity. Figure 19 has these classes on the x-axis and the number of porpoises per hour on the y-axis. This indicated that the first three velocity classes (<-0.40) appeared underrepresented. Between stage 5 and 6, when velocity was between -0.19999 m/s and 0.2 m/s, most porpoises are observed. There appeared not much difference during the other velocity stages. The Ratio Chi-Square of this test did show significance (X2=32.654, p= <0.001) and the AIC was 801.381, higher than using the four velocity classes. This may mean that the first model using four classes was more suitable.

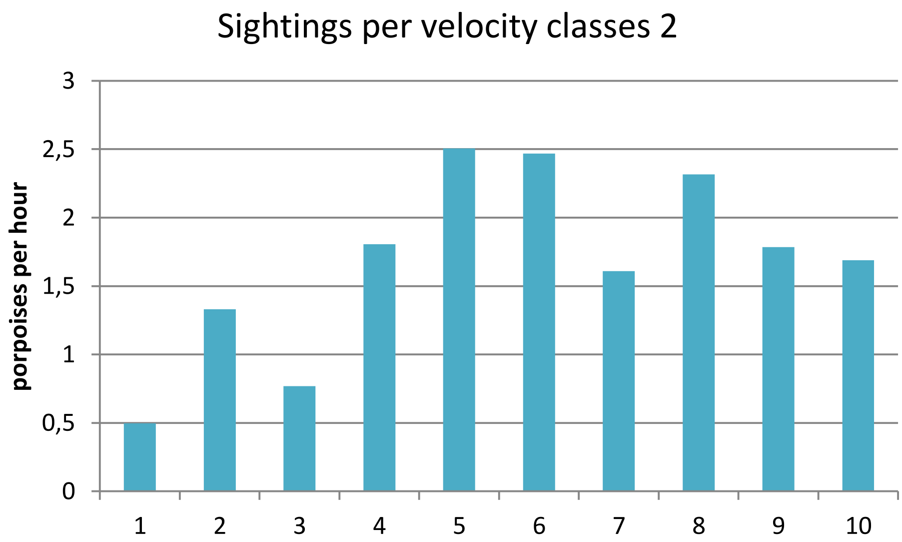

Figure 19: Harbour porpoise sightings per velocity classes (2)

To investigate the importance of tidal stage versus water velocity, the combination was tested with GLM. The combination yielded a statistically significant effect (GLM: X2=111.335, p<0.001) but with an AIC of 797.930. This AIC is higher than using only tidal stages as a variable. Water velocity thus appeared not to be a better variable to predict presence of porpoises than tidal stages.

3.3.2 Local water temperature

Water temperature during all survey days ranged from 1.25 °C to 4.47 °C. The average water temperature during all fieldwork days increased until after the 21st of March. Due to cold weather and cold easterly winds, snow and ice made the Wadden Sea colder again. An obvious drop of about 2 degrees in temperature was therefore noted in Figure 20.

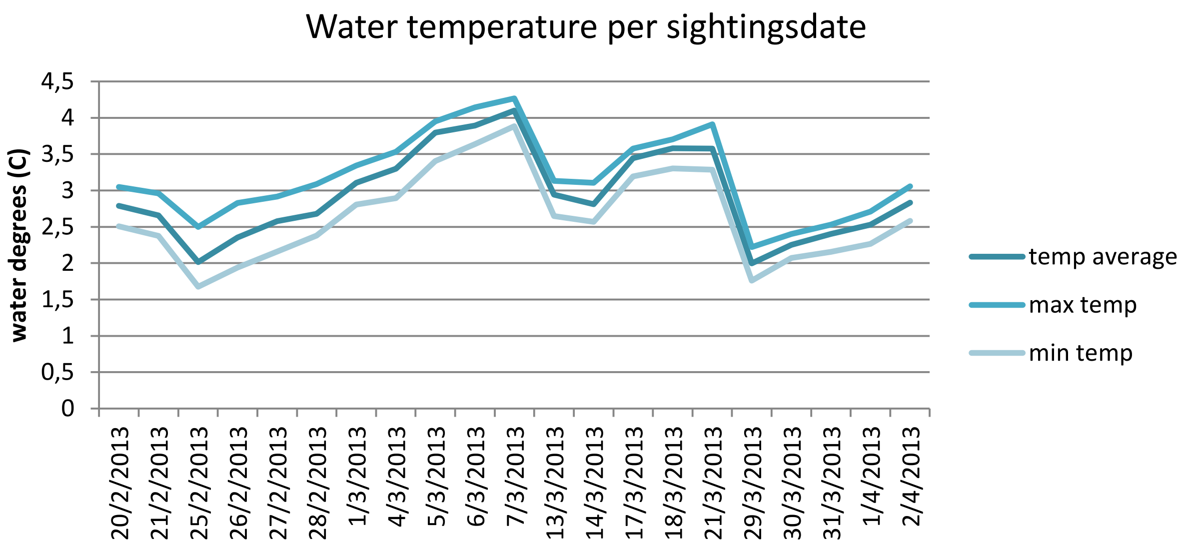

Figure 20: Water temperature averaged per sighting per date

Table 3 shows the standard deviation, the average and the standard error of mean for each tidal stage 1 for the water temperature.

	Standard deviation	**Average**	**Standard Error of Mean**
High tide	0.563725052	3.235708136	0.075330929
Descending tide	0.578697792	2.984498497	0.081840227
Low tide	0.700448899	2.57590519	0.233482966
Rising tide	0.430036046	3.35852598	0.098657035

Table 3: Statistical measurement of local water temperature at each tidal stage

To analyse the effect of water temperature on harbour porpoises sightings, water temperature was divided into 6 classes with increasing 0.5 °C per class (1.5°C to 2°, 2.0°C to 2.5°C, 2.5°C to 3.0°C, 3.0°C to 3.5°C, 3.5°C to 4°C, >4°C). Figure 21 shows these classes on the x-axis and the number of porpoises per hour on the y-axis.

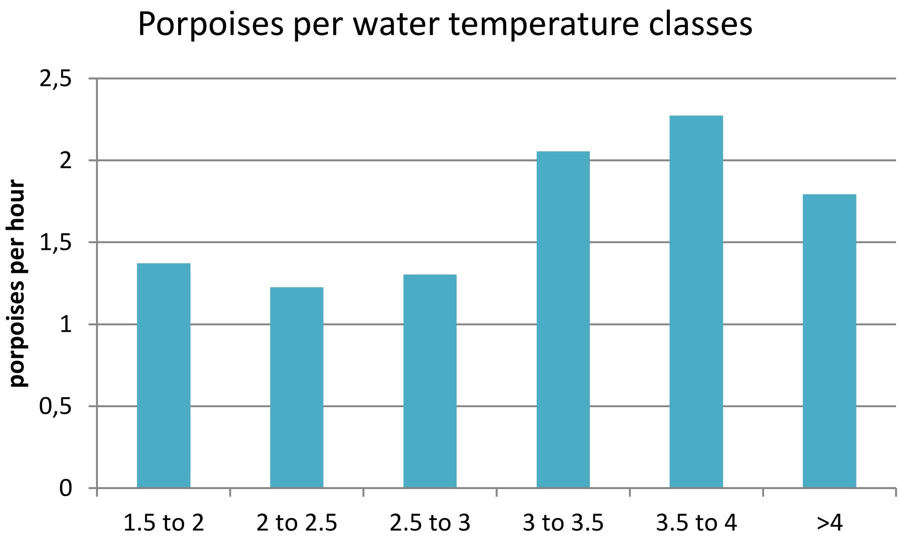

Figure 21: Harbour porpoises per temperature class

This pattern suggests a preference for swimming in warmer water, since more porpoises were detected in water warmer than 3°C. To test this a GLM is used. This showed a significance of p=0.002 with an AIC of 798.678 when testing the effect of temperature on the sighting chance of porpoises in the area. This indicates a preference for warmer waters.

Since ttemperature associates strongly with the tides the interaction between these two variables on the sightings is also tested with a GLM. This resulted in a significant test (X2=101.034, p=<0.001) with an 'AIC' of 797.610.

4 Discussion

This study shows that harbour porpoise presence is centered around high tide, with a decrease during descending tide and an increase during rising tide. Within this, there is also a preference in the position of porpoises discovered. During high tide, descending tide and low tide, double the amount of porpoises are detected on the Texel side. During rising tide, more porpoises are detected on the Den Helder side. This difference is not very obvious, although statistical analyses did show a significant difference.

It is important to emphasize that both environmental conditions and behavioural aspects might influence the observed sighting rate. Environmental factors involve weather conditions. Poor weather conditions influence sight ability and makes detecting porpoises difficult. Analyses show that sea state does actually effect the distance porpoises can be observed. This means that when the sea state increases, porpoises further away from the observation platform are less likely to be seen. This is also found in several other studies (see e.g. Palka, 1996). Although statistical tests in the interaction between sea state and tidal stage on the effect of sightings did show a significance, it is likely porpoises further away from the platform are missed in a higher sea state. The effect of sea state is particularly relevant for large scale ship-based surveys or aerial surveys that aim to estimate absolute abundance and habitat selection. When surveying a particular region under favourable conditions, sighting rate might be high either because there is a high abundance of porpoises, or it might be caused by a high sight ability. We expect this to have little impact on the results of this study, because within a single crossing, there is relatively little variation in sea state. Hence we expect that increasing sea states affects the sight ability on the Texel and Den Helder side approximately equally.

Behavioural characteristics of harbour porpoises also affect the sight ability. They are particularly shy animals. They do not jump and they are easily frightened (Verwey, 1975a; Read, 1999 A harbour porpoises back with a 'rolling moving' dorsal fin, referred to as wheeling, is usually the only thing visible out of the water. Harbour porpoises are often found alone or in small groups (Camphuysen & Peet, 2006). Harbour porpoises seem to avoid boats and other dolphin species and are very elusive (Camphuysen & Peet, 2006). This makes observing harbour porpoises in the wild challenging. The impact of this on the results is inconclusive, but it is likely that due to the speed of the ferry porpoises are missed. However, similar to the environmental conditions we expect this to have little impact on our results. Observations could only be done on one side of the bridge wing. Porpoises on the other side are thereby missed. Strong easterly winds during the fieldwork period makes observing against the wind less successful. Due to this the best side for observation was chosen (starboard or port). This resulted in the North Sea side of the Marsdiep being 66% more observed than the Wadden Sea side. This may have had an impact on the observed swimming direction (see below).

Low tide and rising tide in the period when fieldwork was done were shorter than high tide and descending tide. In the western Wadden Sea, the rise of the water level is faster than the descent which results in stronger flood than ebb currents, although ebb duration is longer (Buijsman, 2007). The longer ebb duration is due to the difference in water level throughout the area as well as the strong easterly winds that were present during the fieldwork period, contributed to the results of less time low tide and rising tide. The difference in the tidal cycle resulted in almost half the time observed during low and rising tide in contrast to high and descending tide. This is not accounted in the beginning stages of this project. It is easier to try to correct for this during fieldwork rather than after. Due to the high amount of hours spent observing, this was not a problem. Furthermore, all sighting rates are corrected for effort (in hours), so any difference in survey effort for the different tidal stages only influences the sample size in each class, not the estimated sighting rates.

The difference in porpoise occurrence at the Texel and Den Helder sides is as expected and also noted in the past by other researchers. Verwey (1975a) wrote that harbour porpoises seem to have a habit of visiting the harbour entrance at high tide and direct movements with ebb and flood were seen (Verwey ,1975a). Also Boonstra et al. (in press) found tide dependent occurrence of porpoise in the Marsdiep, with most sightings during late flood and early ebb. This was based on four sighting locations, located on Texel and near Den Helder. Boonstra et al. (in press) also suggested the highest numbers of porpoises near Texel. However, the observations were carried out by different observers and no corrections were made for differences between observers. In this study, all data was collected by a single observer, with effort allocated equally between the Texel and Den Helder site. Therefore, this study is the first to make a solid statement that harbor porpoises are more abundant on the Texel side of the Marsdiep.

Tide dependent patterns in occurrence of harbour porpoises is also detected in other places in the Netherlands and abroad. Lucke et al. (2012) detected a tidal dependence of occurrence of porpoises in the Eems with the use of acoustic devices. Research on harbour porpoises in the Bay of Fundy, Canada, also showed a significantly higher density of porpoises during flood than ebb phases. This is detected by using satellite telemetry in combination with line transect surveys (Johnston et al. 2005). Goodwin (2008) studying the diurnal and tidal variation of harbour porpoises in Southwest Britain noted no tidal difference in one area (Morte Point), while in another area (Lee Bay) the tides resulted in a difference in behavior, group size and distance. Stevick et al. (2002) writes that diurnal movements are likely the result of vertical migration of prey species, but names foraging movements associating with the tides less common in cetacean species.

The ADCP measurements of local water velocity and water temperature are compared with the sightings. Water velocity does correlate with sight rate, but it explains variations in sighting rate less well compared to tidal stage classes based on water height. Velocity is averaged per passage which resulted in one value for the entire passage. This made it impossible to detect preferences of porpoises at the different sides and depths within the same passage.

Harbour porpoises were mostly seen in water warmer than 3 degrees Celsius. The average water temperature during all fieldwork days increased until after the 21st of March. Due to bad weather and cold easterly winds, snow and ice made the Wadden Sea colder again. An obvious drop of about 2 degrees in temperature is therefore noted in the data. This year, peak abundance in porpoises was later than previous years (early April, rather than mid-March, see www.trektellen.nl). This may have been caused by these relative cold weather conditions. Water temperature also associates strongly with the tides. When the tides go out, the area fills with colder Wadden Sea water. Porpoises leave the area. When the tides come in, the warmer North Sea water fills the Marsdiep area and porpoises are detected. Although the influx of porpoises is probably driven by tidal conditions, temperature may also play a role at these shorter time scales. If so, we would expect a higher abundance of porpoises when the Wadden Sea temperature increases. Future studies should look at this possible effect, by tracking the tide dependent occurrence of porpoises throughout the season.

No sign of any behavior that indicated foraging is observed in this study. This can be due to the speed of the ferry, which makes observing behavior difficult. The effect of the ferry on the behavior of the porpoises is also unknown. Pelagic feeding is done by feeding against the tides (Verwey, 1975b). This means that expectations are that during high tide, most individuals should swim from west to east (or variations of that as southwest to northeast and/or from northwest to southeast). Expectations for descending and rising tide are a high fluctuation in swim direction, due to the possibility of feeding against the tides. Low tide should show a distribution out of the area, so a swim direction that is from east to west (again with variations southeast to northwest and/or northeast to southwest). High tide shows a broad variety of porpoise swimming direction with a peak for swimming easterly and westerly. This is as expected due to movement with the tides (energetic favourable) and movement against the tides (feeding). In this study, porpoises are seen swimming westerly most of the time during the entire tidal cycle. One possible explanation is that most sighting effort took place on the North Sea side of the vessel. If harbour porpoises move away from the boat, this would lead to more westerly swimming porpoises. A similar pattern may be observed on the Wadden Sea side, with porpoises swimming easterly away from the ferry, but due to differences in survey effort, these were less likely to be spotted.

A possibility why porpoises are mostly seen swimming westerly could be because they enter the area at a different place and leave the area by swimming through the Marsdiep into the North Sea. This however is unlikely. Counts from a land based station in Huisduinen, Den Helder (Trektellen, 2013) show porpoises swimming in all kind of direction. Verwey (1975a) also witnessed porpoises entering the Marsdiep at the Den Helder side swimming easterly. Rebel (2010) noted that he witnessed porpoises swimming together with the tide inside the Marsdiep assume these were swimming both easterly (flood) as westerly (ebb). Rebel mentioned foraging behaviour when observing porpoises in the Marsdiep from Den Helder; again this is however not observed in this study. Both Hoekendijk et al. (in prep) and van der Bolt (pers. Comm) observed more porpoises swimming in westerly direction. Sighting rate was highest approximately two hours before high water, when there is an incoming flood tide. This would also suggest that porpoises predominantly swim against the currents.

The assumption of Verwey (1975b) that porpoises feed against the tides makes this more complicated as it is not visible when porpoises are feeding if they feed on non-pelagic fish as gobies, which cover a big part of their diet (Leopold pers. Comm; Jansen, 2012). Benthic feeding is not visible on the surface and can therefore not be detected from the observation platform used.

Another reason for no observed feeding behavior is that porpoises do not feed in the Marsdiep area. If this is the case, this can be of big concern. Due to their small size and high energetic demands (Goodwin, 2008), continuous feeding is necessary in order to stay healthy and alive (Kastelein et al. 1997; Camphuysen & Siemensma, 2011). The large body surface to body volume ratio means porpoises lose a lot of energy through radiation and conduction. Kastelein et al. (1997) also points out that harbour porpoises cannot survive for more than a few days without food. They consume between 4 and 9.5 % of their body weight daily and require a dependable food supply of which they must eat often (Kastelein et al. 1997). If no feeding opportunity takes place in the Marsdiep, it is unsure why porpoises enter the area.

5 Conclusion

A strong association between the tidal cycle and the presence of harbour porpoises in the Marsdiep area was present. It seems that the tides influence the porpoise presence within the entire area. Most porpoises are detected during high tide and on the Texel side of the Marsdiep area. A smaller amount of porpoises are detected during descending tide on the Texel side. During low tide, only a few porpoises are detected; again more at the Texel side. More porpoises are observed again during rising tide, but here mostly on the Den Helder side. This means that harbour porpoises in the Marsdiep area show a statistically significant preference for high tide.

The smaller basin of the Wadden Sea influences the water temperature of the Marsdiep area. When the tides go out, the area fills with colder Wadden Sea water. Porpoises leave the area. When the tides come in, the warmer North Sea water fills the Marsdiep area and porpoises are detected. However, this occurs only under relative cold conditions. When air temperature increases, the water in the shallow basins of the Wadden Sea increase in temperature more rapidly and a reverse effect takes place. Water temperature has a strong association with the tides. The effect on the presence of porpoises is obvious, but whether it is due to velocity or temperature is uncertain and potentially skews the distribution of these animals.

Porpoises tend to choose places of higher water velocities as these associate with the tidal stage. Most porpoises are detected in an average water velocity of about 0.3733 (tidal stage 'high tide'). Local water velocity has a significant (0.001) effect on sighting probability. Statistical analyses show that tidal stages is a better measurement for predicting porpoise sightings (AIC= 765.651) than using local water velocity (AIC= 796.758).

Cetacean in general, and porpoises in particular are highly dependent on sound to navigate, socialize and detect prey. For that reason, anthropogenic sound may negatively impact the behaviour and distribution of porpoises (Camphuysen & Siemensma, 2011). Those conflicts are particularly lilely to occur in coastal regions, like the Marsdiep area with its harbour and two naval bases. Those conflicts only occur when porpoises are indeed present, and therefore information on this aspect of their life cycle is essential. Other studies have shown that porpoises are most abundant in March (Boonstra et al. in press), and this study shows that they are most abundant around high tide accros the entire Marsdiep region between Texel and Den Helder, with the highest abundance on the Texel side. This is valuable information for conservation and management. To reduce potential adverse impacts on porpoises, one could decide to reduce some activities during those times.

6 Recommendations

In this study, a relation between a physical process and the presence of harbour porpoises is found. To investigate this further in the future, more data needs to be gathered over several years. A seasonal pattern for harbour porpoise presence in the North Sea is known (Camphuysen & Siemensma, 2011). Investigating the sightings of harbour porpoises in the Western Wadden Sea might contribute to expending the knowledge about this seasonal patterns; how, when and why this occurs. It is unfortunate that no identification methods are nowadays present in order to help understanding these patterns.

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8 Table of figures

Appendix 1: Behaviours

	Behaviours	
70	Wheeling or swimming slowly	Cetaceans
71	Escape from ship (rooster tail)	Cetaceans
72	Swimming fast, not avoiding ship	Cetaceans
73	Breaching clear out of the water	Cetaceans
74	At the bow of the ship	Cetaceans
75	Apparently feeding: herding behaviour	Cetaceans
76	Apparently feeding: other behaviour	Cetaceans
77	Calf at the tail of adult	Cetaceans
78	Calf swimming freely in herd	Cetaceans
79	Basking, afloat	Cetaceans
80	Spy-hopping	Cetaceans
81	Lob-tailing	Cetaceans
82	Tail/flipper slapping	Cetaceans
83	Approaching ship	Cetaceans
84	Only blow visible (whales)	Cetaceans
85	Only splashes visible (dolphins)	Cetaceans
86	Acrobatic leaps	Cetaceans
87	Sexual behaviour	Cetaceans
88	Play	Cetaceans
89	Haul-out	Pinnipeds
90	Under attack by kleptoparasite	Misfortune, disease
91	Under attack (as prey) by bird	Misfortune, disease
92	Under attack (as prey) by mar. mammal	Misfortune, disease
93	Escape dive (seabirds)	Misfortune, disease
94		Misfortune, disease
95	Injured	Misfortune, disease
96	Entangled in fishing gear or rope	Misfortune, disease
97	Oiled	Misfortune, disease
98	Sick, unwell	Misfortune, disease
99	Dead	Misfortune, disease
100	Carousel feeding (orca)	Cetaceans
101	Pod splitting	Cetaceans
102	Pod formation	Cetaceans
103	Source avoiding behaviour	Cetaceans

Appendix 2: Description environmental data

Source: shipboard observer field handbook, SCANSII

Sea state:

Scale	Description	Sea state
0	Calm	Sea like a mirror, surface only glassy.
0.5	Calm	A mix of glassy patches and patches with ripples.
1	Very light	No glassy patches, ripples with the appearance of scales, no wavelets.
2	Light breeze	Small wavelets.
2.5	Light breeze, well established	More pronounced wavelets. Crests well defined, but do not break. Rare white caps.
3	Gentle breeze	Large wavelets, crests begin to break. Always 1 to 5 white caps in one sector of view.
4	Moderate breeze	Small waves becoming longer, more frequent white caps.
5	Fresh breeze	Moderate waves of pronounced long form. Many white caps, some spray.

Glare:

Glare	Description
0	No glare
1	Mild, glare present, but with minimal impacts on sightibility
2	Moderate, glare present with some impact on sightibility
3	Severe, substantial or total affect on sightibility

Visibility:

Visibility	Description
0	Good: able to see >9 km
1	Moderate: able to see 4-9 km
2	Poor: able to see 2-4 km
3	Fog: 0.5-2 km
4	Impossible: <500m

Appendix 3: Environmental datasheet

Ferry-based Harbour Porpoise Survey - NIOZ/Imares — **Environmental datasheet**

Ship:	Observer:	Date:	Page: of

Sea state:	**Glare:**	**Visibility:**	**Cloud Cv.**	**Precipitatation**	**Wind direction:**
0 = sea like a mirror					**N**
1= small ripples	0= No glare	0= >9km	1 - 8	N= none	NW 2 NO
2 = small wavelets	1= Mild	1= 4-9km		R= rain	9 3
3 = crests break	2= Moderate	2= 2-4km		F= fog	**W** 8 1 4 **O**
4 = numerous white caps	3= Severe	3= 0.5-2km			7 5
5 = moderate waves, some spray		4= <500m		I= intermittent	ZW 6 ZO
6 = larger waves, more spray				C= continious	**Z**

Dep.	Time	Sea state	Gl + Angl	Visibility	Cloud Cv.	Precipitat.	Wind dir.	Wind Sp.	Comm.

Appendix 4: Sightings datasheet

Ferry-based Harbour Porpoise Survey - NIOZ/Imares — **Sighting datasheet**

Ship:	Observer:	Date:	Page: of

Distance:	**Direction:**	Dyke or Horizon	Estimate or Measure-ment	**Main behaviours:**
	N			70= Wheeling or swimming slow
A= 0-50m	NW 2 NO			71= Escape from ship (rooster tail)
B= 51-100m	9 3			72= swimming fast, not avoiding ship
C= 101-200m	**W** 8 1 4 **O**			75= apparently feeding; herding behaviour
D= 201-300m	7 5			76: apparently feeding= other behaviour
E= 301-500m	ZW 6 ZO			77= calf at the tail of adult
F= >501m	**Z**			79= basking, afloat
				83= Approahing ship

Sighting time	Species	Sighting id	Group size	Age class	Dist.	Dy/Hz	Es/Meas	Angle	Sw dir.	Behaviour	Photo nr.	Comm.