The relation between tide and Harbour porpoise behaviour and group structure in an underwater trench

De Vries & Van Engelen

The relation between tide and harbour porpoise behaviour and group structure in an underwater trench situated in the Eastern Scheldt

A behavioural and photo-identification study on effects of tide and Harbour porpoise behaviour and group structure in an underwater trench within the Eastern Scheldt.

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Abstract

The Netherlands has planned and executed many coastal protection measures to combat the effects of flooding. Such a coastal protection measure is the storm-surge barrier (SSB) along the mouth of the Eastern Scheldt (SW-Netherlands). Despite the SSB maintaining the unique intertidal saltwater ecosystem, it has affected its ecosystem, including the harbour porpoise (*Phocoena phocoena*), as previous studies suggest that the barrier might act as an ecological trap. As a potential sub-population, the conservation plan created for the harbour porpoise in Dutch waters has stated that these porpoises do deserve special attention and monitoring, and perhaps even area-based management in years to come. This motion is further supported by the listing of the harbour porpoise on Annex II of the Habitats Directive, which has made the Netherlands obligated to appoint Special Areas of Protection (SACs) for this species. To achieve this however, more research needs to be done on the habitat use within the Eastern Scheldt and other factors, which could influence this habitat use such as the tidal currents passing through the SSB. Studies already suggest that porpoises use tidal streams for foraging. To uncover which areas of the Eastern Scheldt are of high priority for the porpoises, this study conducted boat-based surveys between the 7th of July and the 3rd of September 2017 in a particular area; a roughly 16 kilometre long underwater trench and roughly 2 kilometre wide area, with 45 metres being the approximately maximum depth. During these surveys, photo-identification, group structure and behavioural data was collected, in addition to other important factors, such as the tidal state, which allowed for the relation between the tide and the behaviour and group structure to be studied. The results showed that there was a significant increase in foraging behaviour in de deeper areas of the underwater trench. Despite no significant relation being found between the tide and foraging porpoises, their movement pattern suggest that they use the tidal stream in the deep area in front of the port of Kats to possibly concentrate prey. However, a positive significant relation between tide and water depths of the travelling behaviour was found, as expected. During surveys, most travelling was observed during changing tide. Furthermore, when the travelling behaviour data was plotted in QGIS it was observed that the currents produced by the tide seemed to influence the whereabouts of the porpoises within the study area, as most were observed towards the east after flood where the water runs in from the SSB inland, and towards the west of the study area after ebb, where the water runs back out towards sea. No significant relations were found between the tide or water depth and group structure. Nevertheless, both observations made during surveys and QGIS demonstrated that most encounters of a mother-calf pair were along the edge of the underwater trench, during all tidal stages, suggesting that the presence of a calf could perhaps influence the habitat use of the porpoise. More groups were significantly found during late afternoon, although based on this data no conclusion could be drawn. The results of this study suggest that these deep-water areas in the Eastern Scheldt are important to this potentially trapped population, particularly for foraging purposes. Especially for calves, the shallow area on the side of the trench in front of the port of Kats seemed to be an important (foraging) area. This study also demonstrates that further research should be conducted, to be able to understand their full use of the Eastern Scheldt, in order to establish SACs to conserve and protect this harbour porpoise population.

Contents

Glossary

Beaufort Sea State (BSS)	The Beaufort Sea State is a simple scale that can be used to give an approximate but concise description of sea conditions (WDC, 2017).
Diel	A 24-hour period, in relation to animal behaviour patterns (TheFreeDictionary, 2018).
Echolocation	The capability of toothed whales to emit sounds that travel from their melons (or foreheads) and reflect off objects, to gather information in order to “see” the world around them (NOAA Fisheries, 2017).
Ecological trap	Ecological traps are scenarios in which rapid environmental change leads animals to prefer to settle in (most often-) poor-quality habitats (Robertson, 2017).
Estuary	A water passage where the tide meets a river current, especially, an arm of the sea at the lower end of a river (Merriam-webster, 2017)
Foraging	Specific feeding methods to catch their prey (Breed & Moore, 2016).
High trophic levels	These trophic levels consist of apex predators, these animals have little to no natural predators and are therefore at the top of the food chain (Biology dictionary, 2017).
Indicator species	A species of plant or animal whose wellbeing confirms the wellbeing of other species in the area (Collins dictionary, 2017).
Lower tidal velocities	The speed of the lower tidal current (Dictionary.com, 2017).
Marine sentinel species	Such species are used to gain early warnings about current or potential negative trends and impacts that ultimately affect animal and human health associated with the oceans (Bossart, 2011).
Migration pattern	Seasonal movement pattern of animals from one region to another (oxford dictionaries, 2017).
Neonates	A newborn calf, or one in its first 28 days (Dictionary.com, 2017).
Group structure	A combination of the nature, quality, and patterning of the relationships among the members of a population (Whitehead & Van Parijs, 2010).
Storm-surge barrier	A 9 kilometre long structure that can seal off the Eastern Scheldt if there is a threat of flooding (Rijkswaterstaat, 2017).
Tidal flats	A level of muddy surface, alternately submerged and exposed to the air by changing tidal levels (Britannica, 2017).

1 Introduction

The harbour porpoise *(Phocoena phocoena)* is the smallest and most commonly found cetacean in Dutch waters, reaching on average 1.6 and 1.5 meters (m) in length for females and males respectively (Camphuysen & Peet, 2006; Olafsdóttir, et al., 2003). They are most abundant in coastal waters and shelf seas, and usually forage near the sea floor in waters less than 200 meters in depth (Bjørge & Tolley, 2002; Read & Harrison, 1999). The flank pattern of the harbour porpoise is unique to every individual (figure 1). Between the ages of three (males) to four (females) they become sexually mature. Adult females produce one calf after a gestation period of 10-11 months every 1-2 year(s) on average (Camphuysen & Siemensma, 2011). From stranded porpoises in Dutch waters, Addink et al. (1995) found an evident birth peak around July (June-August), with some neonates also found in May and September. Harbour porpoises are mainly seen solitary or in small groups existing of two to three individuals (Camphuysen & Siemensma, 2011). Since they use echolocation for communication, foraging, orientation and navigation, they are vulnerable to loud deep-water noises (Koschinski, 2011). They are opportunistic generalist species (Leopold & Camphuysen, 2006), feeding mainly on cod, gobies, herring, and mackerel in Dutch waters (Schelling, et al., 2014).

Figure 1: Harbour porpoise flank pattern. Source: Marprolife

After a decline in the 1950s and 1960s, as a result of a decrease in prey availability in the northwest North Sea (Barlow & Boveng, 1991; Camphuysen, 2004; Cashwell, et al., 1998; Zanderink & Osinga, 2010; Australian Bureau of Statistics, 2013), the harbour porpoise made its comeback in Dutch waters, with a peak of sightings and strandings in 2006 (Bakkers & Tuhuteru, 2016; Camphuysen & Heijboer, 2008; Reijnders, et al., 2009). Since harbour porpoises are unable to store large reserves of potential energy due to their small size, it is likely that their movement pattern is strongly related to their prey's distribution (Johnston, et al., 2005; Koopman, 1998). Recent population estimates for the Dutch Continental Shelf (DCS) are approximately 26,000 porpoises in summer, 30,000 in autumn and 80,000 in early spring (Geelhoed, et al., 2011; Scheidat, et al., 2012).

In the Eastern Scheldt (figure 2), a semi-closed part of the Dutch Delta Area, harbour porpoises have also returned after an absence of several decades following the construction of a storm-surge barrier between 1979 and 1986 (Camphuysen & van den Avoirt, 2008; Zanderink & Osinga, 2010). This storm-surge barrier (SSB) was constructed across the mouth of the former Eastern Scheldt estuary as part of The Delta Project after a north-westerly storm in 1953 breached approximately 180 kilometres (km) of Dutch coastal-defence dikes and 160 000 hectares of polderland were flooded. To lower tidal velocities in order to reduce the tidal influence on the Delta area, dams were built across the mouths of the estuaries as part of the Project. Only the SSB was constructed with open gates that can close in case of extreme weather forecasts to reduce the risk of flooding, while also maintaining the unique intertidal saltwater ecosystem within the Eastern Scheldt (Nienhuis & Smaal, 1994). The Rugvin Foundation started an annual survey in 2009 in which 37 individuals were observed, including five calves. Over the years, new-borns have also been observed, indicating that the harbour porpoise is doing well and reproducing in the Eastern Scheldt, with a peak of 61 porpoises in 2011. Though the number of sightings has been fluctuating over the years, which could have been caused by a change in weather conditions during surveys, it has not sharply declined either (the Rugvin Foundation, 2015; Zanderink & Osinga, 2010).

Of the total area of the Eastern Scheldt, about one third is an intertidal area, which becomes dry during low tide (Deltares, 2017).

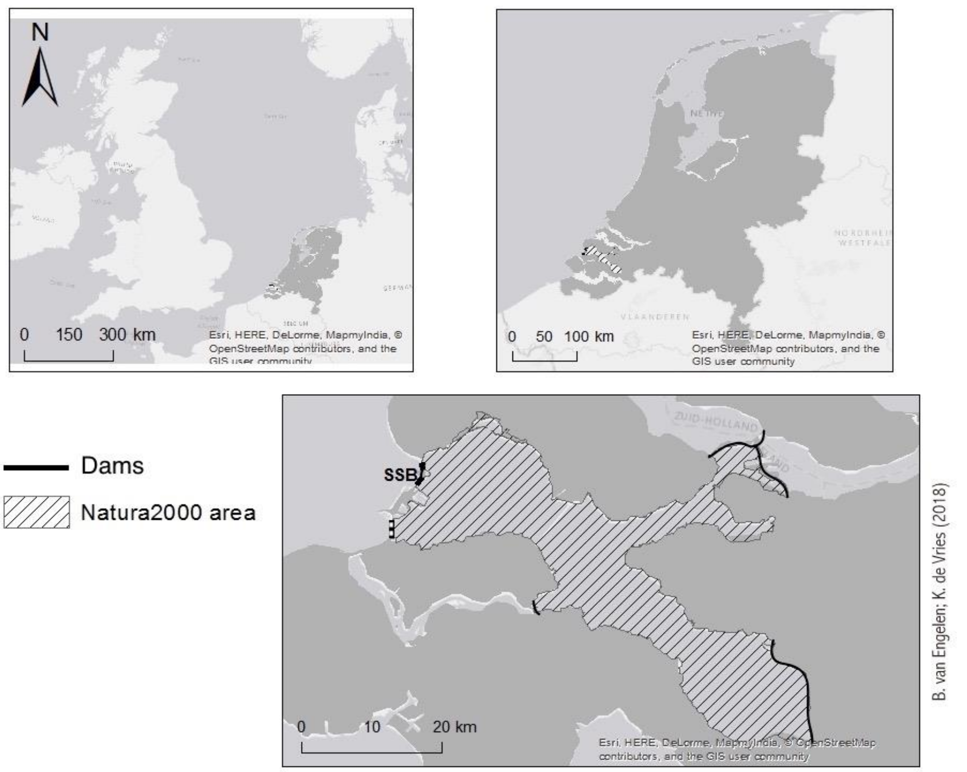

Figure 2: The Eastern Scheldt shown as a Natura2000 area in the Zeeland province, displaying also the storm-surge barrier (SSB) and (compartment) dams.

The Delta Project resulted in a decreased tidal volume in the Eastern Scheldt, which caused the current velocities to decrease with around 30%. In total, the tidal range is reduced by about 12%. As a result, the deep trenches are too wide for the reduced water volume. Sediments are therefore continuously eroded from the steep slopes of the tidal flats, whereas tidal currents are too weak to bring back the excess sediments on the tidal flats. As a consequence, the sediments from the higher intertidal zone, existing of about one third of the total area, are deposited into the trenches (Nienhuis & Smaal, 1994; Tangelder, et al., 2012). Currently, the tidal range varies from 2.5 m at the gates of the barrier to 4 m at the eastern boundaries.

The incoming flood tide through the SSB is used by numerous different taxa, such as plankton, crustaceans, fish and cetaceans to enter the tidal zone, and the ebb tide is in turn used to retreat (Gibson, 2003). Because fish and crustaceans modify their distributions and behaviours as response to variation of these tidal phases (Reis-Filho, et al., 2011), top predators, such as the harbour porpoise, take advantages of these temporal changes in the marine environment to optimize their prey capture (Lin, et al., 2013). Several studies support this hypothesis by reporting harbour porpoises waiting on prey being funnelled towards them by strong tidal currents occurring in deeper areas, such as the underwater trenches in the Eastern Scheldt (Johnston, et al., 2005; Korpelshoek, 2011; Pierpoint, 2008; Rodrigues, 2014; Watts & Gaskin, 1985). Additionally, Pierpoint (2008) reports foraging harbour porpoises during ebb tidal state above and adjacent to a steep-sided trench on the seabed directly into the tidal stream, whereas pods with calves prefer areas on the edge of the fastest flowing water, where current speeds are slower. Moreover, Rebel (2010) shows that during ebb harbour porpoises swim at a calmer pace, floating towards the North Sea with the current. A previous study in the western Eastern Scheldt already showed that harbour porpoises move to deeper areas in the Eastern Scheldt with strong tidal currents that are likely used for foraging, although further research was needed (Bakkers & Tuhuteru, 2016). Further research in understanding the habitat use of harbour porpoises in these underwater trenches during the tidal states is therefore important when dealing with a changing ecosystem. Furthermore, because of the open gates of the SSB the Eastern Scheldt will be directly affected by the consequences of climate change as a result of rising sea levels. This in turn can affect the tidal movements, and therefore possibly affect the entire ecosystem of the Eastern Scheldt.

Moreover, there is concern that the SSB might be acting as an ecological trap for the Eastern Scheldt harbour porpoise population. In recent years, harbour porpoises have been observed year-round within the Eastern Scheldt (Camphuysen & Heijboer, 2008; the Rugvin Foundation, 2015), which is in contrast with the Dutch coastal zone, where studies show seasonal migration of harbour porpoises (Evans, et al., 2003; Gilles, et al., 2009; Haelters, et al., 2011; Jung, et al., 2009; Teilmann, et al., 2008) with peak numbers in winter and early spring (Camphuysen & Siemensma, 2011; Scheidat, et al., 2012). Concern is that the noise of the water passing through the shafts of the SSB, especially during incoming tide, prevents them from migrating from the Eastern Scheldt back to the North Sea (the Rugvin Foundation, 2017). Jansen et al. (2013) reports that the stranded harbour porpoises within the Eastern Scheldt foraged long-term within the area and did not leave it frequently to forage in the Dutch coastal areas, suggesting a recent shift in habitat use of harbour porpoises from the Dutch coastal zone to the Eastern Scheldt. This means that the population in the Eastern Scheldt can possibly be considered as a sub-population (Jansen, et al., 2013). Furthermore, 20 dead porpoises were reported in the Eastern Scheldt in 2011, while 61 living porpoises were observed; compared to 820 reported dead porpoises along the Dutch coast with an estimate of around 86,000 living porpoises in Dutch coastal waters within the same year (Geelhoed, et al., 2013; the Rugvin Foundation, 2017). This could suggest a higher mortality of harbour porpoises in the Eastern Scheldt compared to the Dutch coast (Jansen, et al., 2013). Around 50% of the harbour porpoises found dead within the Eastern Scheldt between 2008 and 2012 died of starvation and emaciation (the Rugvin Foundation, 2017). It is already known that porpoises are, due to their small size, extremely sensitive to changes in food availability caused by, for example, overfishing or other changes in environmental conditions (Read & Hohn, 1995). In contrast to the situation in the North Sea, the total fish biomass in the Eastern Scheldt is relatively low and shows a decreasing trend (Smaal, et al., 2013). Zorgno (2014) further reports that a lack of prey availability in the Eastern Scheldt, especially of the main prey sand goby *(Pomatoschistus minutus),* is the most reasonable cause of death of these stranded harbour porpoises among which many calves.

However, although the Eastern Scheldt being a National Park since 2002 and a protected Natura2000 area (figure 2) (Nationaal Park Oosterschelde, 2017), it is only appointed as a protected area for seals and vulnerable bird species. Nonetheless, harbour porpoises inhabiting Dutch waters, including the sub-population of the Eastern Scheldt, are listed as endangered and therefore strictly protected under several international, European and national legislation. They are listed as threatened or endangered under several conventions, agreements and action plans, such as the EC Habitats Directive (92/43/EEC) (Annex II and IV), Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) (Annex IV), Convention on International Trade in Endangered

Species of Wild Fauna and Flora (CITES) (Annex II), and the Agreement on the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS), which was concluded under the Convention of Migratory Species (Camphuysen & Siemensma, 2011; Reijnders, et al., 2009). Therefore, The Netherlands has legal obligations to survey the conservation status of the harbour porpoise and to take requisite measures to establish a system of strict protection for the species in their natural habitat (OSPAR, 2009; Reijnders, et al., 2009). The conservation plan of the harbour porpoise, commissioned by the Ministry of Economic Affairs in 2011, emphasize that current research on the assessment of the harbour porpoise population and habitat requirements of the species, needs to be prioritized among others to develop effective protection measures, such as the establishment of protected areas for the harbour porpoise, and area-based management. It also reports that the small Eastern Scheldt population suffering from a high mortality rate deserve special attention and monitoring, even area-based management (Camphuysen & Siemensma, 2011; Jansen, et al., 2013). To this day, however, most studies carried out have been focused on the North Sea harbour porpoise population, meaning little to no research has been carried out studying the Eastern Scheldt sub-population, despite The Netherlands having a legal obligations to do so.

Bjørge (2003) suggests cautiously that in order to ensure appropriate conservation for this species, management plans of harbour porpoises should be site-specific, incorporating local knowledge about the population's structure, habitat use, and various environmental factors, since these may differ largely per area. However, except for population numbers, little is known about the group structure, environmental factors and habitat use of this seemingly isolated population of harbour porpoises within the Eastern Scheldt. For conservation measures to be most effective, greater knowledge of habitat use and habitat preference is highly desirable, especially as spatial planning is becoming the framework for management of human activities within the marine realm. As underwater trenches within the Eastern Scheldt are busy waterways and harbour porpoises seem to use the tidal streams to forage in these areas, it is necessary to study their habitat use in these site-specific locations and their importance in case of appointing protecting areas. Especially since Special Areas of Conservation (SACs) are to be designated through the EC Habitats Directive for this species when needed (OSPAR, 2009; Reijnders, et al., 2009; Britannica, 2017). The group structure of the harbour porpoise has not been studied in detail, as the species is generally considered living solitary, although groups of around eight or more are not uncommon. Relatively little is still known about their social interactions (Bjørge & Tolley, 2002; Gowans, et al., 2008). Designating protected areas for calves is especially important as harbour porpoise calves in the Eastern Scheldt are vulnerable as a result of the decrease in their main prey as mentioned previously, and thus find it difficult to catch their own prey once they become independent from their mothers in autumn (Zorgno, 2014).

Harbour porpoises, like many other marine mammal species, have long life spans and feed at a high trophic level, and can therefore be seen as a prime marine sentinel species. Since marine mammals have a popular appeal for observation it is more likely to assume that health issues concerning these species are sooner to be detected. This means that harbour porpoises can measure or predict current or negative impacts on individual- and population-level animal health or even whole ecosystems within the Eastern Scheldt, which in turn permits better insight and management of impacts affecting animal and human health associated with the oceans (Bossart, 2011).

The aim of this study is to gain a better insight on the tidal influence on the behaviour and group structure of the Eastern Scheldt harbour porpoise population in an underwater trench, by using photo-identification and behavioural observations, in order to gain a better understanding of the importance and habitat use of these deep waters within the Eastern Scheldt. The results from this study could provide a better understanding of the relation between environmental factors and the habitat use and spatial distribution of the harbour porpoise within the entire Eastern Scheldt area. This in turn could be used in future studies to ultimately help with establishing site-specific conservation and management measures in the form of SACs. To achieve the aim of this study, the following research question has been formulated:

"What is the relation between tide and the behaviour and group structure of the Harbour Porpoise (Phocoena phocoena) in an underwater trench situated in the Eastern Scheldt?"

To answer this question, the following sub-questions have been set up:

i. What is the relation between the tide and the behaviour of Harbour Porpoises in an underwater trench in the Eastern Scheldt?
ii. What is the relation between the tide and the group structure of Harbour Porpoises in an underwater trench in the Eastern Scheldt?

2 Materials and methods

2.1 Study area

The study area (figure 3) exists of an underwater trench (Engelsche Vaarwater) within the Eastern Scheldt. It lies alongside the ports of Colijnsplaat, Kats and Goessche Sas in the Zeeland province, the Netherlands. The focus of this study lies on this particular part of the Eastern Scheldt as during former observations it became apparent that water currents are stronger within these deeper areas, especially near the port of Kats. The Eastern Scheldt has a surface area of 350 square kilometres (km^2) (Deltares, 2017), in which the underwater trench exists of a 16.3 km long and roughly 2 km wide area. However, due to fishing and mussel cultivation areas within the shallow areas on both sides of the trench, only 1.5 km of the width of the trench was used as study area. The study area is divided into four areas depending on water depths; 0 m – 10 m, 10 m – 20 m, 20 m – 30 m and 30+ m (figure 3), with 45 m being approximately the maximum depth. Besides recreational diving and fishing spots from the shore, it is possible for recreational-, fishing-, and ferryboats to sail through the study area around the waterways, depicted in figure 3.

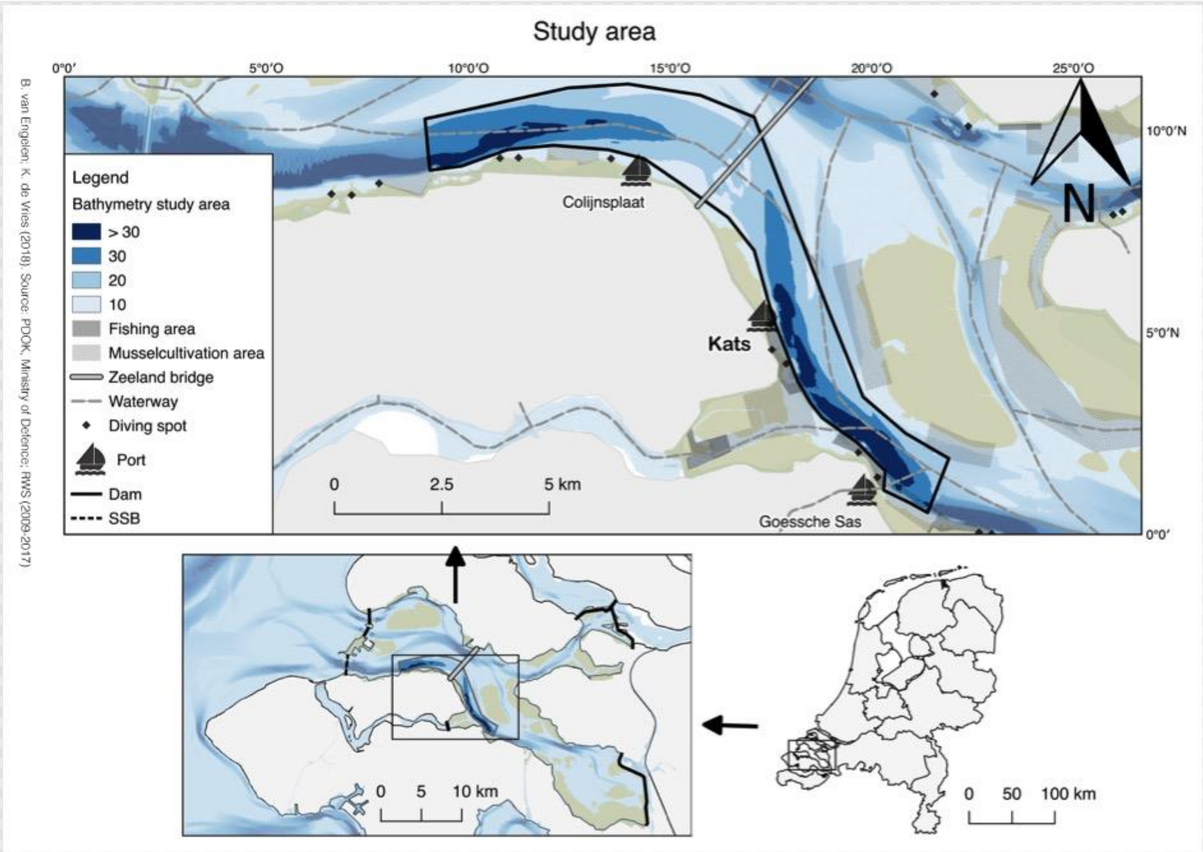

Figure 3:Study site existing of a deep-water trench situated in the tidal bay Eastern Scheldt, situated in the south-west of the Netherlands. Sandbanks are indicated in beige.

2.2 Data collection

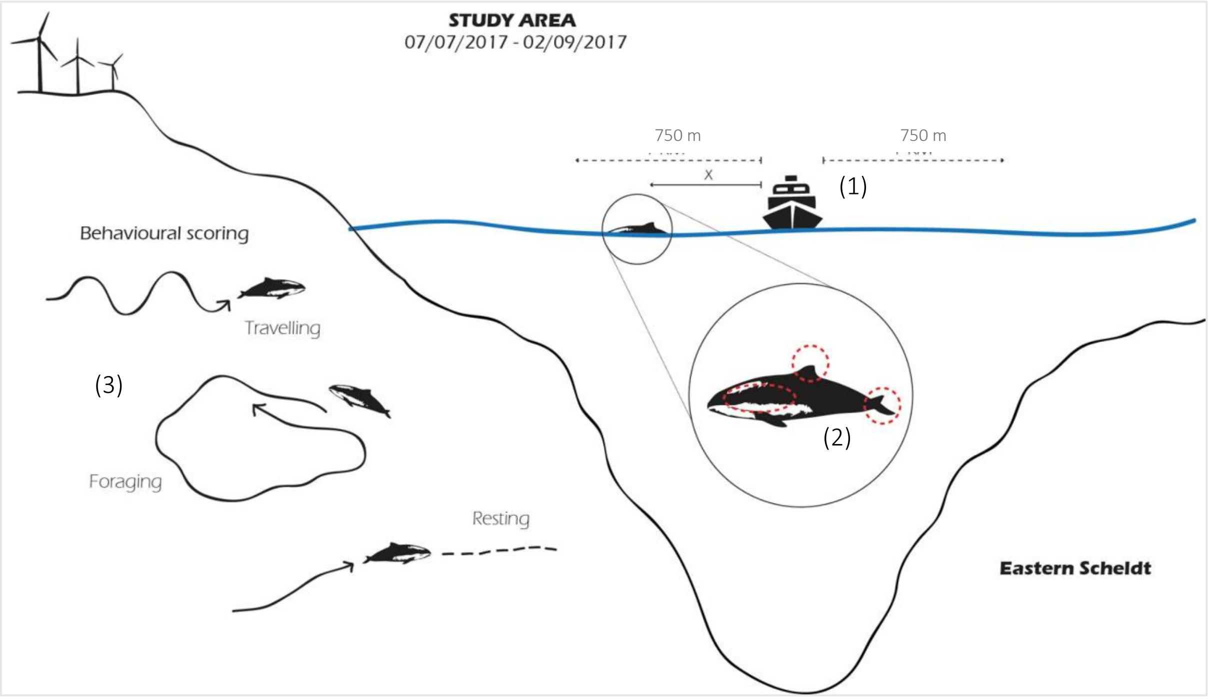

Figure 4: Research design displaying (1) the transect in the middle of the trench, (2) the areas of the harbour porpoise used for photo-identification and (3) the three behavioural traits that were recorded.

Boat-based surveys were carried out between the 7th of July and the 3rd of September 2017 from a BRIG Falcon 500L, with a 30hp engine, departing from the port of Kats. Because this type of research vessel is easily influenced by waves and since harbour porpoises are more likely to be observed during calm weather conditions, as they are small, relatively inconspicuous and often live solitary (Evans & Hammond, 2004), surveys were only carried out under favourable weather conditions; Beaufort Sea State (BSS) ranging between 0 and 2, and with visibility of at least 1 km. This means that surveys were terminated as soon as white caps appeared (>3 BSS) or when the visibility deteriorated due to rain or fog. The observers decided whether observations were possible when the BSS in the study area was not homogeneous due to strong tidal currents or landmarks such as the Zeeland bridge, acting as a wind block.

During the surveys the boat followed a single line transect through the study area (figure 4 (1)), assuming that all harbour porpoises present in the area from the boat to the ends of the trench (750 meters each side of the boat) could be sighted. The start direction from the port to either end of the study site was equally alternated, sometimes dependable on the tidal state, wind- and current direction.

Observations for harbour porpoises were done by two or more observers by the naked eye and one or more with the aid of a binocular. Each observer was assigned a different section around the boat, ensuring that the whole 360° view around the boat was covered.

At the beginning and end of each survey, **the time and date** (including day of the week), **GPS location, tidal state**, and **weather conditions** were recorded on the survey form (Appendix I). A change in weather condition during the survey was also noted down. The weather condition data existed of the following:

- *Weather:* sunny, sunny with clouds, overcast, showers, rain, hail or fog (Appendix II);
- *Beaufort Sea State (BSS):* ranging from 0-5, with 0= smooth and mirror-like, and wind calm and 5= moderate waves, many whitecaps, and a fresh breeze;
- *Visibility:* excellent, very good, good, fair and poor (Appendix II);
- *Cloud coverage (CC):* ranging from 1 to 5; with 1= 0-20%, 2=21-40%, 3=41-60%, 4=61-80%, 5=81-100%.

Field notes were taken and later transferred to Microsoft Excel 2016. Upon encountering a harbour porpoise the encounter form (Appendix II) was used, in which the **time** and **GPS location** of the encounter, **tidal state, weather conditions** at the time of the encounter, number of individuals/**group size**, the presence of a **calf**, the **behaviour** displayed by the porpoises and when possible the **travel direction** were recorded. The GPS location of the harbour porpoises were collected by driving the boat to the initial and final encounter site, using landmarks and ripples in the water left behind from the surfacing harbour porpoise. This method was used as the harbour porpoises surface for a very short time and are unpredictable in where they will surface next, which is especially the case during foraging. Thus no location was recorded for the secondary behaviours.

As many photographs as possible were taken of both sides of each individual using SLR cameras with 300 mm optic zoom lenses (Bakkers & Tuhuteru, 2016). These photographs were used to identify individuals. By using photo-ID, the relationship between harbour porpoise behaviour and group structure and the tide could be studied.

Encounter recordings were stopped when the harbour porpoises were no longer observed or, to minimize disturbance, when enough photos of good enough quality were taken of both sides of all observed individuals.

After filtering out the photos of good enough quality per encounter and individual, the best photos of each individual were selected depending on the most distinctive markings (figure 1 & 4(2)). These markings include nicks and notches on the leading and trailing edges of the dorsal fin, pigmentation, scarring and peduncle marks (Würsig & Jefferson, 1990; Zanardo, et al., 2016). When these natural markings were not present on harbour porpoises, the flank pattern was used to recognize individuals.

2.2.1 Tide

The twelve-hour tidal period was divided into four tidal states (figure 5), which were measured relative to NAP Eastern Scheldt by Rijkswaterstaat (see website: getij.nl):

i) *High tide*. Water levels reached the highest 40 centimetres (cm) margin.
ii) *Ebb*. Water levels dropped below the high tide margin but had not yet reached the low tide margin.
iii) *Low tide*. Water levels reached the lowest 40 cm margin.
iv) *Flood*. Water levels passed the low tide margin but had not yet reached the high tide margin.

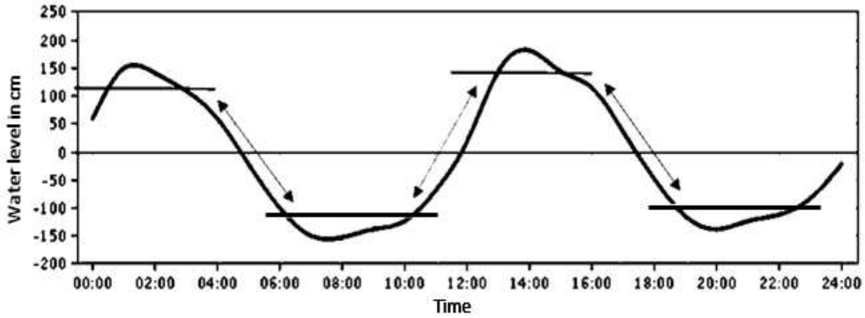

Figure 5: The four tidal states relative to water levels (cm). Solid lines; high and low tide, arrows; ebb and flood. *Source graph: getij.nl*

2.2.2 Behaviour

When encountering a harbour porpoise (or a group), the (duration of-) behaviour was recorded, being either foraging, resting or traveling (figure 4 (3)). Both initial and secondary behaviours were recorded. The behavioural states were assigned to one of the three categories modelled on Shane et al. (1986) and experience gained during previous study seasons of the Rugvin Foundation:

i) *Foraging.* Harbour porpoises involved in any effort to capture and consume prey displayed by either chasing prey on the surface, or taking a couple of quick breaths before diving for a few minutes and surfacing roughly in the same area. The breaths in between the dives can be irregular.

ii) *Resting.* Harbour porpoises are logging; the animals appear like logs at the surface, inactive.

iii) *Travelling.* Harbour porpoises are moving in one direction, taking 3-4 breaths before going under again. The animals will resurface further down in the same direction that it was heading.

The duration/continuous sampling method was used to gather behavioural data to gain more detailed information on the behaviour and relationships of each specific individual for a long period of time (Mann, 1999).

2.2.3 Group structure

Upon encountering harbour porpoises, the number of individuals and calves were recorded. A group was defined as two or more adult harbour porpoises observed in close proximity to one another, moving in similar direction and/or engaged in similar behaviour (Defran & Weller, 2006).

When encountering a mother and calf or a group with a calf, only the behaviour of the mother and/or other adults were recorded, as it is assumed that the calf copies the behaviour of the mother (Teilmann, et al., 2007). The presence of a calf was noted as this could perhaps have influence on the behaviour and movement patterns of the mother. Because female and male harbour porpoises reach around the same body length (females 1.6 m and males 1.5 m) (Olafsdóttir, et al., 2003), the sex could only be determined by the presence of a calf.

2.3 Data preparation

All collected data was stored in Microsoft Office Excel 2016 and exported to IBM SPSS Statistics 24. As the harbour porpoises continued moving throughout the study area during some encounters, the tide, group size/structure and area occasionally changed during an encounter. To be able to study the behaviour and group structure during the multiple tidal states, group sizes and areas within an encounter, a new row was added for each individual when the tidal state, group size or area changed, called an interval. Therefore, an encounter may exist of multiple intervals. These intervals were used in the analysis, not the encounters. A mother with calf accounted as one individual.

In order to run the model successfully, the following data was recoded:

The tidal states were converted from four states to three states, where *ebb* and *flood* were converted into *changing tide*.

Due to the double-peaked (bimodal) distribution (close to 0 or 100%) of the observed behavioural data (appendix III), the behaviour was recoded into the following categories:

- *Present: The behaviour was observed for more than 70% (>=0.7) of the encounter (mostly 100%);*
- *Not present: The behaviour was observed for less than 70% (<0.7) of the encounter (mostly 0%).*

To analyse the group structure, the presence of a group during an interval was tested. To study the presence of a group, all intervals were divided into either single or group, despite the group size. It was considered a group when there were two or more adults, calves were not included:

- *Single: A lone harbour porpoise (1 individual);*
- *Group: A group of harbour porpoises (>1 individuals).*

To study the presence of a calf during an interval, all intervals with a calf present were divided into either calf present, or calf not present, despite it being in a group or with a lone harbour porpoise:

- *Calf present: Present both within a group or with a lone harbour porpoise;*
- *Calf not present: No calf present either within a group or with a lone harbour porpoise.*

To analyse the time of the interval, the half time of each interval was placed within a time step. These time steps were then pooled into three groups:

- *Morning: Earliest timestep up to timestep 12 (till 12:00);*
- *Afternoon: Timestep 13 up to timestep 15 (12:00 till 15:00);*
- *Late afternoon: Timestep 16 up to the highest timestep (from 15:00 till latest).*

To analyse the day of the week, the days were categorised in:

- *Week day: Monday to Friday;*
- *Weekend: Saturday and Sunday.*

All unidentified individuals were assigned a random ID so that the ID could be used as a random effect variable.

2.3.1 GIS-datasets

To further analyse the behavioural movement pattern of the porpoise within the trench, the data from Excel was also exported to QGIS (version 2.18.9) to be analysed in maps. Multiple map layers were derived from the Ministry of Defence, PDOK, and Rijkswaterstaat (RWS) (Table 1). The *Pronvincies Nederland* was used as a base map because it did not contain any other attributes except for province borders. The *Bathymetrie Nederland* map displays, among others, the bathymetry (water depths) of the Netherlands, including the Eastern Scheldt. The *Visvlak* and *Schelpdiervlak maps* shows the fishery and mussel cultivation-area's surrounding, and therefore also outlining for the most part, the study area. This also accounts for the *Hoogtebestand Oosterschelde* map, which shows the areas that become dry during low tide. Besides the fishery/cultivation area layers, *Vaarwegen* (water ways) is also included as they might explain any disturbance within the study area. Additionally, all datasets were projected on the same coordinate system (EPSG:28992, Amersfoort / RD New).

Table 1: Metadata of the GIS-datasets.

File name	Description	Format	Year	Scale / raster size	Owner
World topographic grey base map	Topographic background map of the world in grey	Raster	2016	1:72.000	Esri
Provincies Nederland	Provinces of the Netherlands	Raster	2017	1:1.250.000	PDOK
Bathymetrie Nederland	Depth (m) of Dutch waters	Raster	2009	1:120.000	Rijkswaterstaat
Beschermingsgebieden	Natura2000 area Eastern Scheldt	Vector	2009	1:250.000	Rijkswaterstaat
Hoogtebestand Oosterschelde	Hoogte zandbanken en-platen Oosterschelde	Raster	2013	1:80.000	Ministry of Defence
Visvlak	Fishing areas within the Eastern Scheldt	Vector	2017	1:160.000	Rijkswaterstaat
Schelpdiervlak	Shellfish cultivation areas within the Eastern Scheldt	Vector	2017	1:1.000.000	Rijkswaterstaat
Vaarwegen	National (Dutch) water ways through all water bodies	Vector	2017	1:400.000	Rijkswaterstaat

To analyse the data in QGIS, the bathymetry layer of the Netherlands was reclassified into the four areas based on depth. All encounters, except for individuals observed less than five minutes, were plotted in QGIS against the four areas based upon water depth. As only the locations of the start and end of the encounters could be documented, a line was drawn between the start and end location, using the tool *Point to lines*, to get an oversight of their behavioural movement pattern within the trench. The assumption was that the distance of the line (in %) within each area equalled the amount of time a harbour porpoise was present within each area. As a result, an estimate of time spend within each area per interval could be made.

To analyse any changes in the behavioural movement pattern of harbour porpoises within the trench during *flood* and *ebb* tidal stream, both tidal states were included instead of converting them into *changing tide*.

2.4 Data analysis

The criterion for an interval to be included in the analysis was that the duration had to be 5 minutes or longer (>=5). This criterion was set in order to omit those intervals of which an accurate judgement of displayed behaviour could not be made, due to the short duration of the interval.

With the use of a Generalized Linear Mixed Model (GLMM) the relation between *tide* and behaviour, group structure and explanatory variables (*time of day*, *day, month, CC*, *BSS and visibility*) within the trench could be analysed (IBM Corporation, 2016). This model was chosen due to the bimodal distribution of the data and the categorical nature of the dependent variables. This model also allows for a pairwise comparison test to be done, where each category of the independent variables is matched one-on-one with each of the other categories (IBM Corporation, 2016).

Initial analyses performed for each variable indicated that all variables with the exception of tide, area and visibility, could not clarify variation in behaviour or the presence of a calf (p: <0.25). Initial analysis performed for each variable with group presence as the dependent factor, indicated that only tide and time of day could clarify variation in group presence (p: <0.25), thus remaining variables were left out of further analysis with group presence. After filtering out the variables, the model selection was done based on the Akaike Information Criterion (AIC) (Wagenmakers & Farrell, 2004). The AIC estimates the quality of each model, relative to each of the other models. For both the behavioural targets as the presence of a calf, the model with tide and area were the most suitable models. For group presence, the model with tide and time of day was used, as no further variables fulfilled the criterion of p: <0.25 as mentioned above, thus no variables had to be eliminated.

The date, encounter numbers and ID's were included as random effects, with the tide, area, group and visibility as fixed effects, and the behaviour and group structure as the target. As the sample size was small, the varied across test was used as the degrees of freedom. A binary logistic regression was performed for testing the effects on the foraging and travelling behaviour, and a multinomial logistic regression was used to test the effects on group structure. Data are presented as mean ± SEM (Standard Error of Mean); significance of <0.05 was accepted in the final analysis in order for variables to have a significant effect on the behaviour or group structure. A pairwise comparisons test was performed to study the in-between effects of the independent factors (IBM Corporation, 2016).

3 Results

3.1 Survey effort

During the study period from the 7th of July till the 3rd of September of 2017 (*survey effort: 64 hours and 50 minutes*), 27 encounters were made, of 49 harbour porpoises. In total, 38 porpoises were included in analysis as a result of the >5 min/interval criterion. In total 15 individuals were identified via photo-ID. Two individuals were resighted, of which one was a mother with calf, who was resighted 8 times during the study period. Survey effort varied between months due to restricting weather conditions. The earliest survey started at 08:25, the latest survey at 19:05, with an average starting time of 12:07. The latest survey ended at 20:20, with the average end time of 14:45. Most survey effort took place during sea state 1 (42%), followed by sea state 2 (27%). Less survey effort was carried out at sea state 0 and 3 (14% and 15% respectively). Little to no survey effort was carried out at sea state 4 or 5 (2% and 0% respectively). The visibility during surveys was on average 3/4 (very good/good). The average cloud cover during fieldwork days was 2.88/5 (40-60%). Most intervals were of encounters during changing tide (39%) (and in the late afternoon (44%) (15:00 onwards).

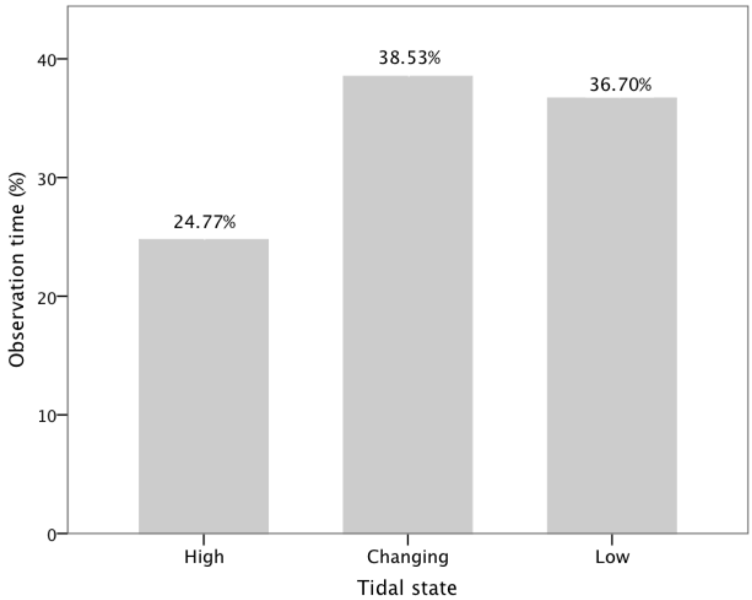

Figure 6: Total observation time in the three tidal states.

3.2 Basic data

<u>Behaviour</u>

The most observed behaviour during the intervals was foraging (76.4%), and less frequently travelling (21.2%) (figure 7). The least observed behaviour was resting (2.4%). However, resting took place most during foraging (18%) as opposed to travelling (6%). There were 87 intervals that fulfilled the criterion >=5 minutes, with the exception of all resting intervals. Thus, resting behaviour was left out of any further statistical analysis with GLMM.

<u>Group structure</u>

Most intervals were of encounters of harbour porpoises in a group (>2 individuals) (64%), with little intervals of harbour porpoises with a calf present (31%) (figure 8). Group size varied from one to six individuals per interval. The average group size was 2.02 porpoises with a standard deviation of 1.018.

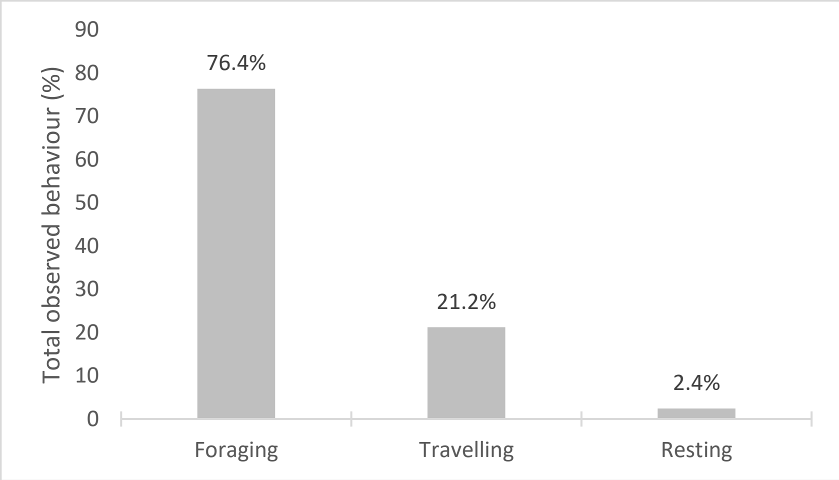

Figure 7: Total observed harbour porpoise behaviour.

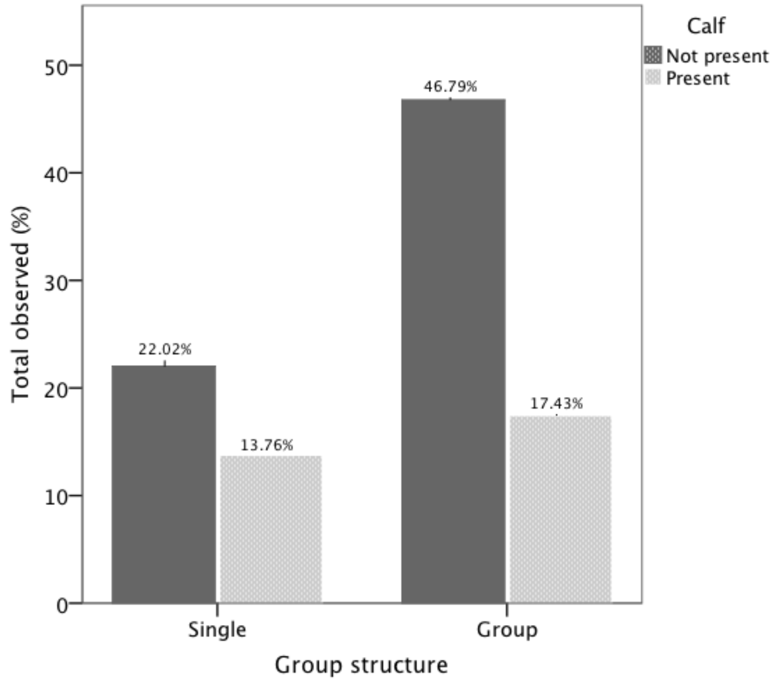

Figure 8: Total observed group structure (single/group), including calf presence.

3.3 Behaviour

The **foraging behaviour** being present during an interval significantly increased in greater depth (F (3.103)= 2.765, P= 0.046) (table 2) (figure 9).

Table 2: End results of the areas, displaying the mean of foraging present during intervals per area.

Area	N	Mean	Std. Error	95% Confidence Interval Lower	Upper
0-10m	6	0.429	0.252	0.081	0.865
10-20m	12	0.542	0.222	0.148	0.890
20-30m	33	0.891	0.083	0.550	0.982
30+m	23	0.894	0.092	0.519	0.985

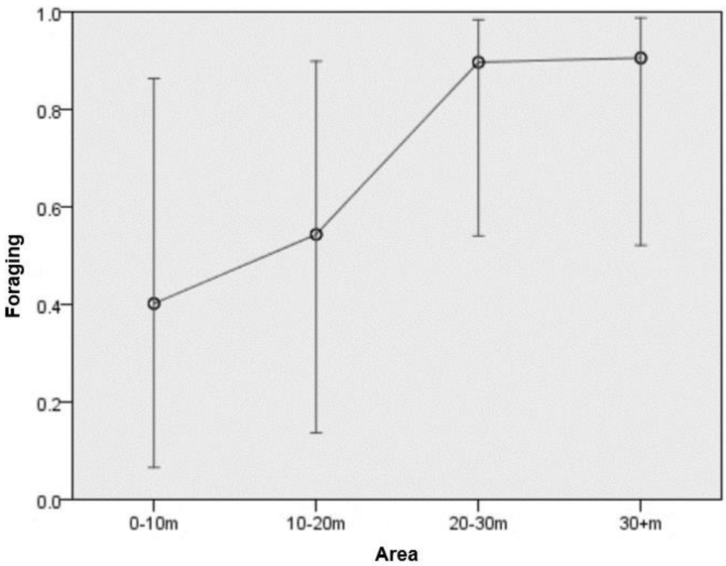

Figure 9: Chance of harbour porpoises foraging within the four areas correlated to water depths, within the study area.

The pairwise comparison showed the same result; harbour porpoises foraged per interval significantly more in greater depth (area 3 (20-30m)) compared to most shallow areas of the study area (0-10m) (0.461 +/- 0.230; t(66)= 2.008, P= 0.049).

The *tidal state* did not significantly influence the foraging behaviour being present during intervals (F (2.103)= 1.882, P= 0.158). The pairwise comparison further resulted in no significant difference in foraging behaviour between the three tidal states, as can be seen in appendix IV.

Most travelling behaviour was observed during changing tide (50%). The **travelling behaviour** being present during an interval however, was not significantly different between *tidal states* (F (2.103)= 1.382, P= 0.256). The pairwise comparison further resulted in no significant difference in travelling behaviour between the three tidal states (appendix IV).

The travelling behaviour being present during an interval was not significantly different (appendix IV) between the *areas* (F (3.103)= 1.673, P= 0.177). The pairwise comparison further resulted in no significant difference in travelling behaviour between the areas.

However, looking at the encounters plotted onto the study area map (figure 8), both foraging and travelling behaviour were observed more often on the (south)eastern side of the study area during high tide (figure 10a and 10d). As opposed to low tide, during which harbour porpoises were observed more often foraging and travelling on the (north)western side of the trench (figure 10b and 10e). During all tidal states harbour porpoises were observed foraging most often in the deep area in front of the port Kats (figure 10a to c), where the current was observed stronger than shallower areas. During ebb, their southeast movement direction during foraging was often against the tidal stream (figure 10b). Furthermore, looking at changing tide, porpoises travelled often the same direction as the tidal streams during ebb and flood (figure 10f); the water flows towards the SSB on the north-western side of the Eastern Scheldt during ebb, and towards the eastern side of the Eastern Scheldt during flood. While harbour porpoises foraged significantly more often in deep areas, it seems that they use the in-between shallow areas (0-20 m) more frequently for travelling (figure 10d to f).

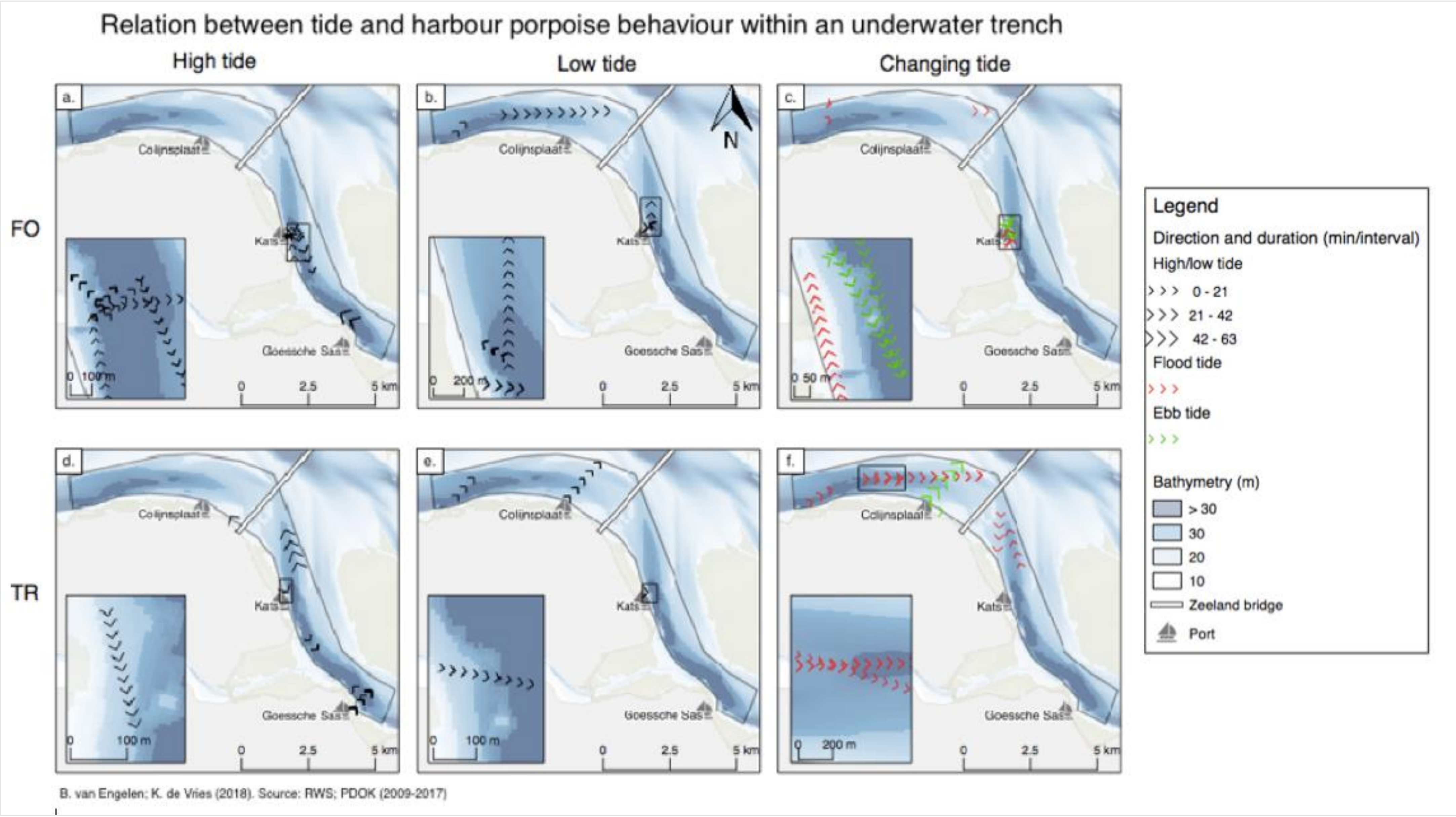

Figure 10: Harbour porpoise behaviour foraging (FO) and travelling (TR) of each interval plotted in the three tidal states (ebb (green) and flood (red) are both changing tide), in which FO= foraging, and TR= travelling.

3.4 Group structure

The presence of a **group** during an interval significantly differed during the *time of day* (F (2.58)= 4.314, P= 0.018) (table 2), where groups were per interval significantly observed more during late afternoon than during morning and afternoon (figure 9).

Table 2: End results of the time of day, displaying the mean of a group being present during intervals per time period.

Time of day	N	Mean	Std. Error	95% Confidence Interval Lower	95% Confidence Interval Upper
Morning (till 12:00)	12	0.391	0.194	0.095	0.798
Afternoon (12:00 – 15:00)	13	0.377	0.180	0.098	0.773
Late afternoon (15:00 till latest)	45	0.907	0.079	0.572	0.986

The Pairwise comparison results showed the same: per interval, harbour porpoises were observed significantly more often in groups during late afternoon compared to afternoon (t(29)= 3.075, P= 0.005) or morning (t(22)= 2.669, P= 0.014).

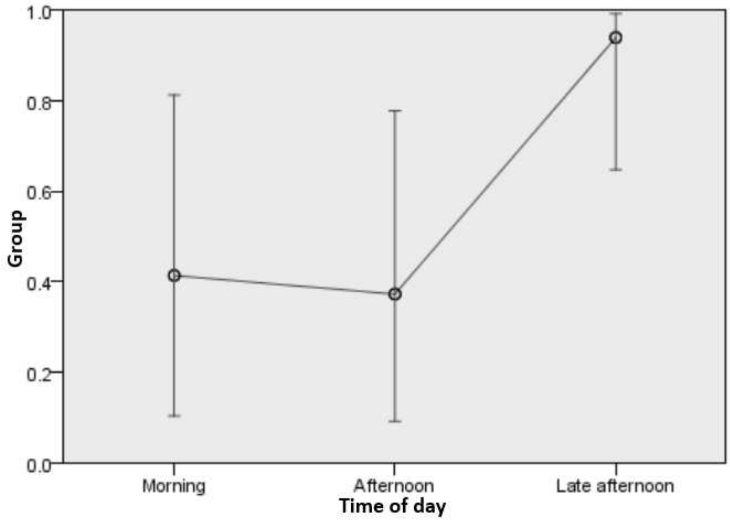

Figure 11: Chance of harbour porpoises being in a group during the day within the study area.

The *tidal state* did not significantly influence the group structure between intervals (F (2.48)= 1.182, P= 0.315). The pairwise comparison further resulted in no significant difference in group structure between the three tidal states.

The *areas* did not pass the initial analysis, thus no significant relation was found between the presence of a group and the areas depending on water depth.

The presence of a **calf** during an interval did not significantly differ between *tidal states*, (F (2.103)= 0.606, P= 0.548). The pairwise comparison further resulted in no significant difference in calf presence between the three tidal states (appendix IV). This is also reflected in figure 12a; groups and mothers with calves were observed foraging during all tidal states, except for flood, on the side of the deeper area of the trench in front of the port Kats, where current speeds were observed to be slower than the deeper area.

The presence of a calf during an interval did not significantly differ between the *areas* within the study area (F (3.103)= 0.594, P= 0.620). The pairwise comparison further resulted in no significant difference in calf presence between the areas (appendix IV). Travelling however, only occurred in the shallower waters (figure 12b).

The presence of a calf during an interval did not significantly differ between the *areas* within the study area (F (3.103)= 0.594, P= 0.620). The pairwise comparison further resulted in no significant difference in calf presence between the areas (appendix IV).

The presence of a calf during an interval did not significantly differ between the *time of day* (F (2.101)= 1.221, P= 0.299). The pairwise comparison further resulted in no significant difference in calf presence during the day (appendix III).

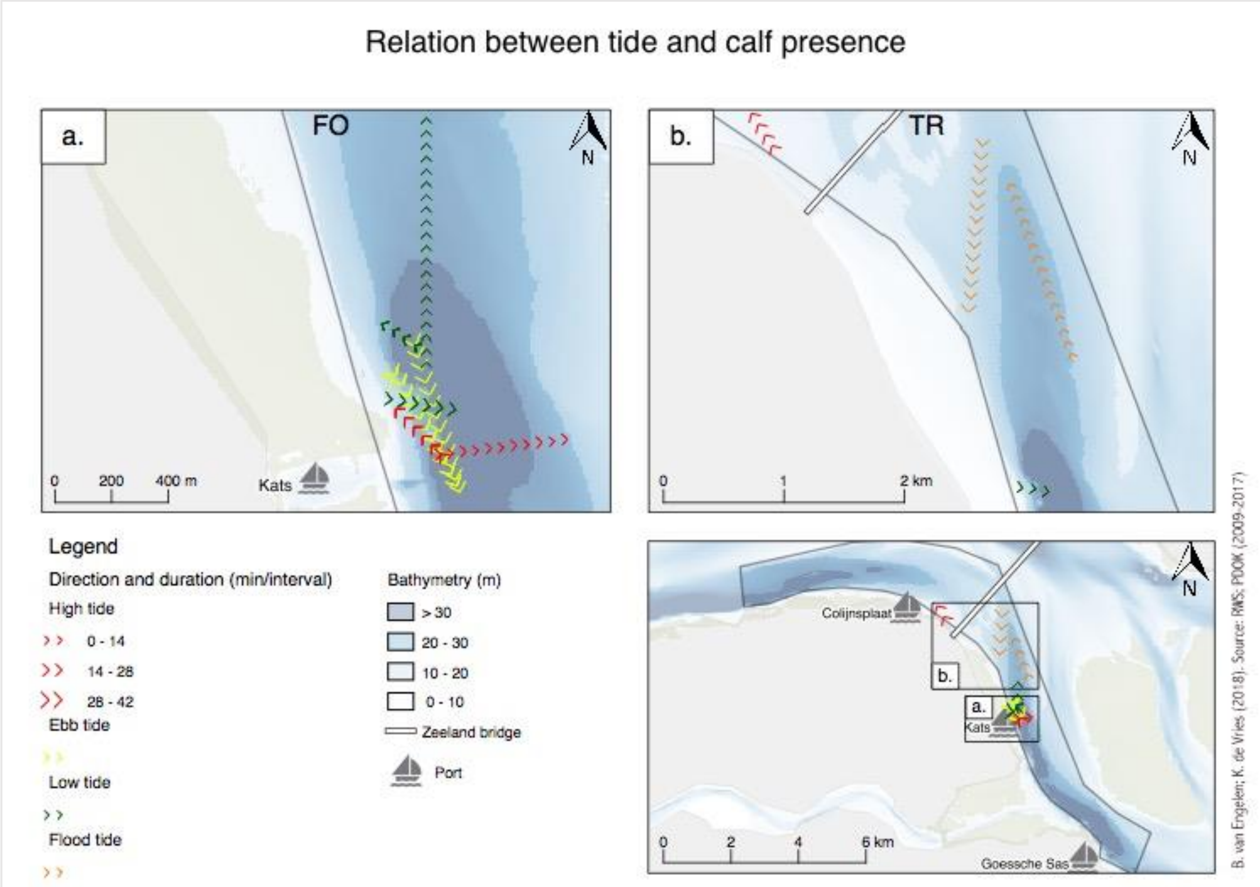

Figure 12 Movement patterns with calf presence plotted during all tidal states.

4 Discussion

The aim of this study was to gain a better insight in the tidal influence on the behaviour and group structure of the harbour porpoises within an underwater trench situated in the Eastern Scheldt. To achieve this aim, boat-based surveys were carried out throughout the study area, during which photographs were taken for photo-ID. Furthermore, behavioural and social characteristics were documented during encounters. Encounters were divided into intervals based on a change in tidal state, group size and area (based on water depth), to study their influence on harbour porpoise's behaviour within the trench (see chapter 2.5). In total, 87 intervals fulfilled the requirements and were analysed. The insight gained during this study can be used in the future to build upon, in order to establish site-specific conservation and management measures for the Eastern Scheldt harbour porpoise population.

4.1 Study limitations

Although the research study has provided results, there were some unavoidable limitations. It is important to mention that both weather conditions and the behavioural characteristics of the harbour porpoise might influence the encounter rate. Poor weather conditions, such as a high BSS and cloud coverage are known to influence the ability to detect a harbour porpoise (Hammond, et al., 2002; IJsseldijk, et al., 2015; Teilmann, 2003). Therefore, only surveys under similar and favourable weather conditions could be conducted. As a result, the time limit of eight weeks was reduced to the point where full day surveys were also limited due to a change in weather. The time limit also influenced the number of encounters that could be used for the analysis, which resulted in a small dataset. Likewise, the behavioural characteristics of the harbour porpoise might also have had an effect on the encounter rate, possibly resulting in a small sample size. In particularly the 'rolling movement' when surfacing, referred to as wheeling, where only the dorsal fin and a small area of the peduncle are displayed for a short moment above the surface of the water. Additionally, harbour porpoises usually only spend 5% of their total time at the surface (Camphuysen & Peet, 2006; Westgate, et al., 1995). As a result of their short time spent at the surface, their unpredictable surfacing locations, and because their underwater movements cannot be tracked by the naked eye, it is challenging to detect harbour porpoises, and/or to observe their behaviour. Therefore, it cannot be assumed that the recorded behaviour used for analyses included all of the behaviour of all harbour porpoises during an encounter. Also, the assumption was made that all animals along the transect would be detected. However, animals with long durations of submergence have a high probability of remaining undetected during the passage of the research vessel. This assumption is therefore often violated during marine mammal surveys (Smith & Perrin, 1997), meaning that it is probable that some harbour porpoises did avoid the vessel during this current study. This has minimal impact on this study however, as this study does not focus on the abundance of this population, but rather the observed behaviour and group structure.

Despite the small size of the research vessel used during this study, the recent study of Dyndo et al. (2015) reported that even low levels of high frequency components in deep-water vessel noise caused strong stereotyped behavioural responses in harbour porpoises. This means that the small research vessel could potentially have influenced the observed behaviour during this study. Boat-based surveys were needed however, as it allowed for photographs to be taken for photo-ID. The small size of the research vessel used also made it possible to closely observe the behaviour of encountered harbour porpoises. Also, effort was made to minimize the disturbance potentially caused by the presence of the small research vessel by switching off the motor as often as possible and by keeping distance from the harbour porpoises. Nevertheless, taking vessel density into account as a possible disturbance factor might provide more accurate results when explaining porpoise behaviour.

Additionally, as a result of the tidal state, group size and area occasionally changing during an encounter, the data had to be converted into intervals. This strategy meant that intervals, which were of the same encounter, would be seen as independent intervals, despite being related. To keep the influence of this on the results to a minimum, the ID's were used to identify between individuals. However, not every encountered porpoise could be identified, resulting in a higher amount of related intervals that were seen as independent intervals. Additionally, the small dataset meant most data had to be recoded (see chapter 2.5), possibly further resulting in less accurate results. This was necessary however, to allow for the statistical analysis to be performed. In addition, the small dispersion of the data could have possibly resulted in non-significant results, as most of the data is clustered around the mean, resulting in a small variance and standard deviation. By studying this study area and population for a longer period of time however, this could be resolved, as the dataset would become larger and thus more dispersed, leading to a larger variance and standard deviation (Australian Bureau of Statistics, 2013).

4.2 Behaviour

During this study harbour porpoises were observed foraging more often (76.4%) than the behaviours traveling (21.2%) and resting (2.2%) within the underwater trench. These results are supported by the study of Watson & Gaskin (1983), in which harbour porpoises were observed 75% of the time in apparent foraging behaviour, 21% in point-to-point movement (travelling behaviour), and 4% lying at the surface (resting) in the southwest coast of the Bay of Fundy. This high percentage in foraging behaviour was expected, due to the high energy demands of this small cetacean (Kastelein, et al., 1997; Yasui & Gaskin, 1986).

The underwater trench is used as a waterway by ferry-, fishing-, and recreational boats, of which the underwater noise is known to disturb harbour porpoises, which could explain why resting behaviour was observed the least, as it may hold excessively disturbance as a resting area. Watson & Gaskin (1987) showed however, that harbour porpoises rest predominantly during feeding periods compared to travelling. They further suggest that surface rotating behaviour may represent acoustical scanning for pelagic fish swimming near the surface. Although this current study has no exact data on the rotating behaviour during logging, it is possible that this was present. Although resting behaviour was not taken into the GLMM analysis, it was observed however, that resting behaviour took place more often during foraging (18%), as opposed to travelling (6%) within the intervals. Further research on the relation between foraging and resting during both day and night, might result in a better insight on their resting behaviour.

Foraging

Not only was the foraging the most observed behaviour, it also significantly increased within greater depths. This was expected, as several studies report harbour porpoises preferring habitats consisting of narrow, (steep-sided) trenches, headlands, and restricted channels for foraging (Johnston, et al., 2005; Pierpoint, 2008; Rodrigues, 2014; Watts & Gaskin, 1985). This type of habitat of enhanced relative vorticity seems to increase primary productivity and aggregate smaller prey items existing often of schooling fish. This makes foraging for marine predators that feed at low and medium trophic levels, such as the harbour porpoise, more likely within these areas (Johnston, et al., 2005; Scott, et al., 2010; Watts & Gaskin, 1985).

Although no significant relation between foraging porpoises and tide was found in this study, their foraging (movement) direction in the deep area in front of the port of Kats indicated that they use the tidal stream during changing tide for foraging. This was expected, as the tidal states flood and ebb (in this current study merged into *changing tide*) seem to play an important role in explaining the movement patterns of harbour porpoises, as they are associated with the concentration of prey. However, the use of the tidal stream seems to vary in-between areas; Pierpoint (2008) reports harbour porpoises using strong currents that are formed during flood tide for foraging in an underwater trench at the coast of southwest Wales (UK), whereas Rebel (2010) reports the opposite in the northern coast of the Netherlands, where harbour porpoises seem to forage mostly during ebb tide. Nevertheless, foraging porpoises were mostly observed in the deep area in front of the port Kats during all tidal stages, indicating that this deep-water area plays an important role as foraging area within this trench.

Contrary of what was expected, time of day did not have a significant relation with foraging behaviour. IJsseldijk et al. (2015) for example, reports time of day being the second-best variable in explaining harbour porpoise presence within a tidal inlet. Several studies show a difference in day and night patterns in dive and click activity of studies on free-ranging tagged harbour porpoises, in which most studies reported higher click activity at night in some regions (Linnenschmidt, et al., 2012; Todd, et al., 2009; Carlström, 2005). It is thought that diel activity and availability of dominant prey is related to foraging behaviour of porpoises, which is site-specific and linked to click activity, which could explain the difference in activity patterns between regions (Amano, et al., 1998). Several main prey of the harbour porpoises, such as herring, sand eels, sprat, and whiting, are known to become active at night (Linnenschmidt, et al., 2012; Santos & Pierce, 2003; Santos, et al., 2004). For this study however, recording foraging behaviour at night was not possible. Nevertheless, stomach contents of stranded porpoises within the Eastern Scheldt between 2003 and 2014 showed that their diet consisted mostly of (sand) gobies, especially for juveniles and calves, while adults also consumed gadoids (e.g. whiting), clupeids (e.g. herring and sprat), and sand eels in lower amounts (Schelling, et al., 2014). On the basis of the literature currently available, it seems fair to suggest that time of day could explain foraging behaviour of harbour porpoises, despite no significant evidence found during this study.

Travelling

Although no significant relation between travelling porpoises and tide was found in this study, travelling harbour porpoises were most observed during changing tide (50% of the travelling intervals) as opposed to low or high tide. A closer look on the data indicates that porpoises use the tidal states ebb and flood to travel towards west and east respectively. This was expected, as Rebel (2010) reports harbour porpoises swimming at a calmer pace, floating towards the North Sea with the current during ebb. It is possible that they use the current to save energy (Rebel, 2010). In addition, no significant relation between travelling porpoises and in-between areas was found. However, most travelling behaviour occurred in the shallower areas (0-20 m deep) of the underwater trench. As foraging behaviour was significantly observed more in deeper areas (>20 m), this could perhaps mean that the harbour porpoises use the stronger currents during changing tide (Korpelshoek, 2011) to travel to and from these suitable (deep-water) foraging areas within the Eastern Scheldt.

4.3 Group structure

Although relatively little research has been done on the group structure of the harbour porpoise, mostly because they live solitary and are generally considered as asocial (Bjørge & Tolley, 2002; Gowans, et al., 2008; Westgate, et al., 1995), porpoises were seen more often in small groups of two to four individuals than solitary during this study. Groups were significantly observed more often in late afternoon (15:00-18.00) than in the morning and early afternoon. These results contradict the results of a study done in a tidal inlet in northern Netherlands, where IJsseldijk et al. (2015) observed solitary porpoises in 71.6% of the sightings, and where porpoise presence was highest in early morning with decreasing numbers during the day.

Furthermore, a recent study by Van Dam et al. (2017) concluded that the Eastern Scheldt harbour porpoise population may have developed specialised feeding skills to cope with low prey availability. In addition, nutritional challenges also include feeding adaptations as a result of predator presence. The relative asociality of harbour porpoises, as well as several other members of the porpoise family, may indicate that predation risk on these small species may be too great to lead to the formation of groups (Gowans, et al., 2008). The harbour porpoises encountered during this study however, were more often seen in small groups than solitary, contradicting current literature. Recent post mortem research of Podt & IJsseldijk (2017) on the Eastern Scheldt population reports that at least ten harbour porpoises found in this area died from wounds inflicted in grey seals attacks. Additionally, bilateral tailstock lesions and additional body scarring that matched descriptions of lesions induced by grey seals were observed on four individuals through photo-ID (Podt & IJsseldijk, 2017). Although not the case in the Eastern Scheldt, it is already thought that the harbour porpoise's small size makes them vulnerable to predation by a number of species of sharks as well as killer whales in most areas where they occur (Gowans, et al., 2008). The harbour porpoises in the Eastern Scheldt are therefore possibly faced with predation risk due to co-existence with grey seals, which in combination with the adaptations in feeding skills, could significantly induce behavioural and distributional changes (Podt & IJsseldijk, 2017). However, based on these results and lack of research on social structure and presence of grey seals, no firm conclusions can be drawn on the influence of predation risk on the harbour porpoise's group structure within this underwater trench.

On average, calf presence within a group or with a solitary individual did not greatly differ (18% and 14% respectively). Although no significant relationship was found between calf presence and tide, observations made during surveys made clear that mother-calf pairs preferred areas on the edge of the trench for foraging during tidal stages, close to the port of Kats (see figure 10), where current speeds are slower. The results did not significantly reflect this, most likely due to the research vessel not being able to reach some of the shallow areas, thus the GPS coordinates had to be obtained as close as possible to the encounter locations. This was expected as Pierpoint (2008) reports groups of harbour porpoises with calves foraging in similar areas along a steep-sided trench. The research vessel used during this study could not get close enough to shore however, in order to attain the exact GPS coordinates of the locations of the encountered mother-calf pairs. Thus coordinates obtained as close as possible to the encounter location were used for QGIS, resulting in slight incorrect plotting, thus, perhaps influencing the results.

5 Conclusion

No significant relation was found between tide and harbour porpoise behaviour or group structure in an underwater trench within the Eastern Scheldt (N=87). However, foraging behaviour did significantly increase with greater water depth in the trench. Most travelling behaviour occurred during changing tide, in the late afternoon and in the shallower areas (0-20 m). A significant relation between the time of day and the presence of a group was found. Groups were significantly observed more often in the late afternoon (15:00-18:00) than in the morning and early afternoon, contrary to current research. No significant relations were found on the presence of a calf. On average, calf presence within a group or with a solitary individual did not greatly differ. However, observations made during surveys made clear that mother-calf pairs preferred areas on the edge of the underwater trench during foraging, where currents are possibly slower.

The results of this study provide the first insight on the influences of the tide on the behaviour and group structure of the Eastern Scheldt harbour porpoise population. It has indicated that the water depth of the trench and the tidal currents that flow through it influence the foraging behaviour. Despite the limited significant results, this study has led the path to future research, which should be focused on establishing Special Areas of Conservation (SACs), to which the Netherlands are legally obliged in doing so.

6 Recommendations

To gain enough knowledge on the harbour porpoise in the Eastern Scheldt to ultimately establish SACs for this species within Dutch waters, and by following the results that came forth from this research study, the following recommendations have been set up:

- Due to the short study period and thus small study population of this research project, it is recommended that this research is continued for the next couple of study seasons to increase the study population. This will increase the amount of data that can be used for analysis, leading to more accurate results as the encounters will not need to be recoded into intervals. By continuing the study and photo-ID, social (group) structures and behavioural patterns can also be studied in greater detail in the future, as family trees and other connections between the individuals can be established. This information will allow for the needs of male, female and young porpoises to be well understood within the Eastern Scheldt.

- More research focused on the resting behaviour, in particular the relation between foraging/travelling and resting needs to be done, to be able to establish protected foraging and perhaps resting areas (in the form of SACs) for the harbour porpoises in the Eastern Scheldt, as the results of this study suggest that most resting behaviour is seen during foraging. Additionally, the behaviour that can be observed during surveys should be noted down more specific to study the behaviour in greater detail, instead of classifying them in three behaviours. Therefore, other explanatory factors such as disturbance could be taken into account.

- It is recommended that this research is expended to other parts of the Eastern Scheldt, in particular other deep-water areas, where surrounding circumstances might be different, to be able to extrapolate the results. This will confirm the hypothesis that harbour porpoises use these deep-water areas, especially underwater trenches, for foraging purposes.

7 References

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Appendix I: Survey form

Date (dd/mm/yy): …………/…………/………… **Vessel:**

Surveyors	General remarks

Departure information	Return information
Start time:	End time:
Start location:	End location:
Start GSP: 51……………………3……………………	End GSP: 51……………………3……………………
Start weather:	End weather:
 H F	 H F
Beaufort (sea state): 0 1 2 3 4	Beaufort (sea state): 0 1 2 3 4
Visibility: excellent very good good fair poor	Visibility: excellent very good good fair poor
Cloud coverage: …….%	Cloud coverage: …….%
Tidal state: high falling low rising	Tidal state: high falling low rising

Optional change in weather during survey	
Time (hh:mm):	Time (hh:mm):
Weather:	Weather:
 H F	 H F
Beaufort (sea state): 0 1 2 3 4	Beaufort (sea state): 0 1 2 3 4
Visibility: excellent very good good fair poor	Visibility: excellent very good good fair poor
Cloud coverage: …….%	Cloud coverage: …….%
Tidal state: high falling low rising	Tidal state: high falling low rising

Appendix II: Encounter form

Date (dd/mm/yy): …………/…………./……….. **Encounter number:**

Start encounter information	End encounter information
Start time (hh:mm): Start GSP: 51…………………….3…………………….	End time (hh:mm): End GSP: 51…………………….3…………………….

Weather at beginning of encounter	Optional change during encounter
Time (hh:mm): Weather:  H F Beaufort (sea state): 0 1 2 3 4 Visibility: excellent very good good fair poor Cloud coverage: …….% Tidal state: high falling low rising	Time (hh:mm): Weather:  H F Beaufort (sea state): 0 1 2 3 4 Visibility: excellent very good good fair poor Cloud coverage: …….% Tidal state: high falling low rising

Estimated group size			Initial behaviour	Secondary behaviour
Min.	Max.	Best	Foraging / travelling / resting / other:	Foraging / travelling / resting / other:

Optional remarks (e.g. calf present, group structure, heading, ID photo success)

Encounter Data Sheet – Optional behavioural data

Date (dd/mm/yy): …………/…………./…………

Encounter number	Time	Behaviour
		Foraging / travelling / resting / other:
		Foraging / travelling / resting / other:
		Foraging / travelling / resting / other:
		Foraging / travelling / resting / other:
		Foraging / travelling / resting / other:
		Foraging / travelling / resting / other:
		Foraging / travelling / resting / other:
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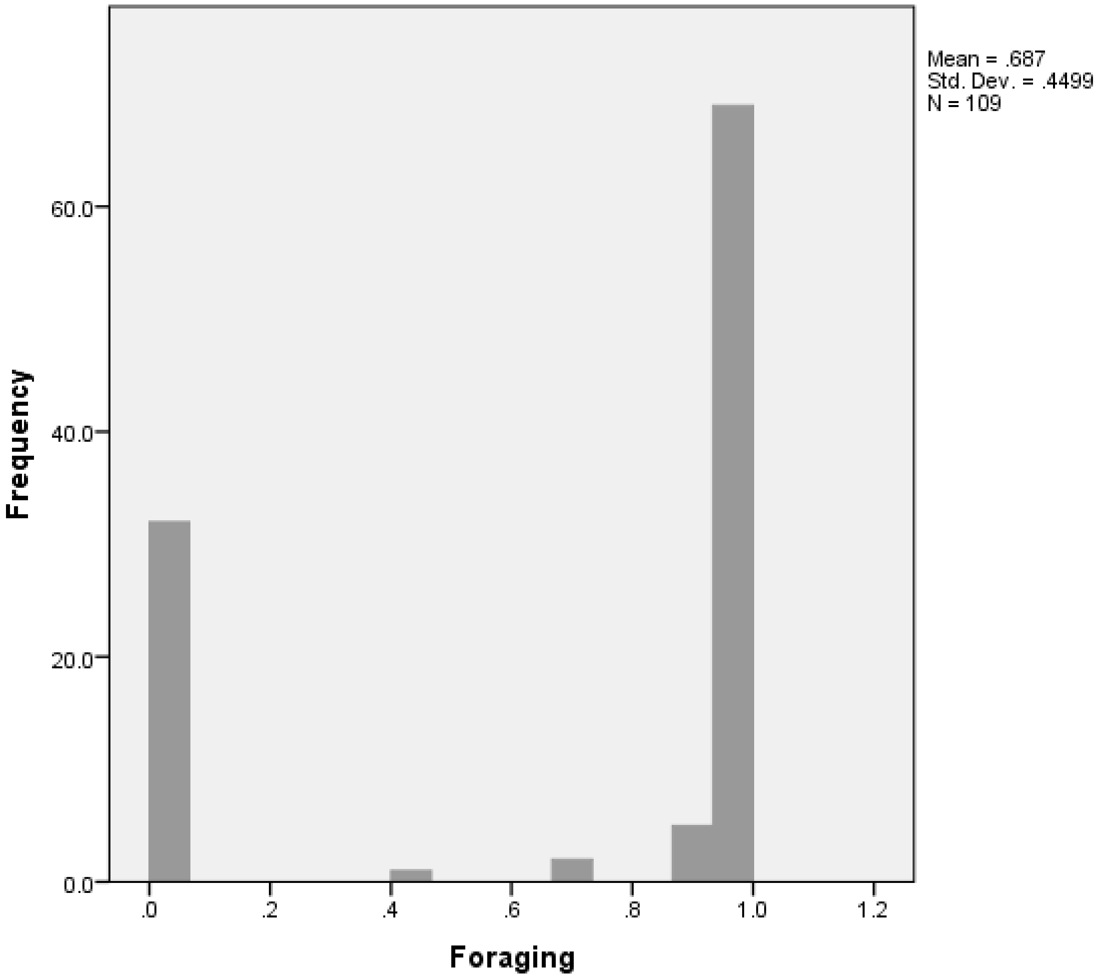
		Foraging / travelling / resting / other:

Definitions

Weather		Definition
	Sunny	Predominantly sunny, no/few clouds
	Sunny with clouds	Predominantly sunny, many clouds
	Overcast	Cloudy/grey with some visible sunshine
	Showers	Light rain on and off with limited visibility
	Rain	Heavy/continuous rain with dark skies
H	Hail	Hail showers/storms
F	Fog	Fog and mist
BSS	**Knots**	**Definition**
0	0-1	Smooth and mirror-like, wind calm
1	1-3	Light ripple, light air
2	4-6	Small wavelets, not breaking, light breeze
3	7-10	Scattered whitecaps, gentle breeze
4	11-16	Small waves, frequent whitecaps, moderate breezes
5	17-21	Moderate waves, many whitecaps, fresh breeze.
Visibility		**Definition**
Excellent		Water is still and calm, very easy to sight animals
Very good		May be slightly uneven lighting or light chop
Good		Light chop/scattered whitecaps, sighting animals is still fairly easily
Fair		Choppy waves with fairly frequent whitecaps, low-light conditions, animals are likely to be missed
Poor		Numerous whitecaps, impeding ability to sight animals, many animals are likely to be missed

Appendix III: Double-peaked (bimodal) distribution of the observed behavioural data



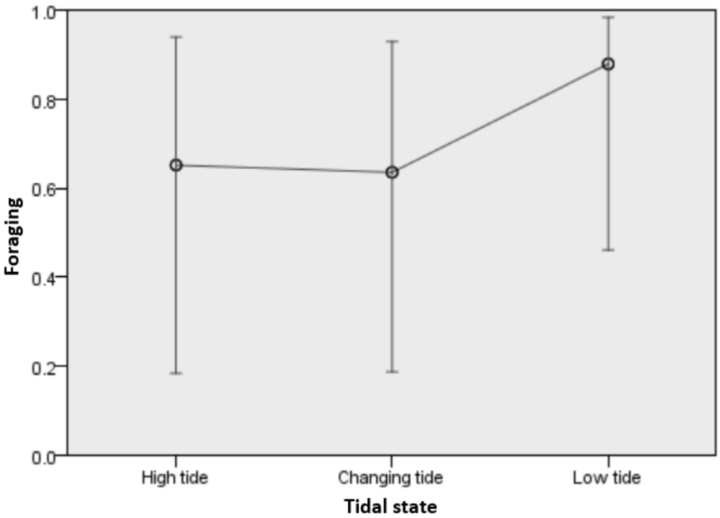
Appendix IV: End results of non-significant outcomes

Foraging:

End results of the *three tidal states*, displaying the mean of foraging present during intervals per tidal state:

				95% Confidence Interval	
Tidal state	N	Mean	Std. Error	Lower	Upper
High tide	15	0.652	0.224	0.184	0.940
Changing tide	24	0.636	0.207	0.187	0.930
Low tide	35	0.879	0.106	0.461	0.984

Chance of harbour porpoises foraging during the three tidal stages within the study area:

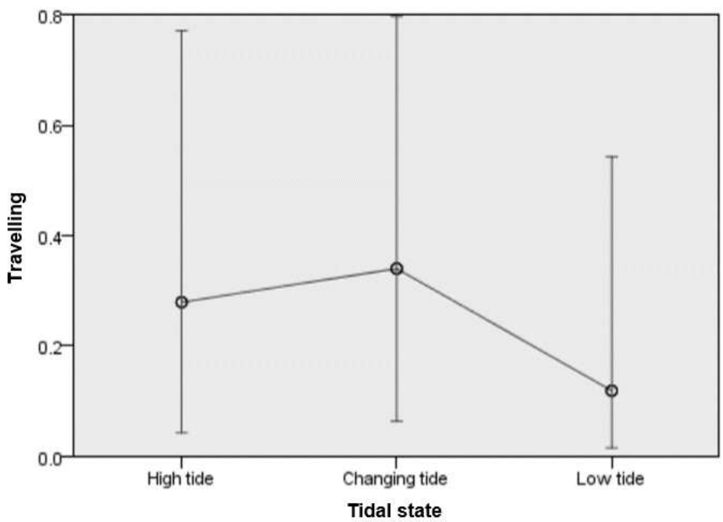


Travelling:

End results of the *tide*, displaying the mean of travelling present during intervals per tidal state:

				95% Confidence Interval	
Tidal state	N	Mean	Std. Error	Lower	Upper
High tide	11	0.279	0.203	0.043	0.771
Changing tide	16	0.340	0.203	0.063	0.797
Low tide	5	0.119	0.107	0.015	0.543

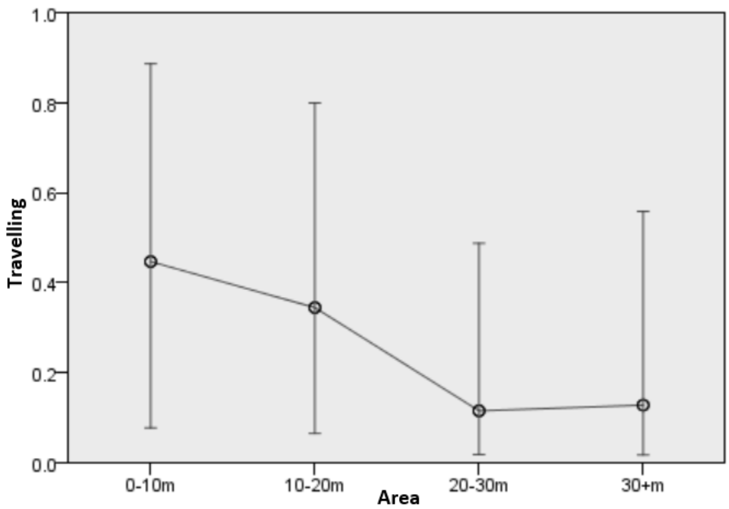
Chance of harbour porpoises travelling during the three tidal stages within the study area:



End results of the *areas*, displaying the mean of travelling present during intervals per area:

				95% Confidence Interval	
Area	N	Mean	Std. Error	Lower	Upper
0-10m	9	0.447	0.270	0.077	0.887
10-20m	10	0.344	0.212	0.065	0.800
20-30m	8	0.115	0.092	0.017	0.488
30+m	5	0.127	0.113	0.017	0.558

Chance of harbour porpoises travelling through the four different areas correlated to water depth, within the study area:

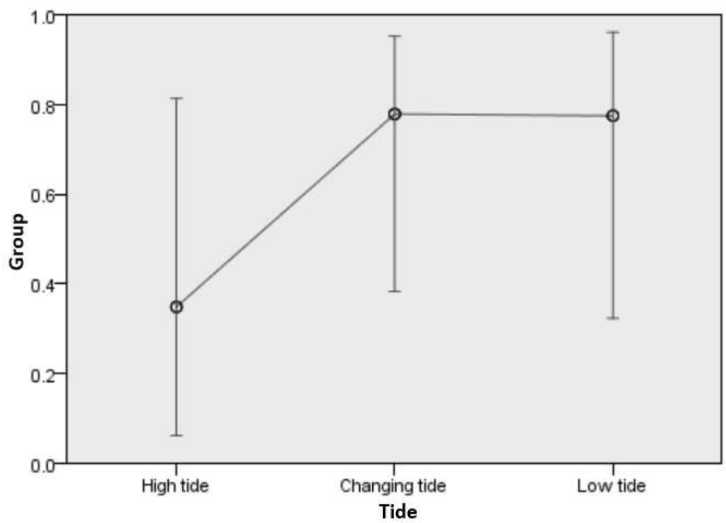


Group:

End results of the *tide*, displaying the mean of a group present during intervals per tidal state:

				95% Confidence Interval	
Tidal state	N	Mean	Std. Error	Lower	Upper
High tide	8	0.348	0.224	0.061	0.814
Changing tide	30	0.779	0.134	0.383	0.952
Low tide	32	0.775	0.161	0.323	0.961

Chance of a group during the three tidal stages within the study area:

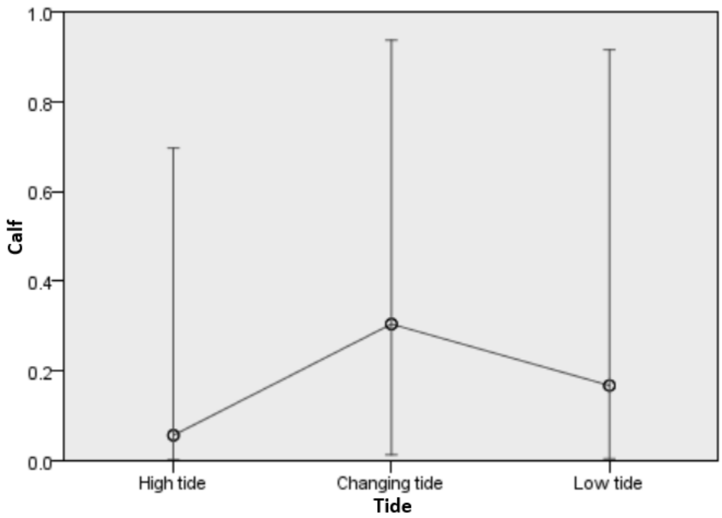


Calf:

End results of the tide, displaying the mean of a calf present during intervals per tidal state:

				95% Confidence Interval	
Tidal state	N	Mean	Std. Error	Lower	Upper
High tide	7	0.056	0.090	0.002	0.697
Changing tide	14	0.304	0.337	0.013	0.937
Low tide	13	0.167	0.265	0.004	0.916

Chance of a calf being present during the three tidal stages within the study area:



End results of the *areas*, displaying the mean of a calf present during intervals per area:

				95% Confidence Interval	
Area	N	Mean	Std. Error	Lower	Upper
0-10m	1	0.058	0.146	0.000	0.931
10-20m	8	0.457	0.427	0.020	0.971
20-30m	14	0.179	0.223	0.007	0.872
30+m	11	0.074	0.117	0.002	0.761

Chance of a calf being present within the four different areas correlated within water depth, within the study area: