Internship Report

"Acoustic research in the Oosterschelde Estuary regarding Harbour Porpoises (*Phocoena phocoena*)"

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1. Introduction

The Harbour porpoise *(Phocoena phocoena)* is one of the smallest marine mammals and the most abundant of the toothed whales in the coastal waters of the North Atlantic and especially the North Sea (Villadsgaard *et al.,* 2007). In the East Atlantic, harbour porpoises may be present in the coast of West Africa to the coasts of Spain, France, United Kingdom, Ireland, Scandinavia, Iceland, Greenland and Scotland. They can be identified by their short, stocky body, which help them to regulate their temperature in the cold waters they inhabit (Figure 1). Adults of both sexes grow up to 1.4 m to 1.9 m with a maximum weight of 76 kg (Bjorge & Tolley, 2008). Like other toothed whales (Odontoceti), harbour porpoises use biosonar as echolocation signals for foraging and orientation (Villadsgaard *et al*., 2007).

Figure 1. Harbour porpoise *(Phocoena phocoena)*. Convention of Migratory Species - www.cms.int.

Harbour porpoises have "returned" to Dutch coastal waters after an absence of several decades and its status changed from rarity to a common resident in just about 15 years (Camphuysen, 2004 IN: Camphuysen & Siemnsa, 2011). This species is found everywhere along the Dutch North Sea coastline in variable densities; low densities in the Wadden Sea area and higher in the inner waters of the Oosterschelde delta area (Zeeland). For many areas in the country, work has been and is currently developing, in order to maintain a favourable conservation status, but still not all measures have been fully evaluated and implemented (Camphuysen & Siemensa, 2011).

The Oosterschelde is a large estuary situated in between several islands and located in the south-western part of the Netherlands. Its water surface comprises about 200,000 ha and it has connection with the North Sea via the Oosterschelde storm surge barrier. The Oosterschelde is a designated Natura 2000 site under the Habitat Directive and the Bird Directive, therefore stricter rules and regulations apply for economic and recreational users. It has also the status of a National Park. However, no conservation objective has been set for the Harbour porpoise as part of the designation decision (Zanderink & Osinga, 2010).

Nevertheless, a small resident population (a resident or semi-resident stock) of harbour porpoises seems to have become established in this Dutch delta area (Zeeland) (Camphuysen & Heijboer, 2008; Zanderink & Osinga, 2010). Recent sightings of small calves suggest reproductive activities within the basin, but there is a little factual data about the exchange of inshore porpoises with the, considerably larger, offshore stock through the Oosterscheldekering (eastern Scheldt storm surge barrier). There is a difference to the seasonal pattern of occurrence (winter/spring visitors) in the north of Hook of Holland. In the delta area (Zeeland) the occurrence is all year-round, notably within the Oosterschelde (Camphuysen & Heijboer, 2008).

It is unclear why harbour porpoises stay in the Oosterschelde instead of migrating northwards in spring, like the ones do in the North Sea. The storm surge barrier might play a functional role in the behaviour of the Oosterschelde porpoises. It is possible that enough food is available in and around the Oosterschelde throughout the year and the tidal currents of the storm surge barrier are used for foraging. During flood, water from the North Sea is flowing into the Oosterschelde through the storm surge barrier, where porpoises may wait for the incoming fish. If so, it is expected that harbour porpoises are more often present at high tide near the storm barrier (Korpelshoek , 2011).

Furthermore, the noise of the water currents passing through the storm surge barrier may hinder the harbour porpoises from swimming to the North Sea. It has already been shown that harbour porpoises are very sensitive to underwater sounds and that they show avoiding behaviour towards the sound source by swimming away from it while increasing the respiration rate (Kastelein *et al.,* 2005). Also, they are deterred by low frequency playbacks of wind turbines (Koschinski *et al.,* 2003). Four times a day, during the slack tide, the tidal currents cease. At these moments, the noise and tidal currents are minimal, which may provide chances for the porpoises to migrate between the Oosterschelde and the North Sea.

In order to understand the possible impact of the Oosterscheldekering in this resident population, and the factors that might be influencing their migrations through the barrier Rugvin Foundation (Stichting Rugvin) is implementing the use of a stationary acoustic monitoring system of so called C-pods. This method is adequate because free-swimming porpoises in the wild have showed to vocalize almost constantly, they rarely remain silent for more than a minute (Akamatsu *et al.,* 2007). This kind of study has also been used in studies investigation behaviour, habitat use and human activities impact on porpoise populations (Scheidat *et al.,* 2011).

Therefore, with the aim of increasing the knowledge about cetaceans in Dutch waters in order to contribute to the protection of these animals, the Rugvin Foundation developed since 2009 this acoustic research in the storm surge barrier. The research is carried out with the financial support from the WWF in The Netherlands and the NP Oosterschelde. But also with the support and supervision of the Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and the Environment).

2. Objective

To obtain more knowledge about Harbour Porpoises in the Oosterschelde and how are their migration patterns between the North Sea and the Estuary by crossing the storm surge barrier.

3. Research Questions

In order to reach the aim of this research the following questions were answered:

- What is the role of the Oosterscheldekering (storm surge barrier)?
- Does exchange take place between harbour porpoises in the Oosterschelde estuary and the North Sea?
- Is there any difference in daily movement patterns? (Do tidal currents play a role?)
- What are some of the comparisons of these aspects between 2010 and 2011?

4. Methods

4.1. Study Area

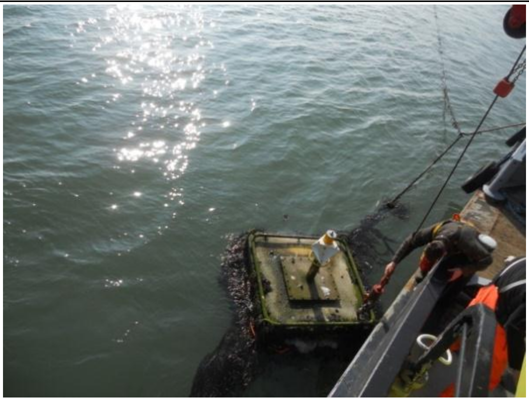
The Oosterschelde is a large estuary situated between several islands, peninsulas and the North Sea and located in the south-western part of The Netherlands (Figure 2). Its water surface comprises about 200.000 ha. It has connections with the Grevelingen through a system of sluices and dams in the north-eastern part and a connection with the North Sea via the Oosterschelde storm surge barrier. The Oosterschelde has the status of a National Park. It is also a designated Natura 2000 site under the Habitat Directive and the Bird Directive and therefore stricter rules and regulations apply for the Harbour Porpoises as part of the designation decision (Koch *et al.,* 2010). A small resident population of Harbour Porpoises seems to have to become established in this Dutch Delta Area (Zeeland) (Camphuysen & Heijboer, 2008; Zanderink & Osinga, 2010).

Figure 2. The Oosterschelde estuary (dark blue), showing the Oosterscheldekering (storm surge barrier) in the west.

4.2. Acoustic research in the Oosterschelde

To investigate the migratory behaviour of harbour porpoises in the Oosterschelde, three C-pods were deployed on the safety lines on both sides of the Oosterscheldekering storm surge barrier in 2011 (Figure 3).

Oosterschelde storm surge barrier

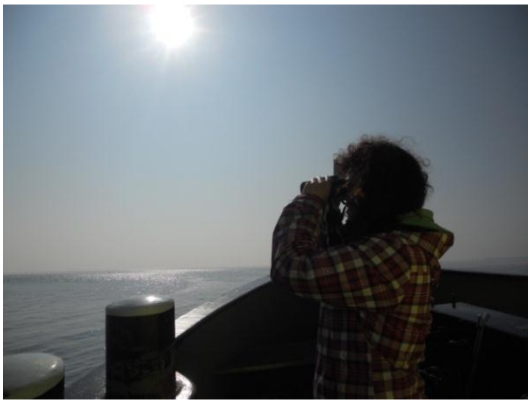


Lines to connect the C-PODs

C-POD

C-POD preparation for deployment

C-POD batteries and internal system



On-board observations

Figure 3. Field work

Regarding the distribution of the C-PODs: one was located in the North Sea (in the same point) and two in the Oosterschelde (Table 1). The data of the C-pods give information about the presence of harbour porpoises on both sides of the storm surge barrier throughout the year. Every two months, batteries were changed and data was collected.

Table 1. Table showing the locations of the three C-PODs placed at the two sides of the Oosterscheldekering; North Sea and Oosterschelde estuary.

Location	C-Pod	GPS Position
North Sea	CP722	51° 36´ 56 ´´ N - 03° 40´ 04 ´´ E
Oosterschelde	CP720	51° 36´ 30 ´´ N - 03° 41´ 81 ´´ E
Osterschelde	CP721	51° 36´ 63 ´´ N - 03° 41´ 86 ´´ E

To open the raw data, software called CPOD.exe v2.001 was used (Tregenza, 2011). This software uses the KERNO classifier to detect cetacean click trains in the data. Only high and moderate quality click trains were used. Harbour porpoise click trains were searched by putting on the setting 'NBHF cetacean', coding for species that produce Narrow Band High Frequency clicks. Trains with features of WUTS (Weak Unknown Train Sources) were excluded. The data was sorted with this software in time-intervals of ten minutes. Data was available as:

- The number of clicks per ten-minute time-interval. This dataset gives information about the production of echolocation clicks near the storm surge barrier.
- DPM = Detection Positive Minutes = the number of minutes (from zero to ten) in which harbour porpoise clicks were recorded per time-interval of ten minutes.

An additional dataset was created from the above-mentioned datasets, in which a "1" code stands for the presence of harbour porpoises during the ten-minute interval and in which a "0" stands for no recording of porpoise sounds. This dataset was used to show if porpoises were more often observed in particular parts of the day or year.

4.3. Migration through the Oosterscheldekering

In order to demonstrate whether harbour porpoises cross the storm surge barrier, a dataset was used in which the 0 codes used for absence in a particular time-interval of ten minutes, and a 1 codes for presence. Migration was assumed to occur when porpoise clicks were recorded in the Oosterschelde and in the next time interval the North Sea or vice versa (Table 2).

Table 2. Table showing the patterns that were assumed to represent the migrations through the Oosterscheldekering. Number 1 codes for presence and 0 codes for absence of harbour porpoise.

Migration		**North Sea**	**Oosterschelde**
North Sea to Oosterschelde (in)	10 min time-interval 1	1	0
	10 min time-interval 2	0	1
Oosterschelde to North Sea (out)	10 min time-interval 1	0	1
	10 min time-interval 2	1	0

By randomizing the dataset, it was possible to know if these patterns were found more often than random. After a data correction, the data was randomized 1000 times for each month using the algorithm Mersenne Twister. When the chances on finding the pattern minimally as often as the original dataset is lower than 0.05, the results are considered not to be based by coincidence (Korpelshoek, 2011).

4.4. Daily movements: The effect of the tide on harbour porpoises

Based on Lisanne Korpelshoek (2011), to answer the question whether tide has an effect on the daily movement patterns of North Sea porpoises and Oosterschelde porpoises, the following methods have been used:

The effect of the tide on porpoises was tested for all the datasets. For the influence of tide, the water levels of the locations *Roompot binnen* (within the Oosterschelde) and *Roompot buiten* (outside the Oosterschelde) were compared (Rijkswaterstaat, 2012). These water levels were given in centimetres compared to NAP per 10 minutes. For all data, Greenwich Mean Time + 1 was used. The water height from *Roompot binnen* was subtracted from the water level of *Roompot buiten*. A positive value indicates a water flow from the North Sea into the Oosterschelde, whereas a negative value means that the direction of the water currents is into the North Sea. The difference in water level was classified into twenty classes (Table 3).

Table 3. Table showing the classes in which the tide was classified.

Classes
From -100 to -81
From -80 to -61
From -60 to -41
From -40 to -21
From -20 to -1
From 0 to 19
From 20 to 39
From 40 to 59
From 60 to 79
From 80 to 99
From 100 to 119

During the next chapter of this report, it has been tested whether a significant difference between the classes could be found in the number of clicks per ten minute time interval, in the detection positive minutes per ten minute time interval and in the presence of porpoises.

5. Results

5.1. Acoustic research in the Oosterschelde

The static acoustic monitoring done by the Rugvin foundation was very successful in 2010 and a very detailed analysis was made by Lisanne Korpelshoek (2011). Unfortunately, in 2011 some C-PODs where lost due to the strong tides and tough weather conditions. Furthermore some data was lost due to technical problems presented in the C-PODs 720 and 722 (Table 4).

Table 4. Table showing all the files that contain the data and to what location and period they belong.

Location	Period 1	Period 2	Period 3	Period 4	Period 5
North sea	12-01-11/25-03-11 File 4: CPOD 722 **OK**	25-03-11/06-06-11 File 10: CPOD722 **OK**	06-06-11/19-07-11 File 2: CPOD 722 **OK**	19-07-11/27-09-11 File 7: CPOD 1712 **OK (only 0)**	27-09-11/ Lost
Oosterschelde R6 Zuid	12-01-11/25-03-11 File 3: CPOD 720 **OK**	25-03-11/06-06-11 File 9: CPOD 720 (overlapped data)	06-06-11/19-07-11 File 1: CPOD 720 (overlapped data)	19-07-11/27-09-11 File 5: CPOD 720 (overlapped data)	27-09-11/24-10-11 File 11: CPOD 720 (less data) **OK**
Oosterschelde	12-01-11/25-03-11 Lost	25-03-11/06-06-11 Lost	06-06-11/19-07-11 Lost	19-07-11/27-09-11 File 6: CPOD722 (overlapped data)	27-09-11/24-10-11 File 12: CPOD 722 **OK**

* (yellow)	Lost C-Pods in the water due to weather.
* (red)	Lost data due to technical problems of the C-PODs.
* (green)	Data used for analysis since it is possible to compare the two locations.
OK	Data used for general descriptions.

NOTE: The results are presented in a similar order than the one made by Korpelshoek (2011).

Harbour porpoise clicks were recorded in the North Sea and the Oosterschelde during the months we obtained data. In the North Sea from January until September (periods 1 to 4) the presence of harbour porpoises was confirmed. In the Oosterschelde estuary harbour porpoises were also registered for the months of January, February and March (period 1) and the months of August and September (period 5).

5.2. Presence of Harbour porpoises in the North Sea

Information was recorded from January to June 2011 in the North Sea. We can observe that there is high presence of harbour porpoises on the month of March, and they seem to stay longer close to the storm surge barrier in this time of the year. This result was already proved by Korpelshoek (2011), and it was also observed to happen in March 2010. On the other hand, the presence seems to decrease in April, May and June, but a constant time spending near the storm surge barrier (Figures 3 and 4).

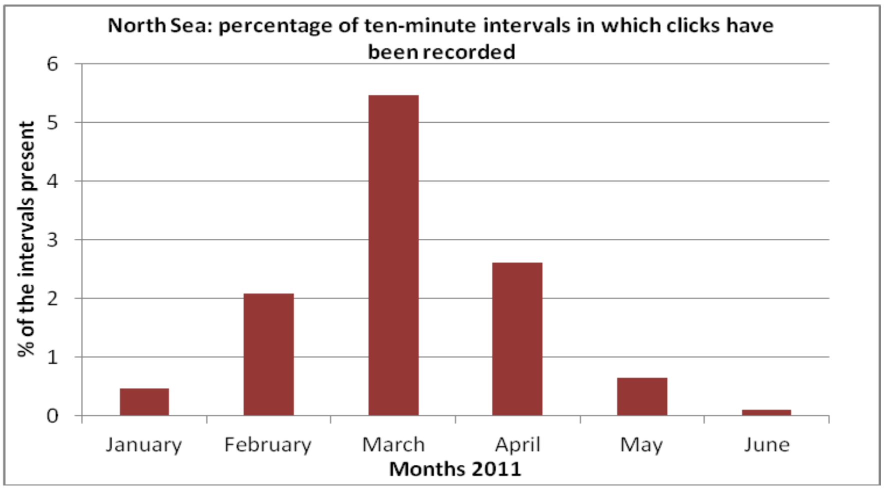


Figure 4. Percentage of DPM with clicks recorded for the North Sea.

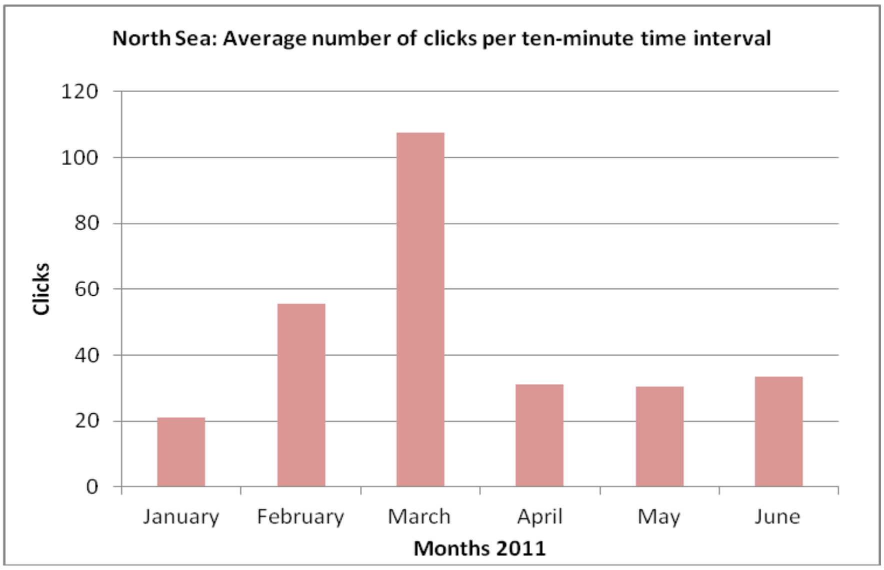


Figure 5. Average number of clicks per DPM for the North Sea.

5.3. Migration through the Oosterscheldekering

Since many data was lost, the only months to obtain migration information were the ones in period 1 (January, February and March). During the whole period, based on the original data, 19 migrations occurred from the North Sea to the Oosterschelde (in) and 16 migrations from the Oosterschelde to the North Sea (out). The highest migration movements where observed in March (12 in and 10 out), then February (6 in and 5 out) and finally only one migration in and one migration out in the month of January.

In January a very low number of detections and clicks were found in the North Sea. In the Oosterschelde the presence of harbour porpoises was more constant during the whole period. Nevertheless, in both sides, the highest presence of harbour porpoises was during March (Figure 5).

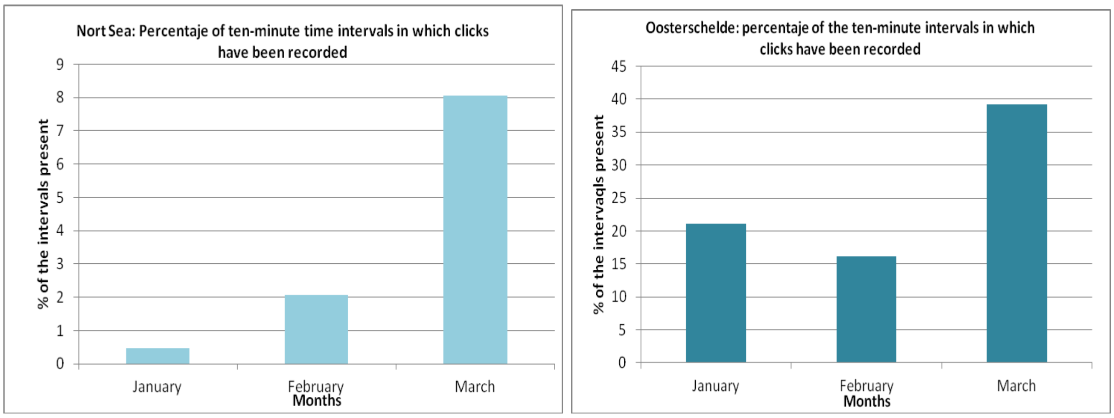


Figure 6. Comparison of the percentages of DPM with clicks recorded for the North Sea and the Oosterschelde.

The pattern representing migration from the North Sea to the Oosterschelde and from Oosterschelde to the North Sea was found in all months tested (January to March 2011). After randomizing the data 1000 times for each month, the chance to find the pattern minimally as often as in the original dataset wasn't lower than 0.05 for none of the three months. Thus, the chance of finding a migration accidentally either in or out of the Oosterschelde is high. Therefore, there is no evident migration during those three months in the southern part of the barrier.

5.4. Tide effect

The effect of tide on the daily movements has been investigated for harbour porpoises in the Oosterschelde as well as for harbour porpoises in the North Sea. When the water level difference is negative, the direction of the water currents is from the Oosterschelde to the North Sea (falling tide in the Oosterschelde). A positive water level difference means that the water in flowing into the Oosterschelde (rising tide in the Oosterschelde). During slack tide, the water level difference is around zero, which means that the water current is minimal. Tidal currents are the strongest when the water level differences are the highest.

It is observed for the North Sea, during the period 1 (January, February and March), that the production of the echolocation clicks follows the bell-shaped histogram (excluding the class from -80 to -61 cm). The bell-shaped histogram indicates that the clicks are less recorded when the difference in the water level is large. But, a high number of clicks were recorded in the intervals between -80 to -61 cm of water height, and a low presence of clicks in the classes between -60 to -41 cm and 80 to 99 cm water height (Figure 6). This can mean that harbour porpoises spend more time in the side of the North Sea when there is high tide.

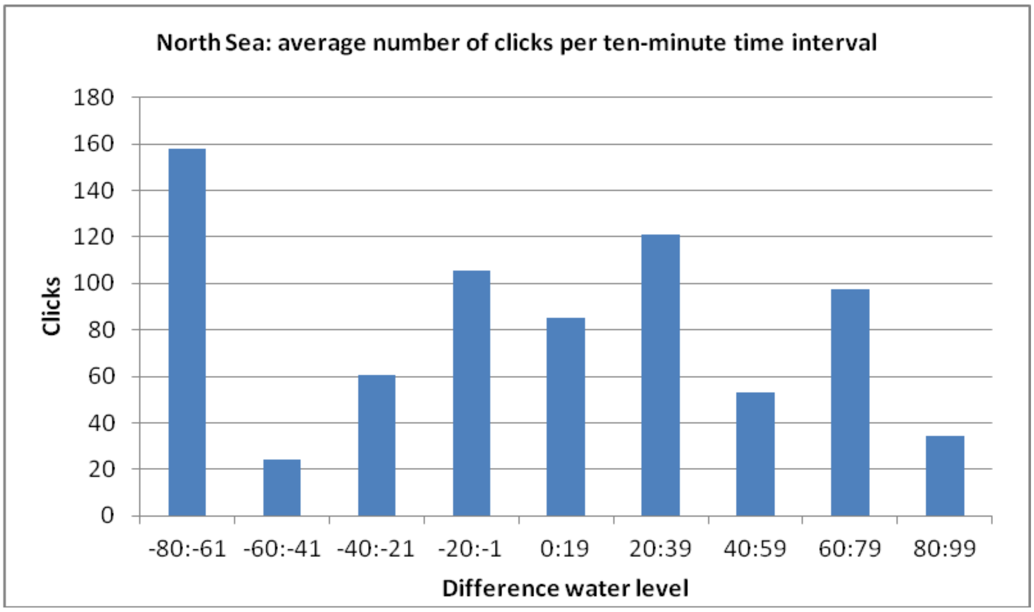


Figure 7. Average number of clicks per DPM for the North Sea in the different water high differences.

The number of clicks and the average of ten-minute time intervals with presence (DPM) are highly correlated, thus we can observe a constant presence of harbour porpoises in all stages of the water level (Chi square test $p= 5.13*10^{-33}$) (Figure 7).

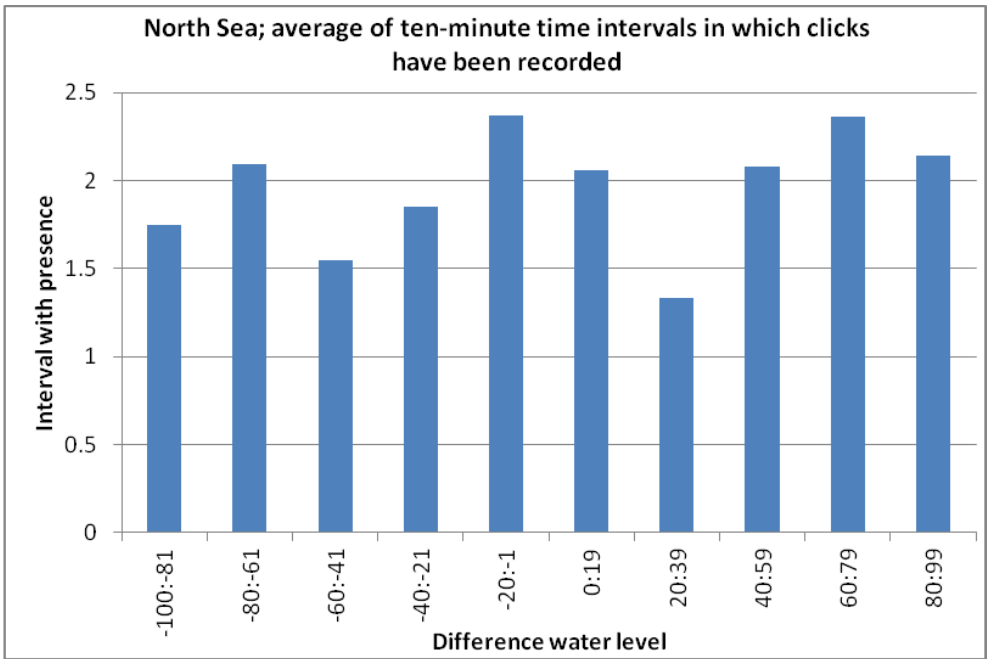


Figure 8. Average of DPMs with clicks recorded for the North Sea in the different water high differences.

Meanwhile, for the Oosterschelde during period 1 we can observe a relatively similar presence (number of clicks recorded) during all the classes of water high. With a peak of clicks recorded in between 40 to 59 cm water high and a very low presence in low tide between -100 to -81 cm water high (Figure 8).

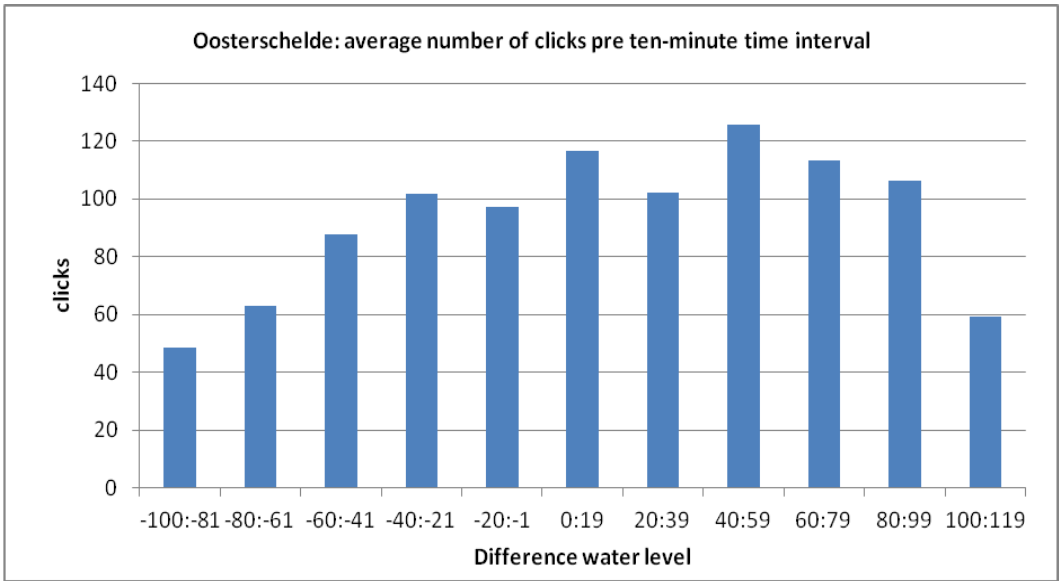
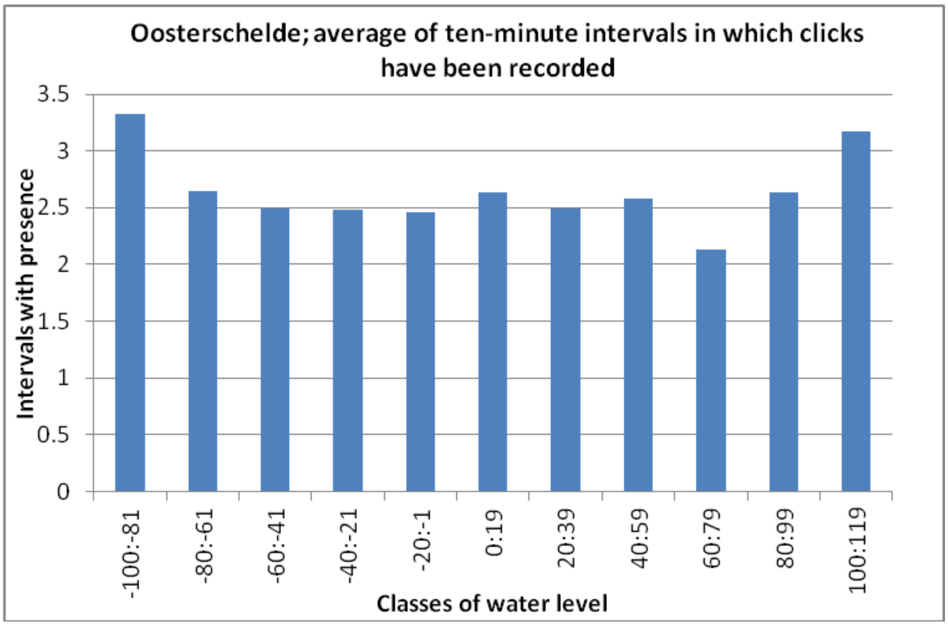


Figure 9. Average number of clicks per DPM for the Oosterschelde in the different water high differences.

Since the number of clicks and the detection positive minutes per time interval (DPM) were already shown to be highly correlated. The harbour porpoises seem to be less active in sound production when the water level differences are the highest. The average number of clicks is decreasing with the rising tide. The faster tide is raising, the lower the average number of clicks (Chi square test p=0) proving that the animals are more active vocalizing when the stream is stronger, thus higher prey availability (Figure 9).



We can observe a constant presence of harbour porpoises in all stages of the water level. That means that the harbour porpoises spend a constant time in the area but they are more active when the tide rises.

6. Discussion and Conclusions

In general, static acoustic monitoring is a method that requires a lot of constant effort and that can be affected by many different factors. Nevertheless, it is one of the most convenient methods to study wild animal like harbour porpoises (Amundin & Wennerberg, 2011). The reason why it is also a good method to study harbour porpoises, is because it can detect the narrow band high frequency (NBHF) click made by this animals (Tubbert *et al.,* 2010). This is reflected on the fact that in the data analyzed for 2010, click trains where recorded in all months, except May and December (Korpelshoek, 2011). Nevertheless, an inconvenient regarding the technology of the C-PODs was present and some data was lost due to an overlapping in the data recording of some C-PODs in 2011. Other C-PODs were lost due to the strong weather and oceanic conditions. Plus, the year before (2010) also data was also lost in May and December. This proves that the method brings a big effort in the recording of clicks.

The biggest inconvenient brought by the loss of C-PODs in 2011 was the comparison of migrations thought the storm surge barrier, since only the months of January, February and March for 2011 were able to be compared. The comparison was made by representing the presence of harbour porpoises the number ten-minute time intervals (DPM) and the time spent by the number of clicks. It was confirmed that migrations in both ways were present during this three months, with a higher number of migrations in the month of March when harbour porpoises migrate south form the North Sea, and that in summer they go north, as it has being mentioned in earlier research; a peak in the coastal number of harbour porpoises in winter and early spring (Gilles *et al.,* 2009; Haelters & Camphuysen, 2009; Jack *et al.,* 2010). This can also prove the establishment of a relation (interchange) of harbour porpoises from the southern North Sea and the

Oosterschelde. The barriers seem not to be a determinate factor that influences the migration and the permanence of the harbour porpoises in the area, since it is possible for them to cross it.

In addition, for the North Sea data was enough to show the presence and the time the harbour porpoises spend on that side of the barrier, from all the months the high presence of animals in the North Sea side confirms what mentioned above. Furthermore, as it was suggested Korpelshoek (2011), the registration of clicks during January and February can mean that late winter and early spring some porpoises swim towards the Oosterschelde instead of migration to the north.

It is important to keep in mind that harbour porpoises use bisonar for foraging and orientation. Therefore, echolocation is used for orientation, pursuing and finding of prey. Thus, the search for fish has been divided in three main phases; search phase, approach phase and terminal phase (Villadsgaard *et al.,* 2006; Verfuß *et al.,* 2008). It might happen that the time spent by the harbour porpoise is determinated by the time they spend in foraging in the two sides of the storm surge barrier, and also, depending how the prey is distributed in the area we can dare to say this might influence the direction of the migrations.

In this point, it must be highlighted that Korpelshoek (2011) did the same analysis using the information for all the year of 2010. Meanwhile, in this report has been used only the months January, February and March, in order to compare the results. The effect of tidal currents on the movements of harbour porpoises was investigated for porpoises in both, the Oosterschelde and the North Sea. According to Korpelshoek (2011) the tidal effect brings no impact on the swimming direction of harbour porpoises in the North Sea, but it does in the Oosterschelde. In the North Sea porpoises were recorded more often when the tide was high (between 140 and 180 cm of water high) and less when the tide was low (classes between 20 and 40 cm water high).

As Korpelshoek (2011) stated, the bell-shaped graph indicates that clicks are recorded in relatively more time intervals when the water level difference between the North Sea and the Oosterschelde is low. According to the figures 6 and 7, the time that the harbour porpoises spend in the North Sea is constant while the amounts of clicks they produce follow the bell-shaped graph. On the other hand, there is a slightly difference but it is obvious (figure 7) that in the Oosterschelde the porpoises spend more time in the surge storm barrier area while there is a high (-100 to -81cm) or a low tide (100 to 119cm). Maybe in high tide there is a high availability of food. Similarly, at Morte Point in North Devon, UK porpoises are found to aggregate in an area of high tidal flow, where prey items are likely to be abundant (Goodwin, 2008). But more studies must be done regarding foraging of the harbour porpoises in the Oosterschelde area (in both sides).

However, the average number of clicks is significantly higher when the direction of the water currents is from the North Sea to the Oosterschelde. This is in contradiction with the results of Korpelshoek (2011), where she proved that the average number of clicks is significantly higher when the direction of the water currents is from the Oosterschelde to the North Sea. Moreover, it is already known that porpoises use strong tidal currents during foraging, because aggregations of prey are funnelled towards porpoises (Watts & Gaskin, 1985; Johnston *et al.,* 2005) However these results might be influenced due to the short period of data collection (January, February and March), in comparison with the twelve months of 2010.

Furthermore, the year-round presence of harbour porpoises inside the Oosterschelde and in the near area of the south North Sea waters in The Netherlands, suggest optimal conditions in these waters for the animals to stay. Harbour porpoises seem to stay in the Oosterschelde area voluntarily, showing migrations in all the months (in and out). We believe it is hard to state how many animals stay inside the Oosterschelde from the migrations detected from the North Sea towards the estuary. It can be happening that the animals are just entering and leaving the area (reflected on the number of migrations from the inside to the North Sea). Nevertheless, the number of porpoises living inside the Oosterschelde suggests that many of the animals stay inside and they are even reproducing there. The reasons why they stay can be because of food availability and optimal conditions for them to live in the estuary.

Some deaths have been reported inside the area of the Oosterschelde. We believe that maybe the carrying capacity of the estuary is not enough to maintain more than the individuals that are already inside the estuary. Nevertheless, to confirm this possibility, more studies must be done about the amount of prey abundance and distribution within the Oosterschelde, and then comparing if those quantities of prey are able to sustain a certain abundance of the population.

The research done with the C-PODs data regarding the presence of porpoises is very helpful in order to confirm the presence of the animals and to see how their migration patterns work outside the Oosterschelde. Nevertheless, to observe the function of the storm surge barrier and how the animals are crossing it and the reasons why they are crossing it requires more data. Unfortunately, the risk of losing the data affected this analysis for 2011. We believe that the technique applied in this research and in Korpelshoek thesis is a good approach to find the number of migrations in and out. But the interpretation is a challenge for the reason that is very hard to know if during the detections are two different animals or one animal going inside and outside the estuary. Even when the randomization is covering this bias in a certain scale, it remains uncertain whether a recount (recording) of animals is happening or not.

Maybe for future studies Rugvin can find the way to create more scans, and work very hard on a photo-id monitoring (even thought we know in harbour porpoises is very difficult) or marking the animals inside the estuary in order to confirm how many animals enter and stay in the area.

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