MORTALITY OF HARBOUR PORPOISES (*PHOCOENA PHOCOENA*) IN THE EASTERN SCHELDT, THE NETHERLANDS

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Abstract:

After the construction of the storm surge barrier in 1986 a small population of harbour porpoises seem to have been established in the Eastern Scheldt estuary in the last decades. But since 2009 the number of stranded porpoises found on the Eastern Scheldt shore increased every year, reaching highest level in 2011. In the same year the largest number of harbour porpoises was counted. Considering the number of alive animals counted by annual surveys, the number of stranded individuals is surprisingly high in the last 4 years. From the carcasses analysis made by the Veterinary Pathologic Diagnostic Centre of Utrecht University, the main reason of death identified was starvation, followed by emaciation. According to these results, the possible reasons of starvation were analysed in the present study. The main diet of harbour porpoises in the Eastern Scheldt is mainly composed by Atlantic cod, whiting and poor cod for adults and sand goby, whiting and herring for juveniles. Data about biomass and number per 1000 m² of the main prey of harbour porpoises were collected from the results of surveys performed every year by research institute IMARES. Evidence of low biomass and number of fish resulted from the collection of data, corresponding to a shortage of food for harbour porpoises resident in Eastern Scheldt. The most abundant fish among the main prey of porpoises is sand goby but it is also the species which shows the most evidence of decrease after 2000 on, with fluctuating trend. The age-group most represented among stranded animals was detected as juveniles. The relation between low prey availability and number of stranded animals is clear between the high decrease of sand goby, which represent the 70% of the juveniles diet, and the high mortality of juveniles for starvation, in the same time. The scenario of low biomass and number of fish is strengthened by interviews to fishermen and fish seller that are used to fish in the Eastern Scheldt waters. The outcome of interviews can be summarized as a general discontent for lack of fish stock of the last years. The shortage of food may also be incremented by competition with the others predators resident in the Eastern Scheldt, harbour and grey seals. Grey and harbour seals are opportunistic feeders but some prey of their main diet overlap with harbour porpoises diet, such Atlantic cod, gobies and whiting. The number of harbour seals is much higher than the harbour porpoises one, so they might influence the availability of prey for porpoises. Grey seals are less in number but larger and stronger than harbour porpoises. The interaction with fisheries and human activities seems to not influence significantly the high number of stranded animals, since there are no evidences of bycatch among the carcasses analysed and, being Eastern Scheldt recognised as Natural Park since 2002, the human activities were being considerably limited. Further research should be done about the reasons of the significant decrease of fish stock in the Eastern Scheldt waters, focussing on the role of the coastal protection structures built in the end of the 80’ and on the massive growth of the invasive species Japanese oysters in the last decade. This species was introduced in the area for aquaculture purpose in the 60’ and, not having any predators or competitors, it spread throughout the estuary and it increased in number without control. The main hypothesis is that the overgrazing of this species is lowering the phytoplankton and primary production of the Eastern Scheldt waters, causing changing in the food chain of the whole estuary and effecting fish abundance. The decrease of primary production is influenced also by the less nutrient income due to the presence of the barriers which are blocking the fresh water flow coming from the rivers.

Table of Contents

1. Introduction: 1
1.1 Background: 1
1.2 Problem definition: 4
1.3 Research Questions: 5
2 Methods: 6
2.1 Literature research and contacting people: 6
2.2 Scanning: 7
2.3 Interviews: 9
3 Results: 10
3.1 Scanning: 10
3.2 Strandings: 11
3.3 Food availability in Eastern Scheldt: 13
3.4 Seal populations in the Eastern Scheldt: 17
3.5 Fisheries in the Eastern Scheldt: 19
4 Discussion: 22
4.1 Is the starvation related to the food availability/quality in the Eastern Scheldt water? 22
4.2 Is there competition with seals? 24
4.3 Is there competition with fisheries? 25
5 Conclusions and Recommendations 26

1. Introduction:

1.1 Background:

Harbour Porpoises *Phocoena phocoena* (Fig.1) are the smallest and most abundant cetacean in the North Sea. They belong to family Phocoenidea, Odontoceti suborder.
Harbour porpoises are found mostly in cool temperate and sub polar waters of the Northern Hemisphere (Jefferson et al.1993). This species, as the name says, is found also in bays, harbours and they can occasionally penetrate in estuaries (Feldhamer et al.2003). After almost extinction of early 1970s and 1980s Harbour Porpoises returned in Dutch waters in the early 21st century. But since the end of 20th century an increase of population was registered in the southern part of North Sea and the redistribution of porpoises in Dutch waters may be due to changes in prey availability (Camphuysen & Siemensa, 2011).
Recent estimation of the Dutch Continental Shelf from aerial survey is about 26000 individuals in summer, 30000 in autumn and up to 86000 in March (Jansen 2013)

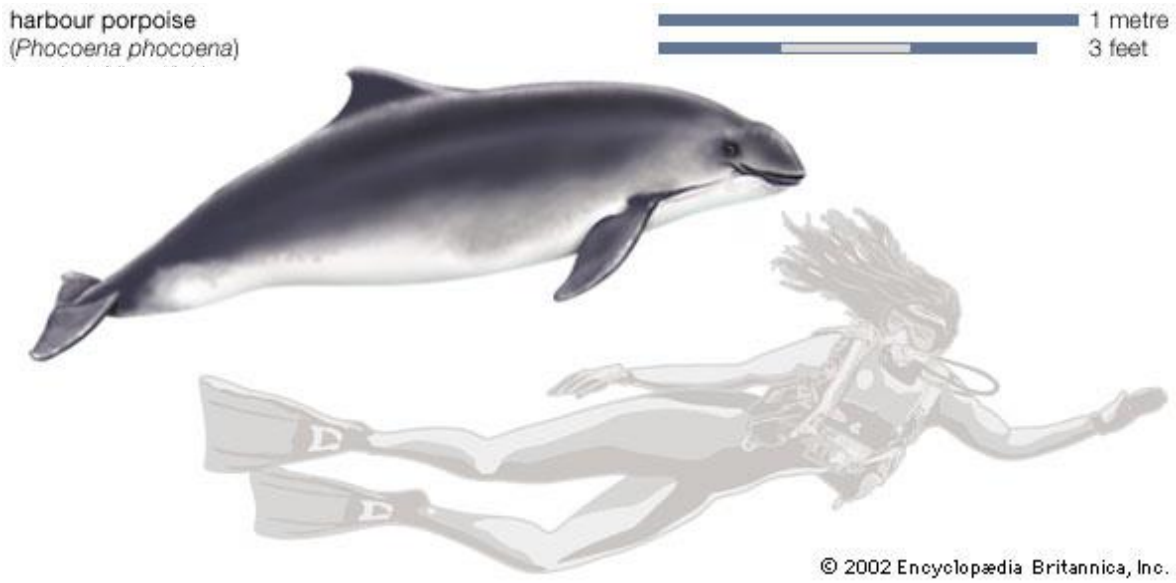


Figure 1: Harbour porpoises (Phocoena phocoena)

Harbour porpoises are exposed to numbers of anthropogenic pressures like bycatch, shipping, acoustic and water pollution, constructions and aquaculture, reason why they are listed as endangered species in several Conventions and action plans (e.g. CITES, ASCOBANS, Habitat Directive 92/43/EEC, Bern Convention) and several international, national and European legislations (Reijnders et al. 2009).

Harbour Porpoises usually have a life span of 8-10 years (exceptionally up to 24 years), and reach sexual maturity when they are 3 and 4 years (Camphuysen & Siemensa, 2011). Males are normally smaller than females and they reach respectively 145 cm and 160 cm (Bjorge, Tolley, 2009).
Reproduction is seasonal, with ovulation and conception in late spring and early summer. Gestation lasts for 10-11 months with a following lactation period of 8 months (Feldhamer et al.2003).
Because of their typical "shy" behaviour harbour porpoises are difficult to observe: they emerge to breathe briefly with a rolling motion ("wheeling") exposing only the dorsal dark-grey dorsal fin, they usually avoid motor boats and they rarely approach non-motor boats to ride waves. They usually form small groups of 8 individuals and when they

aggregate into a large group (from 50 to hundred) it is mostly for feeding and migrating (Jefferson, 1993). Harbour porpoises use echolocation for hunting their prey and for communicating (animals emit sounds and listening the echo they can locate the prey or the objective near them) (Camphuysen & Siemensa, 2011). This species is an endothermic predator with limited energy storage capacity, and needs a big amount of food intake relative to their body mass per day in order to survive. A good and frequent food daily intake is needed and the survivor rate without eating is about only 2 or 3 days, depending also on the season of the year (Camphuysen & Siemensa, 2011).
As most small odontocetes Harbour porpoises are opportunistic feeders, meaning that they usually feed on the most abundant prey, but always with an enough energy intake (Yasui and Gaskin, 1986). The trophic level and feeding location varies according to the season, age and gender of the animals. According to a study by Jansen (2013) on harbour porpoises from the Dutch coastal waters based on fatty acid analysis (that provides mid-term dietary information) the primary prey items are gobies, mackerel, smelt, herring and dragonet. From a study of stomach analysis (that provides short-term dietary information) of Dutch harbour porpoises the diet investigated was mainly consisted of whiting, sprat, sandeels and gobies (Leopold & Camphuysen, 2006).

A small population of Harbour Porpoises was used to visit the Eastern Scheldt estuary in Zeeland(Fig.2), south-west Netherlands, before the construction of the storm surge barrier (Oosterscheldekering) (Jansen 2013). The nine-kilometres barrier, completed in the 1986, was constructed in response to the big damage and loss of life due to the North Sea Flood of 1953 and it protects The Netherland from flooding by the North Sea (Bijker, 2002). The Eastern Scheldt estuary now covers a water surface of about 200.000 ha, and it is separated from North Sea by the semi-close storm surge barrier. Since 2002 it is known as National Park, it is protected area and hosts rich biodiversity. It is a foraging area for migrating birds and is a habitat of seals, rich underwater fauna and plants. The Eastern Scheldt estuary is a place for recreation but also for fisheries. The most famous are the shellfish farms [1] but fishermen boats are also present and the fisheries is controlled by licences that fishermen should have.

Figure 2: map of Zeeland, the Netherland, with a particular of Eastern Scheldt estuary (dark blue)

For a few decades after the construction of the barrier no porpoises were seen in the bay, but since approximately ten years they are returned in the area (Jansen 2013). A small

resident population seems to be established in the estuary and because of the lack of knowledge about this population, Rugvin Foundation, in collaboration with WWF Netherland, started surveys since 2009 in the area in order to gather more information. The aim was to understand the number of animals in the estuary, the seasonality of the population, the migration through the barrier and possible reproductive activity inside the bay [2].
The first count ever in the Eastern Scheldt bay was performed in September 2009 by Rugvin Foundation. The result of the first count was of 37 animals, among which 5 calves, under almost windless conditions [2]. This is indication number used as a minimum estimation of the amount of individuals present in the area since it is not possible to exclude that during the scanning some of animals which are under water are not seen by the volunteers on Rugvin boats [2]. In May 2010 15 individuals were registered but the weather conditions were not optimal. A peak of animals was detected in June 2011, when 61 individuals were counted under optimal weather conditions. According to aerial surveys performed between July 2010 and March 2011 of the Dutch Continental Shelf the highest abundance of harbour porpoises in Dutch waters was found in March 2011 (Geelhoed et al.,2013), same year of the peak of individuals counted in the Eastern Scheldt. In September 2012 the volunteers of Rugvin foundation counted 42 individuals under not optimal weather conditions [2].

Since harbour porpoises have been seen in May, June and September it seems that these animals do not occur seasonally in the bay but year-round. Harbour porpoises usually are present around Dutch coasts during early spring and they departed in the end of April, revealing seasonal migration behaviour usually due to food availability (Jansen 2013). In contrast harbour porpoises detected in the Eastern Scheldt do not show this particular behaviour and it is possible that the storm surge barrier plays an important role in trapping the animals inside the bay. It is still unknown if harbour porpoises in the Eastern Scheldt stay in the bay for a longer period or there is a continuously exchange through the barrier between the bay and North Sea (Jansen 2013). But during the study about harbour porpoises diet of North Sea and Eastern Scheldt undertaken by Jansen et al.(2013) the isotopic signature (which depends on type of pray that animals are feeding on) found in muscle tissue from stranded porpoises of Eastern Schledt between 2006 and 2008 was found different from the signature of animals stranded in the Dutch coastal zone. This means that the animals were feeding in the area long enough, while in case of continuously exchange with North Sea population the signature would be not significantly different.
The presence of 5 calves next to their mothers spotted in 2009 during Rugvin foundation scanning might be an evidence of reproductive activity inside the Eastern Scheldt. The calves usually born during May-June in the northern part of the North Sea and since they were seen in September in the Eastern Scheldt it is unlikely that 5-months calves migrated from the north into the bay passing through the barrier [2].
The use of echolocation for foraging, orientation, communication and navigation makes Harbour Porpoises vulnerable to sound pollution (Koschinski, 2011). The Eastern Scheldt Storm surge barrier is a source of sound pollution due to the noise produced by the movement of water on the walls of the barrier, especially during high tide. Harbour porpoises might be scared or confused by the noise since they are very sensitive to underwater sounds (Korpelshoek, 2011) and consequently they might be trapped inside.

1.2 Problem definition:

Since year 2006 the number of stranded porpoises found on Oosterschelde coasts is recorded and collected in databases by the Eerste hulp bij Zeezoogdieren (EHBZ), i.e. first aid for marine mammals. From 2010 onwards the number of animal found stranded was higher than previous years and considered alarming (Fig.3). Considering the number of alive animals, the amount of stranded animals is anomalous.

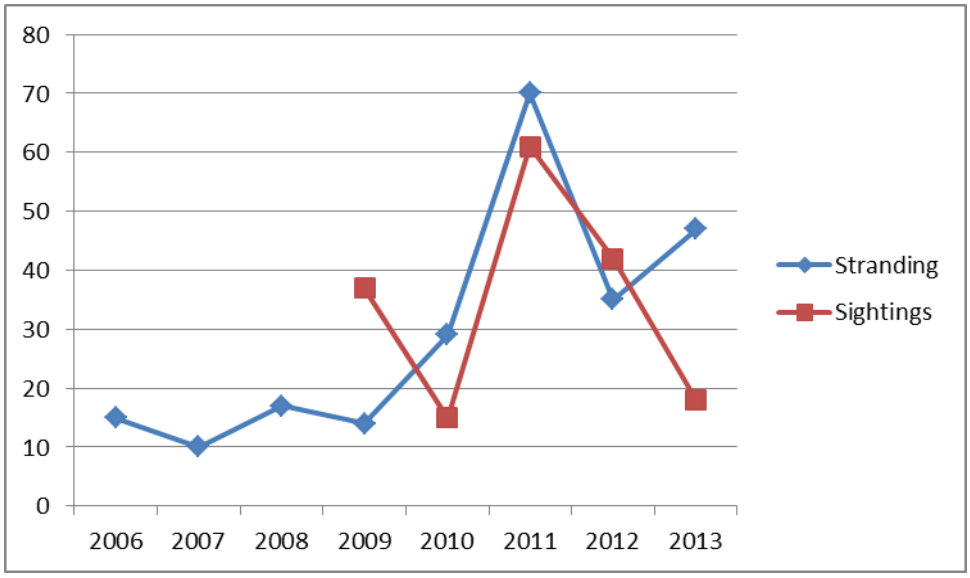


Figure 3: number of stranded harbour porpoises found in the Eastern Scheldt from 2009 to 2013 compared with sightings of harbour porpoises

As can be seen from in the graphs, the highest number of sightings, as well as of stranded animals, was registered in 2011. But in the following years the number of sightings decreased in contrast with the number of stranded individuals which remained higher than in previous years. Analysis made by the Veterinary Pathologic Diagnostic Centre of the Department of Pathobiology from Faculty of Veterinary Medicine of Utrecht University showed that starvation and emaciation were the main reasons of stranding of porpoises in the Eastern Scheldt [2].
Therefore the aim of the present research is to determinate the possible causes of starvation of the large number of harbour porpoises found stranded since 2010 in the Eastern Scheldt bay.
A similar situation was documented in North Carolina in 2005. A marked increase of number of stranded harbour porpoises was measured relative to a threshold to determinate that Unusual Mortality Event (UME) was occurring. The occurrence fulfilled the criteria under which it can be described as "Unusual Event"[3] (Hohn et al., 2013). The high number of stranded animals in the Eastern Scheldt may meet the criteria and be considered an UME as well.

1.3 Research Questions:

In order to reach the aim of the research one main question was set up:

What are the possible causes of starvation of the large number of Harbour Porpoises stranded in the Eastern Scheldt?

Three sub-questions were set up in order to answer to the main research question:

1. *Is the starvation related to the food availability/quality in the Eastern Scheldt water?*
2. *Is there competition with seals living in the area?*
3. *Is there competition with fisheries?*

2 Methods:

To investigate the reasons of high stranded rate of harbour porpoises in the Eastern Scheldt different methods were used.

2.1 Literature research and contacting people:

Gathering already existing data and knowledge from previous research in the Eastern Scheldt was a fundamental step in the study. The time range of the phenomenon under study is of about 5 years, from 2009 to 2013. Therefore data of years before 2013 about stranded harbour porpoises, seals population, stomach content analysis, migration through the barrier and fish population had to be gathered and used as starting points.

Being a National Park, the Eastern Scheldt estuary is monitored by governmental institutions (e.g. Rijkswaterstaat) and since it is a habitat rich in biodiversity, several foundations (e.g. Rugvin foundation) and research institutes (e.g. IMARES) are active in gathering information about the ecology of the area.

In addition, the presence of the storm surge barrier that semi-closes the bay makes the area interesting to study the impact of such a protection structure which can affect the habitat and biodiversity of the area (Jansen, 2013).

By contacting and talking with experts and employees from different institutions and foundations involved in monitoring and research projects in the Eastern Scheldt area, data about years before 2013 were collected. After that, data were united together and interpreted.

Number of stranded harbour porpoises were collected contacting the association Eerste Hulp Bij Zeezoogdieren (EHBZ), which since 2006 records with date and location of founding in a database the Harbor porpoises found stranded on the Eastern Scheldt shores and near the Eastern Scheldt storm surge barrier, with the porpoise of monitoring the population state and collaborating with marine mammal stranding network of Dutch coasts.

General information about body condition, gender, age and most likely reason of death of stranded animals were gathered contacting Veterinary Pathologic Diagnostic Centre of the Department of Pathobiology, Faculty of Veterinary Medicine of Utrecht University. From December 2008 carcasses of harbor porpoises found in a good condition are transported to the Veterinary Pathologic Diagnostic center for being analyzed. The carcasses in very rotten condition are not transported in the Department, as the analysis would be not attainable for a certain level of decomposition. The practice of processing bodies consists of weighting and measuring the animal, examining macroscopically, opening the abdomen for taking samples for histopathology, bacteriology, virology and toxicology analysis (e.g. for the stomach analysis the entire stomach is removed, washed and the contents is analyzed later with microscopes). With this method it is possible to have important information about age, gender, general physical condition and most likely reason of death of the individuals analyzed.

Fish number and biomass in the Eastern Scheldt were collected using data gathered from a survey carried out from IMARES every year since 1970 in the Eastern Scheldt bay. Demersal Fish Survey (DFS) is an annual monitoring which is done in autumn

(September/October) in the waters of the Eastern Scheldt. It a survey carried out using shrimps trawl of 3 meters, in 40 fixed (Fig.4) locations pulled 15 minutes each time.

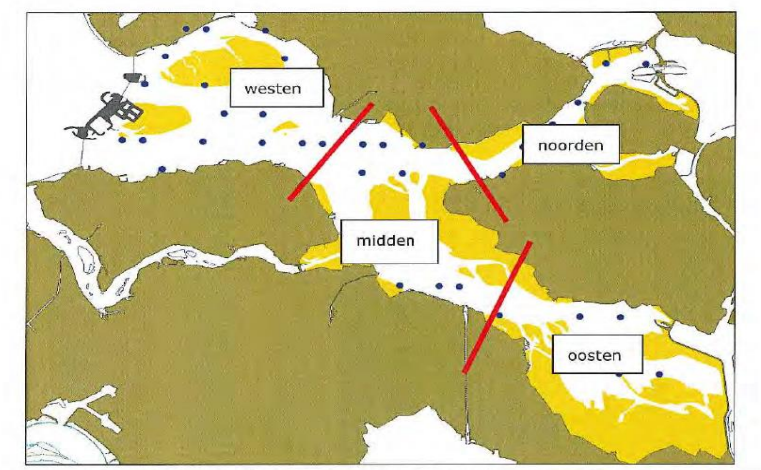


Figure 4: blue spots represent the locations where surveys are carried out. The entire bay is divided in four parts, western, northern middle and southern (Boois, I.J de, en M. van Asch. 2013)

Using the total catch, fish number and biomass is calculated per 1000 m² in the area. The data are reported by IMARES in 2013 (Boois, I.J de, en M. van Asch. 2013).

2.2 Scanning:

The aim of the scanning was to determine the number or harbour porpoises present in the Eastern Scheldt waters. Since 2009 Rugvin foundation organizes once a year surveys for the counting of individuals in the area. Weather influences the results of their counting and for having best success it is important to perform the scanning under the best weather conditions, reason why surveys in the Eastern Scheldt were performed in different months every year. During days with high visibility and calm water without wind it is easier to spot porpoises as they usually emerge exposing only the dorsal part of their fin, as mentioned before. The optimal wind condition is up to 2Bft speed, above this range is not possible to perform efficient scanning[4].

The number of animals counted is considered as minimum evaluation of the individuals present in the Eastern Scheldt bay as it is possible that several animals under the water are not spotted.

Routes:

The scan in which I participated was done on 22th of September 2013. Eight boats scanned the bay from the Eastern Scheldt barrier to the extreme north/eastern reaches (Fig.5).

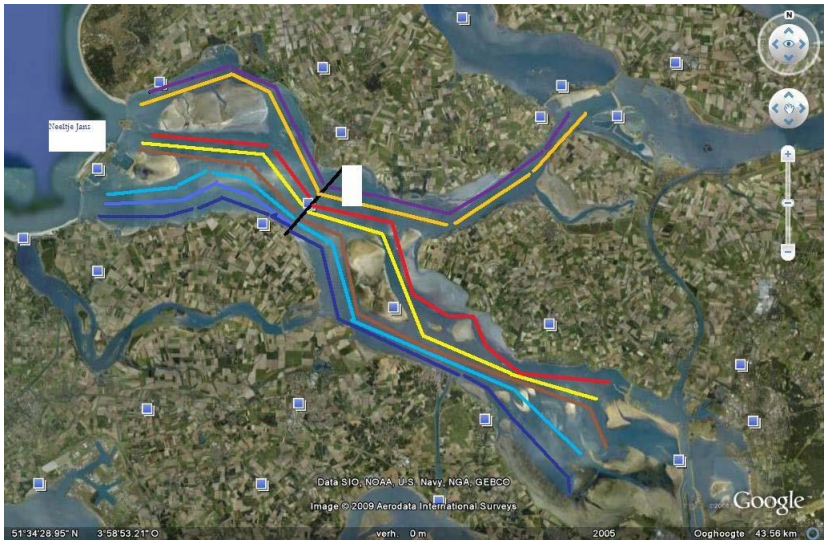


Figure 5: map showing the routes of the 8 boats during the survey in the Eastern Scheldt waters (Rugvin report)

The 8 boats were sailing parallel from west to east. The westernmost position boat was the point of reference for the others in order to stay parallel. About 5 hours were spent on the boat scanning the area.

Observations:

The number of volunteers on each boat varied from 4 to 8. At least 3 observers were needed each boat for the monitoring of the water and each of them watched with a binocular sideways and forward: the first observer looked to the port side (1), the second observer to the starboard side (2) and the third one looked ahead and overlap with the other two (3) (Fig.6). In this way all the area was scanned. The other members were helping the observers to scan the water.

For every spotted porpoises GPS position, swimming direction and precise time were registered in a data form. Every 30 minutes the position of the boat was recorded.

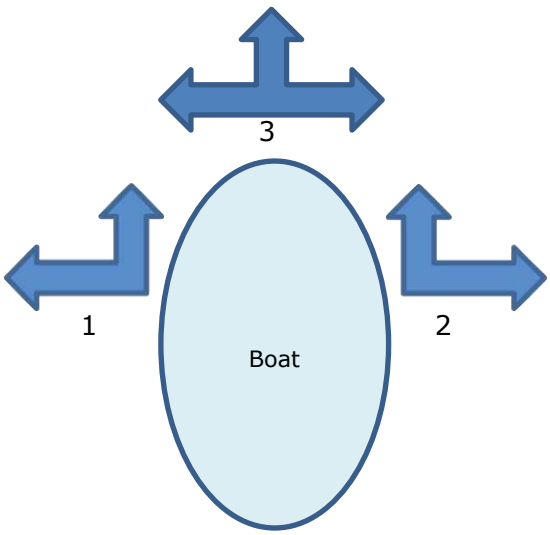


Figure 6: depiction of the positions of 3 observers on each boat and their range of vision

2.3 Interviews:

Talking and interviewing fishermen and people which are used to work in the Eastern Scheldt fish market field was important phase in the process of gathering information and data of the place as qualitative data. People that are working and fishing in the area since several year can see the evident and tangible changes in the bay. Impressions and points of view of these people which have a lot of knowledge gleaned by experience are useful to better understand how the situation was before, if something is clearly changing and what are the possible causes of the changes in their opinions. In addition, understanding which species fishermen are used to catch is important to figure out if there is possibility of interaction and competition between fisheries and harbour porpoises in terms of prey overlap.

The categories of people taking into consideration were: fishermen, recreational fishermen and fish sellers. Fishermen, as well as recreational fishermen, with their daily experience in the sea, are the ones who know the waters of the Eastern Scheldt bay better and they have an overview of the fish availability and abundance in the area. Fish sellers are every day in contact with fishermen that bring fish to them for selling. They have to count, measure and weight the catch before selling, reason why they have knowledge about fish stock.

In order to meet fish sellers and have an idea of the fish commerce of the area, I went to the harbour of Colinjsplaat village (Fig.7). From this little port the largest number of boats usually departs and it hosts an open air fish market.

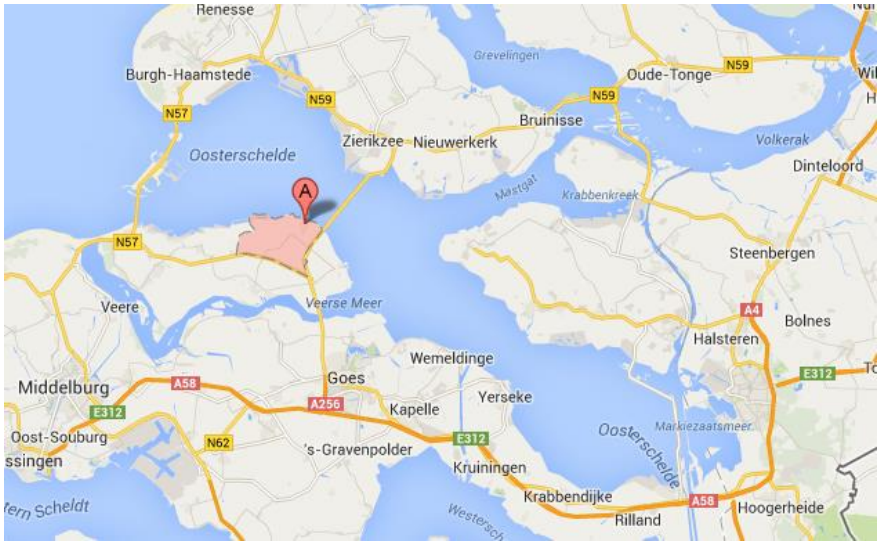


Figure 7: the red marker shows the Colijnsplaat harbour

Because of language problems a Dutch speaker student joined the trip to help in translating.
Two fish sellers were interviewed with an already made questionnaire about fish species abundance in the waters of the bay, common catches of fishermen, personal impressions about differences between the past and the present situation of fish stock.
Nowadays only 2 boats are still fishing in the Eastern Scheldt waters (personal communication). Through connections it was possible to interview one fisherman by telephone with the same questionnaire used to interview fish sellers.
The organisation of recreational fishermen Sportvisserij Zuidwest Nederland [5] is placed in the whole Delta, therefore also in the Eastern Scheldt. Four recreational fishermen were contacted by e-mail asking to fulfil the questionnaire mentioned before.

3 Results:

3.1 Scanning:

The total number of Harbor Porpoises spotted in the Eastern Scheldt waters during the scan performed on 22nd September 2013 was 18 individuals. This number is considered a minimum estimation of the individuals present in the bay. The weather conditions has large influence over the results, because on Sunday 22nd the conditions were not optimal for a good estimation of the total number of individuals in the bay, it is possible that the number counted is lower than what it is in the reality.

Within the 18 individuals counted, 2 were recognized as juveniles and 2 as calves. The number of sightings is lowering after 2011, as is showed by the graph below (Fig 8). A large difference is evident between the number of individuals spotted in 2011 and the result of monitoring in 2010 and the one in 2013. It is important to consider that during both days of monitoring the weather conditions were not optimal.

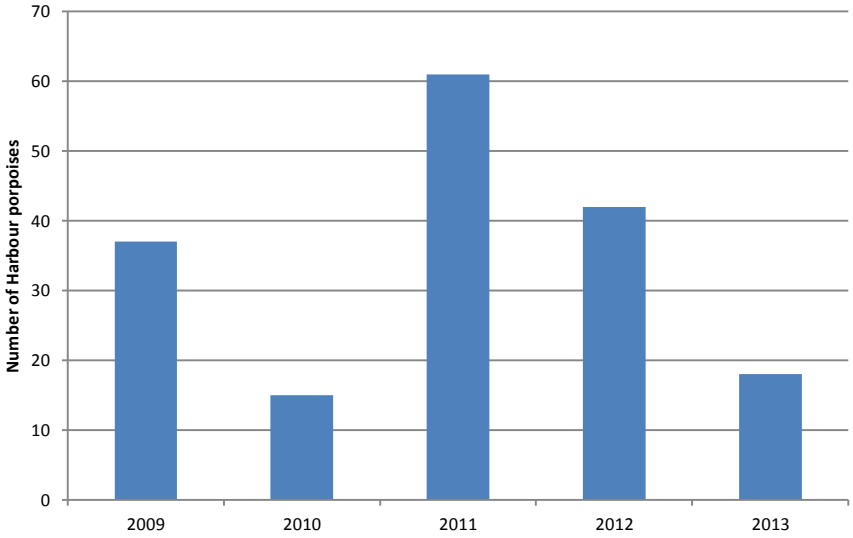


Figure 8: *number of harbour porpoises spotted every year from 2009 to 2013*

The scanning trips were conducted in different time of the years, therefore is also important to take into account the variable of different occurrence of harbor porpoises in the area.

The number of calves spotted every year during the scanning is showed in the Figure 9.

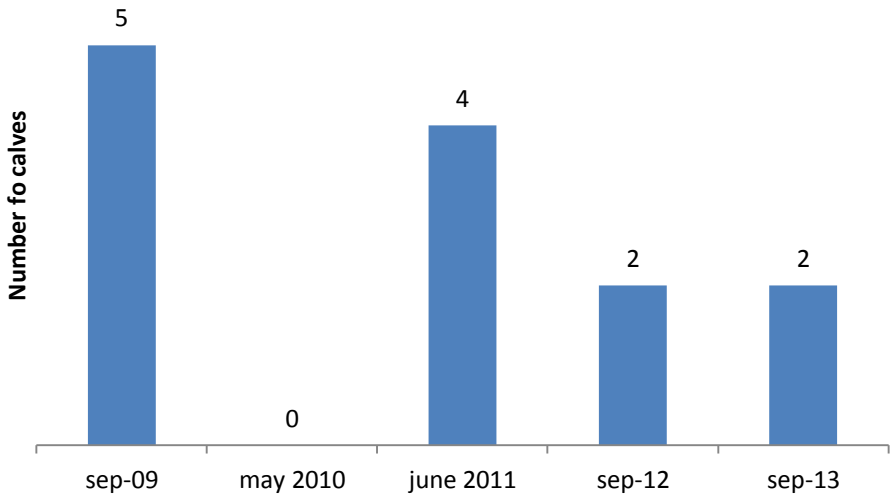


Figure 9: number of spotted calves during monitoring surveys in Eastern Scheldt waters

With exception of 2010 when no calves were spotted (maybe due to the time of the year) in Eastern Scheldt, the number of calves spotted is decreasing after 2009. The presence of calves is reasonably influenced by the time of the year when the scanning was performed.

3.2 Stranding:

The total number of animals found stranded from 2006 till 2013 on the shore is showed in the graph below. After 2009 the number of stranding increased, showing a high peak in 2011 (Fig.10).

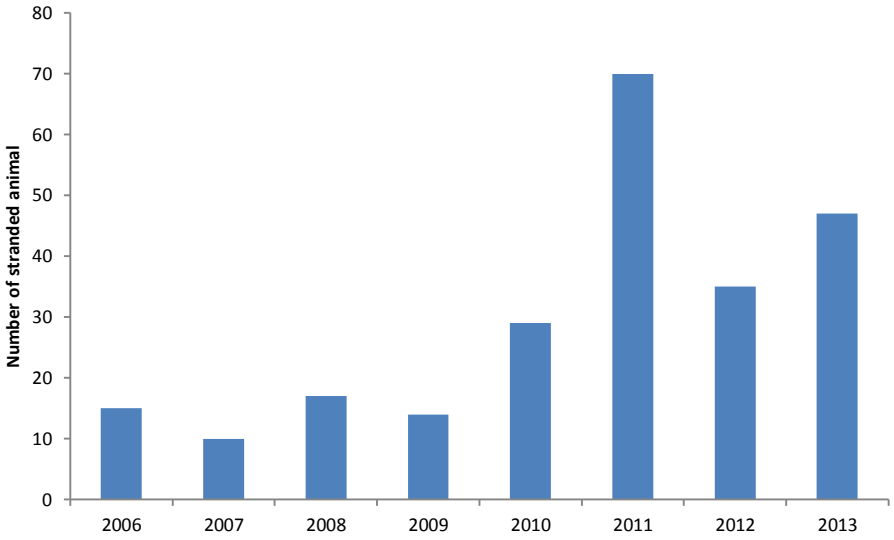


Figure10: number of stranded harbour porpoises found from 2006 to 2013 on the Eastern Scheldt costs

Gathering together month by month carcasses found from 2006 to 2013 it is clearly visible that the month with highest rate of stranding is August, followed by September and July (Fig. 11).

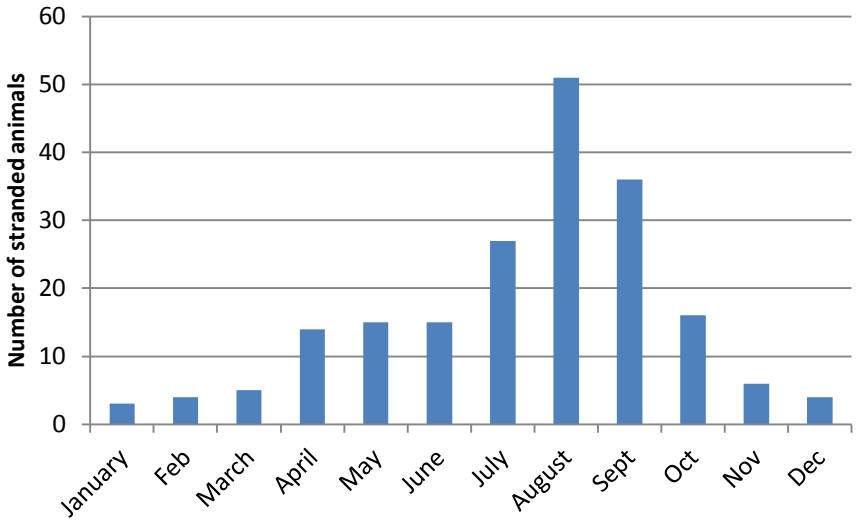


Figure 11: number of stranded harbour porpoises gathered together depending on the month of the stranding, from year 2006 to 2013

The number of carcasses in a good condition analyzed by Veterinary Pathologic Diagnostic center among the total ones is showed in the table 1 below:

Table 1: number of total stranded animals found on Eastern Scheldt shores and next to the Eastern Scheldt storm surge barrier compared with the ones which it was possible the analysis

	Total stranded animals	**Carcasses analysed**
2009	14	6
2010	29	8
2011	70	30
2012	35	19

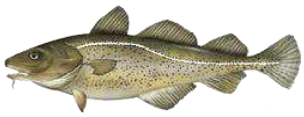
The analysis showed that the age-group more numerous among stranded individuals was represented by juveniles and the main cause investigated was starvation, followed by emaciation. Juveniles and immature individuals are identified with a total length of 90-145 cm. If the results are compared with ones of the total population, which is represented by harbor porpoises of the entire Dutch coasts outside Eastern Scheldt, the ratio of stranded neonates is also high [2].

From year 2006 to 2008 no analysis of carcasses was done, while the animal found in 2013 are still under study.

3.3 Food availability in Eastern Scheldt:

Results of stomach content analysis about main prey of harbor porpoises in the Eastern Scheldt are showed below (Table2)

Table2 : main prey found in the stomach of harbour porpoises stranded in Eastern Scheldt with respective percentage (Korpelshoek, 2011)

Adult	**Percentage %**	
Atlantic Cod (*Gadus morhua*)	46.93%	
Withing (*Merlangius merlangus*)	30.23 %	
Poor Cod (*Trisopterus minutus*)	17.16 %	
Juvenile	**Percentage %**	
Sand Goby (*Pomatoschistus minutus*)	70%	
Whitings (*Merlangius merlangus*)	14 %	
Herring (*Harengus*)	3.60 %	

Data obtained by the Demersal Fish Survey are gathered together in graphs showing trends year by year of biomass and number of the main prey species of harbor porpoises present in the Eastern Scheldt waters (showed in table2).

The graph below shows trends of fish biomass per 1000 m² from year 2000 to 2012 of Poor Cod, Atlantic cod, Herring, Gobies and Whiting, the main prey of harbor porpoises in Eastern Scheldt (Fig. 12).

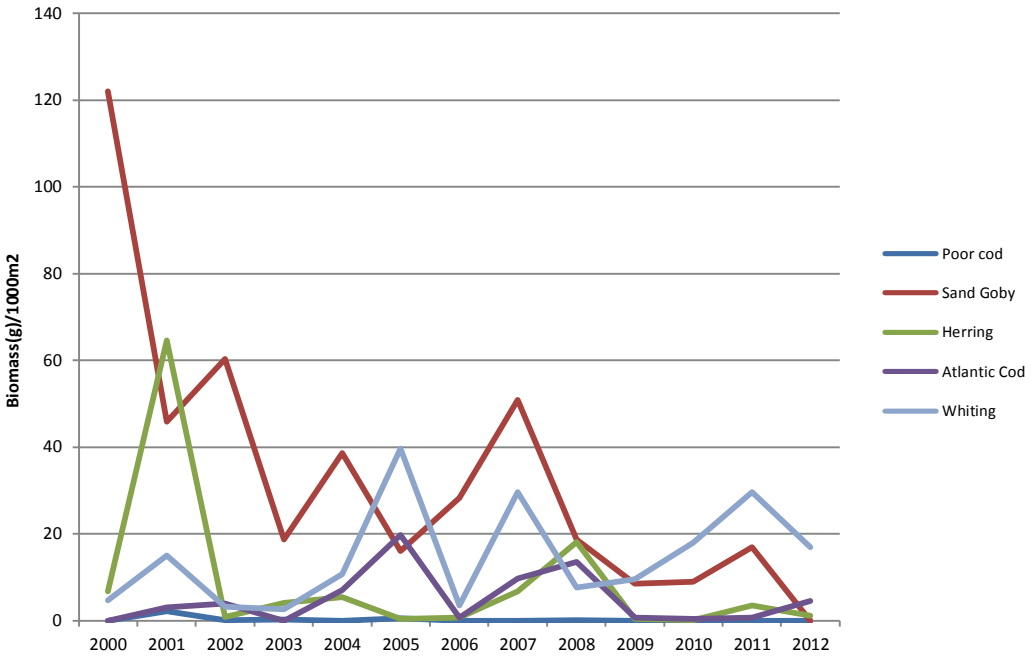


Figure 12: trend of biomass(g)/1000m² each year of poor cod, gobies, herrings, Atlantic cod and whiting in Eastern Scheldt waters from year 2000 to 2011

The biomass per 1000m² shows fluctuating trend, with peak in different years depending on the species of fish. Poor cod shows biomass close to 0 among all the years. Goby shows an evident decrease from 2000 when the biomass was calculated about 122 biomass/1000m² while dropped into almost 0 in 2012. The biomass of Atlantic cod and herring appears fluctuating during all years but particularly steadily low from 2008 on. The only species which appears to do not decrease from 2008 is whiting. 2012 looks to be a year with low fish biomass per 1000m², again with exception for whiting, which have lower biomass than 2011 but still not close to 0 as the other species (16.9 biomass/1000 m²).

In order to have an idea of the respectively biomass found in Eastern Scheldt waters of each species of fish, table 3 shows the average of biomass per 1000m² of each species from 2000 to 2012.

Table3: average of biomass/1000m² of each fish species from year 2000 to 2012

Species	Average of biomass(g)/1000 m2
Atlantic Cod	4.93
Herring	8.73
Poor Cod	0.26
Sand Goby	33.39
Whiting	14.68

Gobies are the most abundant species in the Eastern Scheldt among the species which are common prey of harbour porpoises. The second most abundant are whiting, while poor cod, as mentioned before, has very low biomass compared with the other species.

The number of fish per 1000m² is also measured in the DFS survey. The decrease in fish biomass in the last years is strengthened by the low number per 1000m² of fish measured in the Eastern Scheldt waters. The graph below shows the trend of number per 1000m² of every species (Fig. 13).

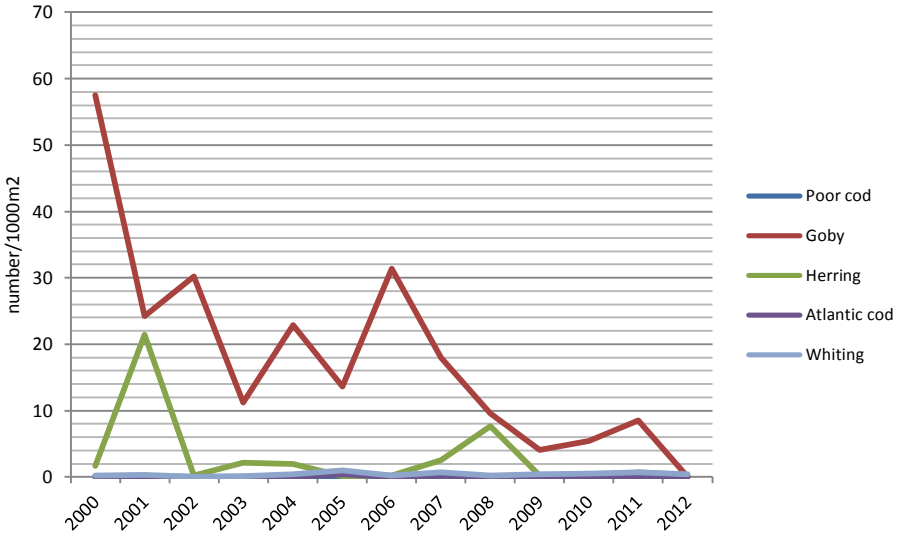


Figure 13: number/1000 m² of every species calculated from year 2000 to 2012

The number of fish found in the area appears low every year, except from gobies which from high number in 2000, dropped down until reaching level 0 in 2012. Comparing with gobies and herring, the number of poor cod, Atlantic cod and whiting is low and it is not possible to distinguish. Therefore graph 14 shows number per 1000m² of these species without goby and herring.

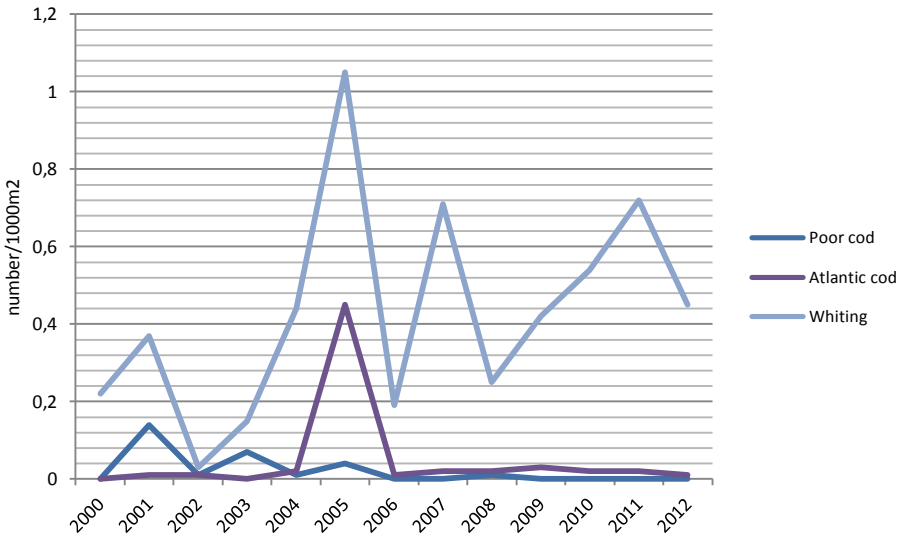


Figure 14: number/1000 m² of poor cod, Atlantic cod and whiting calculated from year 2000 to 2012

Comparing fish biomass with stranding rate of harbour porpoises in a complete overview, it is possible to find a relation between the low biomass of fish and the high rate of stranding (Fig. 15).

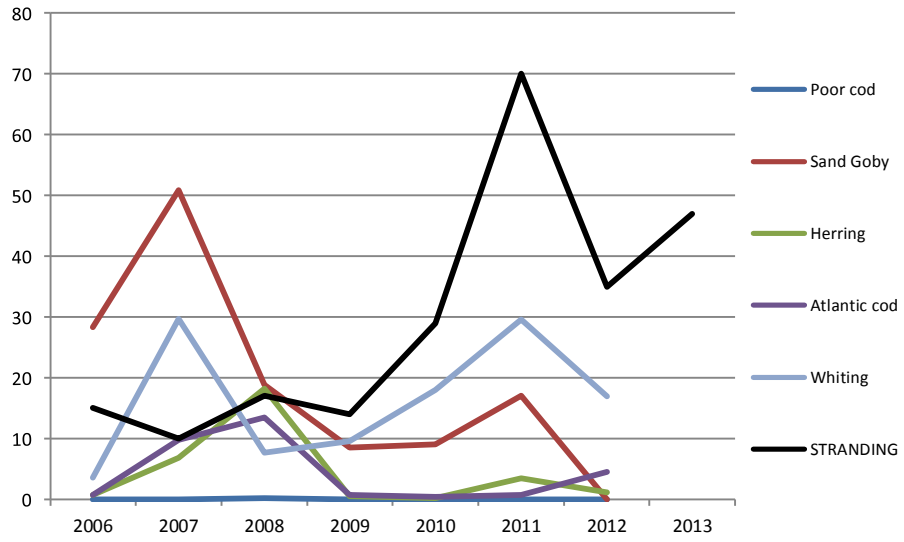


Figure15: relation between biomass(g)/1000 m² of every fish species and number of stranded harbour porpoises from the year 2006 to 2013

Between 2006 and 2009 the number of stranding is low, less then 20 per year. After 2009 the number of stranding animals increases, reaching a peak in 2011 with 70 carcasses found on the schore. Fish biomass is low in 2006, but then increases and lowers again after 2008 (with the execption of whiting). In summary, higher fish biomass per 1000m² is measured in correspondence to low number of strandings, while a lower biomass per 1000m² correspond with higher rate of stranding. The only species which is not following the trend is, as mentioned before, whiting.

The relation between prey availability, considered in term of fish biomass, and number of stranding is showed in the graph below with particular case of gobies biomass compared with harbour porpoises stranded in Eastern Scheldt shore (Fig.16). Gobies are the main prey for juveniles harbour porpoises which represent the most numerous age-group among all the stranded carcasses found on the Eastern Scheldt shore. After 2008 gobies biomass starts to decrease and number of stranded animals starts to increase after 2009.

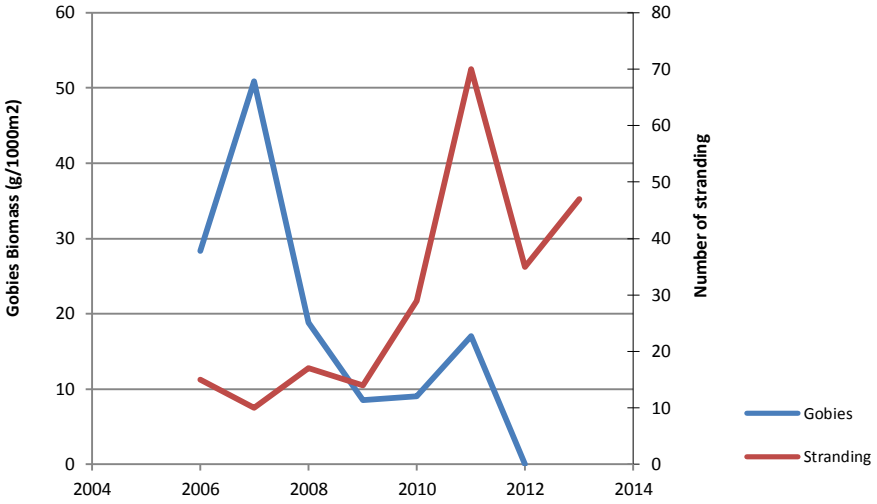


Figure 16: relation between biomass/1000 m² of gobies and number of stranded harbour porpoises from the year 2006 to 2013

3.4 Seal populations in the Eastern Scheldt:

Beside harbor porpoises, two species of seals are important predators resident in the Eastern Scheldt bay; Harbor seal (*Phoca vitulina)* and *Halichoerus grypus,* commonly named Grey seal (Fig. 17).

Figure 17: Harbour seals (Phoca vitulina) and grey seal (Halichoerus grypus) relaxing on the shore (Wikipedia)

The population of grey and harbour seals is counted every year within a biological programme of coastal wetlands in the Netherlands, organized in collaboration between governmental bodies (Rijkswaterstaat) and volunteer, in order to detect the changes in size and composition of seals population [6].

According to the literature, harbor seals *Phoca vitulina* are opportunistic feeders with preference for European Flounder (*Platichthys flesus*), *Myoxocephalus scorpius*, *Agonus cataphractus*, Atlantic cod and gobies. Sometimes whiting are also found in the stomach of harbor seals (Mees & Reijnders,1994). Atlantic cod, gobies and whiting coincide with harbor porpoise's diet and in a shortage of food availability there might be competition between porpoises and seals. Harbor seals population is much more numerous than harbor porpoises individuals resident in the Eastern Scheldt waters, as it is showed in the graph below (Fig. 18). Furthermore, the population of *Phoca vitulina* appears to increase from 2009 to 2012.

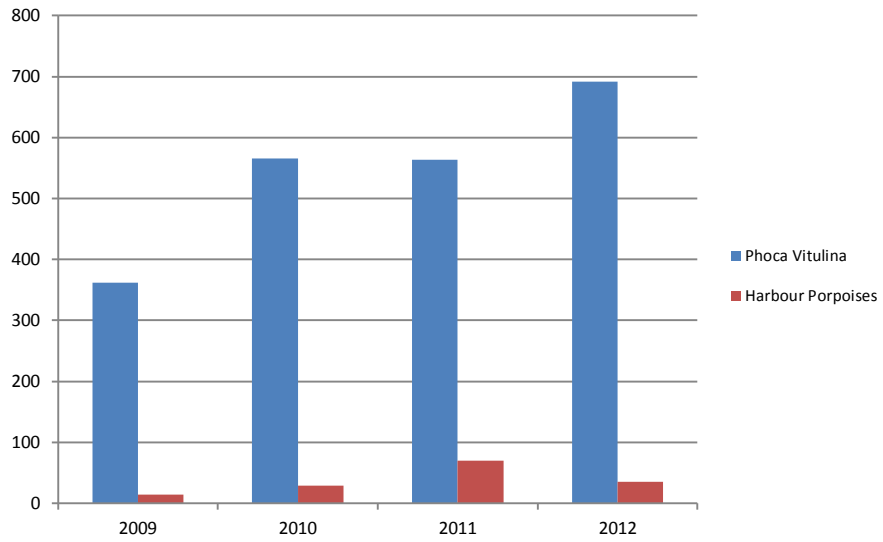


Figure 18: number of Phoca vitulina monitored from 2009 to 2012 in Eastern Scheldt compared with harbour porpoises individuals (the number of seals received by personal communication form Rijksoverheid)

Grey seals *Halichoerus grypus* are less abundant in Eastern Scheldt waters than harbor seals. A study in South-western North Sea show that among all age-groups common prey of grey seals are sandeels (*Ammodytidae*), cod (*Gadus morhua*), dover sole (*Solea solea*) and other flatfish (dab, flounder and plaice).The diet of grey seals varies according to the age-group, gender, location, prey availability and season (Prime, Hammond, 1990).

Different situation from harbor seals population is observed regarding the number of grey seals; in 2009 it exceeds 70 individuals but in 2011 and 2012 the number of individuals decrease under 50 (Fig. 19).

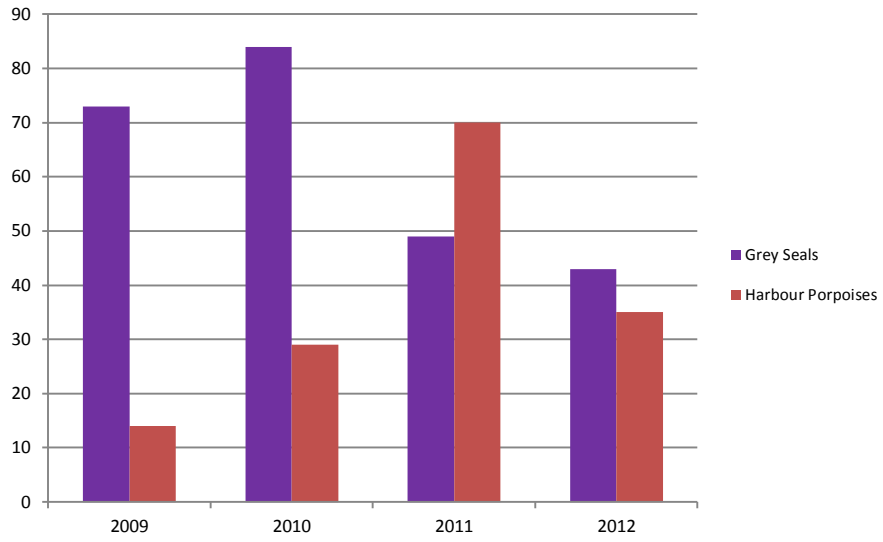


Figure 19: number of Halichoerus grypus monitored through July 2009 to June 2013 in Eastern Scheldt compared with harbour porpoises individuals. There was not count in August 2010. (The number of seals is received by personal communication form Rijksoverheid)

3.5 Fisheries in the Eastern Scheldt:

The Eastern Scheldt had always been an attractive place for recreational fisheries for his particular semi-close bay characteristic. Now the overall situation of fishing activities in the Eastern Scheldt waters is changed. In the 80'there were around 100 sport fishing boats. The amount of recreational boats nowadays is lowered to 20circa but only 5-10 are fishing weekly (on average 5 boats per week, 3 days a week). After 2001 the number of charter skippers is decreasing year by year, and the main reason seems to be lack of catch, due to lack of fish.

Regarding commercial fishing, only 2 boats are still fishing in the area nowadays. The catch are summarize in table 3.

Table3: main prey of commercial fishermen in the Eastern Scheldt waters

Sole (*Solea solea*)	Eel (*Anguilla*)
Sea bass (*Dicentrarchus labrax*)	Common dab (Limanda limanda)
Mackerel (Scomber scombrus)	Lobster

The primary prey items of sport fishermen are showed in a table below (Table 4).

Table 4: main prey of sport fishermen in the Southwest Delta waters, including Eastern Scheldt estuary.

European flounder (*Platichthys flesus*)	Atlantic cod (*Gadus morhua*)
Common dab (Limanda limanda)	Eel (Anguilla)
Seabass (*Dicentrarchus labrax*)	Mackerel (Scomber scombrus)
Sole (*Solea solea*)	Pouting (Trisopterus luscus)
Whiting (Merlangius merlangus)	

According to people interviewed, there are two main causes of the decrease of fish abundance in Eastern Scheldt waters: first, the construction of the Philips and Oesterdam dams. The two civil works create a barrier for the supply of fresh, nutrient-rich water from the rivers coming from the land (Fig.20).

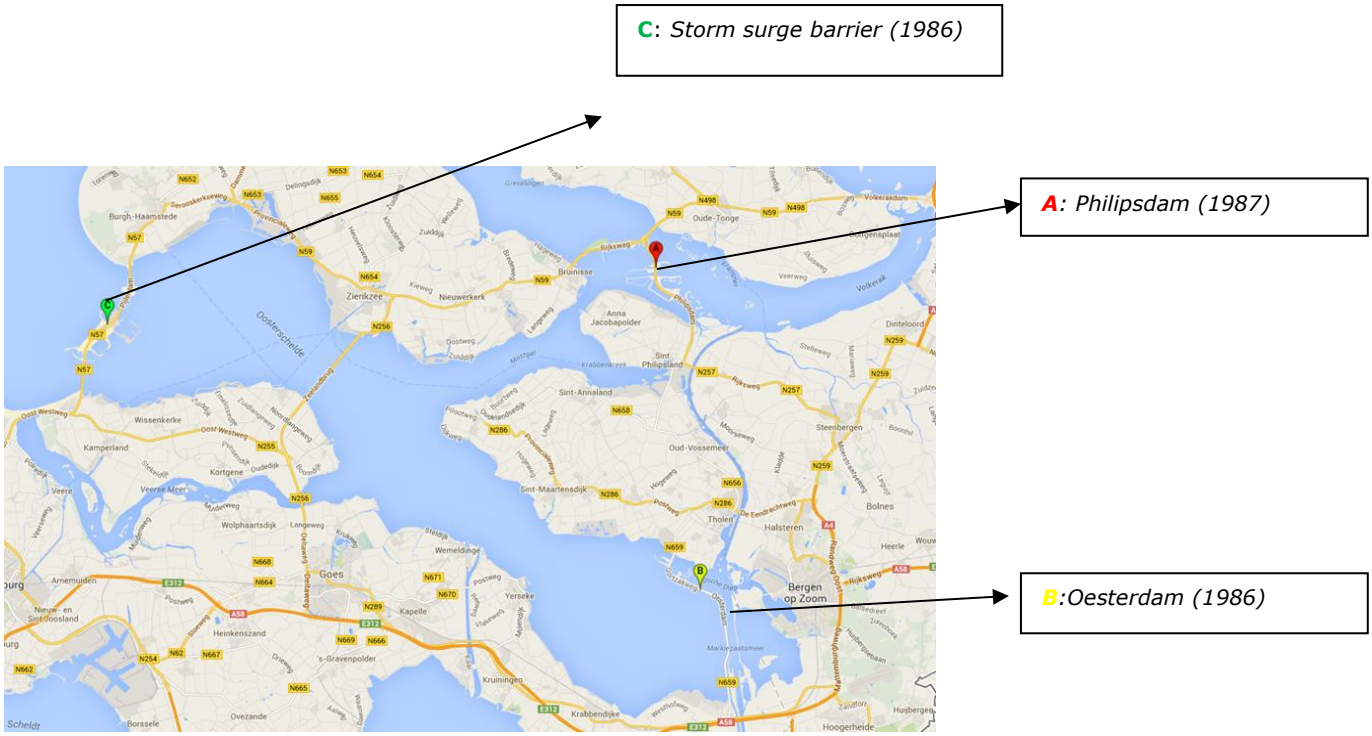
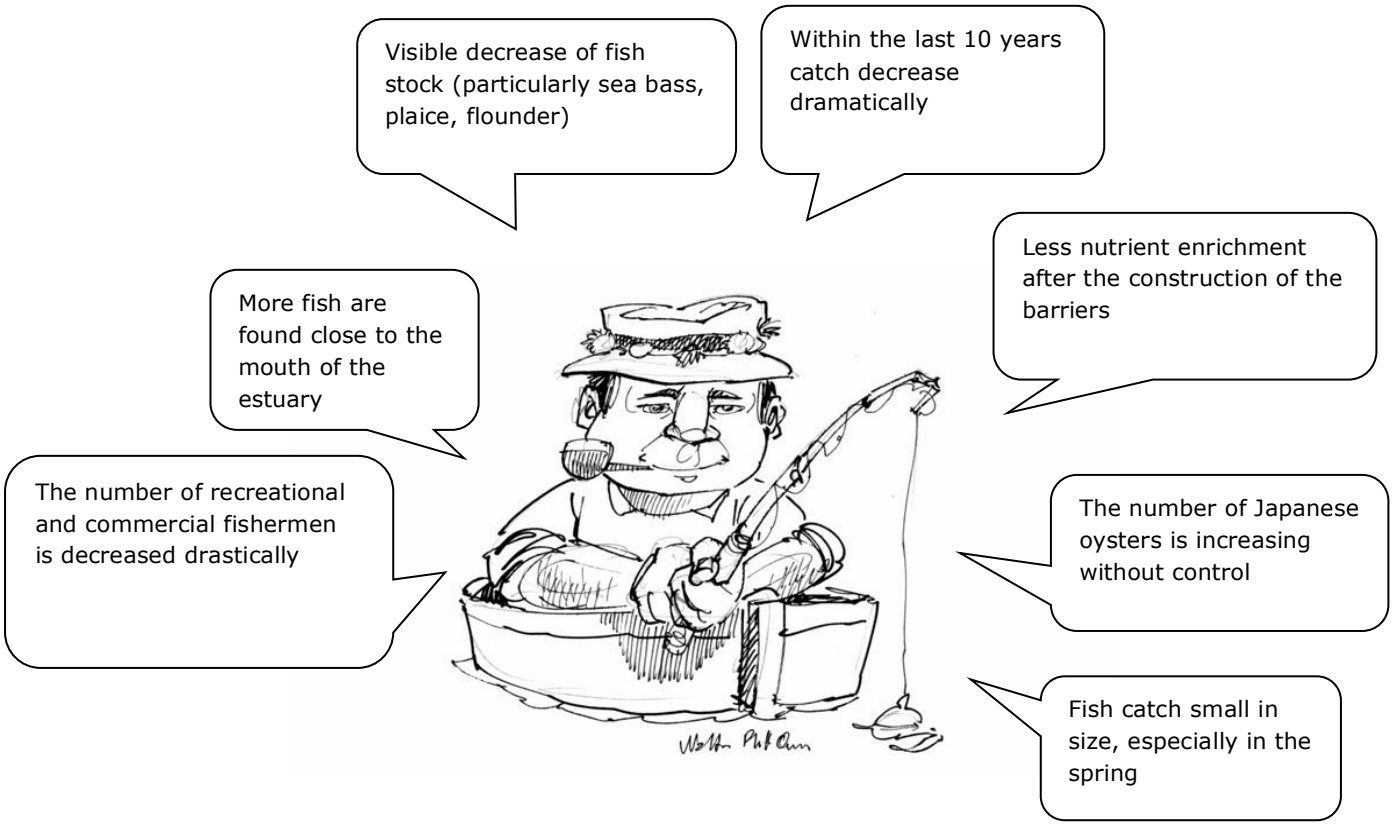


Figure 20: barriers built in the Eastern Scheldt from 1986.

Second, the unusual number of Japanese oysters. It is an invasive species without predators which filters and feed on a large amount of micro-organism, competing with crustaceans and fish larvae, and on phytoplankton, causing decline of primary production due to overgrazing.

The main outcome of all interviews is summarized below:



4 Discussion:

4.1 Is the starvation related to the food availability/quality in the Eastern Scheldt water?

From analyses done by the Veterinary Pathologic Diagnostic Centre of Utrecht University on harbor porpoises carcasses found stranded on the Eastern Scheldt shore, the cause of death was detected as starvation, followed by emaciation for unknown origin.

These results lead to consider shortage of food as possible status in the area. All information about fish abundance from previous research and from personal communication through interviews were collected, in order to understand the current situation of prey abundance and availability in Eastern Scheldt waters. Therefore, quantitative data could be supported by qualitative ones.

Summarizing the results, the biomass per 1000m² of the main prey of harbour porpoises is very fluctuating, but after 2008 it drops, reaching almost 0 in 2012, with the exception of whiting. The year 2011 was a particular with an unusual high number of harbor porpoises in the area and consequently high numbers of stranded animals. Also the number of fish per 1000m² was very low across all years.

Poor cod represents 17% of the adult harbor porpoises diet, but showed the lowest biomass and lowest number per 1000m². The most abundant species was sand goby and it was also the one in which the decrease of biomass and number is more evident. There is a clear link between the low biomass of fish prey per 1000m² with stranding: the biomass, as well as the number, appeared to be low when the number of stranding was high. The most represented age-group of stranded harbour porpoises is the juveniles. 70% of the juveniles diet is represented by sand goby. As the population of the sand goby was decreasing year by year following a fluctuating trend, there could be a possible correlation between high juveniles stranding rate and lack of their main prey. The biomass per 1000m² of whiting is the only one which did not decrease and it seemed to be even increased after 2008. But at the same time the number per 1000m² of whiting was low during all years. It is possible that the size of whiting increased while the number was still very low, which results in a high biomass per 1000m², but a low number of individuals.

Studies in the Baltic Sea [7] and the one of Jansen et all (2013) in the North Sea have found differences between juveniles and adult harbour porpoises diet, mainly because of the limitation of young individuals in catching large preys and reaching a certain depth for hunting. Sand gobies are small and easy to catch, reason why they represent the highest percentage in the juveniles diet. But because since 2000 the biomass and the number of gobies is decreasing, corresponding to a low availability year by year of prey, juveniles may have problems to find food. Whiting, revealing high biomass but low numbers, have possibly a big size, and can therefore be difficult prey for not expert young harbour porpoises.

Kastelein et al. (1997) mentioned that the food consumption of these animals depends on several variables such the blubber thickness, degree of growth, activity level, diet, reproductive state, season and digestibility of the food, therefore the needed energy

intake varies a lot from one individual to another. But in general, being inhabitants of cold waters of the northern hemisphere, thermoregulation is crucial. The heat loss induces harbour porpoises to have a good enough daily energy intake, which means that they need to eat often during the day to survive (Kastelein et al., 1997), reason why the type of prey is important for the essential energy intake. One prey can have lower energy content or there can be higher energetic cost with catching the alternative prey. Therefore, even if harbour porpoises are considered opportunistic predators, it may be not easy for them to switch prey. This concept is shown a study performed by MacLeod et al. (2007) in the Scottish North Sea where a link was found between sandeel consumption and the likelihood of starvation on porpoises. The lack of sandeel in the diet of harbour porpoises for lower sandeel availability in spring coincides with the high proportion of porpoises starving. The high number of stranded animals increased after spring may be due to the fact that the juveniles were weaned during spring and later on they start to be independent and as inexperienced predators they may have more difficulties to face this lower prey availability (MacLeod et al.,2007). Also in the Eastern Scheldt it is possible that through lack of food availability harbour porpoises, especially juveniles, have problems to find food, to satisfy their daily energy needs or to switch prey.

The hypothesis of a decreased fish stock in the Eastern Scheldt as shown by quantitative data given by the Demersal Fish Survey (DFS), is strengthened by qualitative data gathered by interviewing and contacting people working and fishing in the area. The number of commercial and recreational fishermen decreased year by year for two reasons: first, the categorisation of the entire Eastern Scheldt area as Natural Park and the annexation of the ecological network of protected areas Natura 2000, which introduced more restriction in fishing activity. Second, the dramatic decrease of fish stock, which caused substantial diminution of fishermen in the area. All the five people interviewed mentioned the increased discontent for the poor catch over the last years in the Eastern Scheldt waters.

The common hypothesis about the reasons of this abnormal decrease of fish mentioned during interviews were, as written before, the construction of the two barriers Oesterdam and Philipsdam, and the massively increase of introduced Japanese oysters in the area [9].

"I remember when I was a child I was used to go with my father to collect some sea snails, "alikruiken", in Dutch. But now I cannot go with my grandchildren because there are a lot of Japanese oysters, the ground is too sharp and it even cut the boots of the grandchildren" (cit. fish seller)

This second phenomenon is mentioned by the research carried out by Smaal et al. (2013) in the Eastern Scheldt estuary in 2012. The Eastern Scheldt primary production has decreased by 50% in the last 15 years; overgrazing by this invasive species without predators is causing a break into the balance of short-term bottom up control of primary production, and the decline of phytoplankton is larger than the benefit through increase in nutrients. This phenomenon causes a decrease in the carrying capacity of the entire estuary (Smaal et al., 2013). In 1964 Japanese oysters were introduced by oyster farmers in the Eastern Scheldt waters for aquaculture purposes; due to severe winters the existing culture of flat oysters *Ostrea edulis* suffered from a mass mortality, and in order to maintain the culture activities, Pacific oysters were introduced in the estuary. From 1976 they started to spread throughout the Eastern Scheldt expanding from 0 ha in

1975 to 775 ha in 2005 (Smaal et al., 2009), continuing increasing in number till present days. The overgrazing by Japanese oysters limits the presence of phytoplankton and might influence the phytoplankton availability for fish larvae, resulting in a lowering of the amount of fish. In addition to this phenomenon, the nutrient concentrations have decreased a lot since the construction in 1987 in the eastern part of the Eastern Scheldt; i.e. these barriers decreased the freshwater input rich in nutrients into the bay also resulting in a lowering of the primary production (Smaal et al., 2013).

In conclusion, data about biomass and number of fish in the area and personal communications by experts of the Eastern Scheldt waters proved that fish stock is lowered in the whole estuary. For this reason it is possible that harbour porpoises have troubles to find enough food for surviving and the rate of individuals which are dying for starvation increased. The main hypothesis of this alarming decrease of fish in the Eastern Scheldt bay is the influence of human intervention as the introduction of new species Japanese oysters and construction of large scale coastal engineering.

4.2 Is there competition with seals?

Harbour porpoises coexist with other predators in the Eastern Scheldt waters which are Harbour seals *Phoca vitulina* and grey seals *Halichoerus grypus*. But is it a peaceful and no conflicting cohabitation or do they compete for having the best meal?

In a study of Spitz et al. (2006), competition is described as "the negative effects which one organism has upon another by consuming, or controlling the access, to a resource that is limited in availability". There are two types of competition: exploitative competition, when the species that is competing has no direct interactions but the consumption of one species influences or reduces prey availability of the others. And inference competition, when there is direct conflicts between the species competitors (Spitz, et al.2006).

The number of harbour seals was increasing from 2009 to 2012, reaching a peak in 2012 of around 692 individuals. Compared with the harbour porpoises population, the number is much higher. Harbour seals are opportunistic feeders just as harbour porpoises; in their diverse diet the same preys are included, which are Atlantic cod, gobies and whiting. Competition therefore is possible, especially in a situation of shortage of prey.

According to a previous study [10] and to interviewed fishermen, harbour porpoises mostly occur in the deepest part of the Eastern Scheldt, where more food is available. It is difficult to determine if seals occur at the same locations, because during aerial surveys seals are counted when they rest on the shore, and it is challenging to determine where they feed, as this activity requires diving under water.

Grey seals are less abundant then harbour seals, they reached a peak in 2010 with 84 individuals but later the number dropped to 43. The diet of grey seals varies depending on many factors; but in the main diet prey overlaps are found with the harbour porpoises diet, as cod is important for both predators. As already mentioned for harbour seals, grey seals may also compete with harbour porpoises for food. Grey seals are stronger and larger than porpoises, reaching 2.5-3 metres of length and they may be facilitated in a

potential competition for food. Even if only one prey is shared by two predators, intraspecific interaction can occur (Spitz, et al. 2006).

A recent discovery in the Strait of Dover, off the French coast in the eastern English Channel, showed that grey seals have been seen attacking (and maybe feeding on) harbour porpoises (Bouveroux, 2014). Even if in the Eastern Scheldt such events are not being registered, it might be a potential place for this kind of behaviour.

The Eastern Scheldt is a semi-enclosed estuary with limited space and resources, the possibility of interaction might be higher than in the open sea.

In conclusion, the existence of exploitative and inference competition between harbour porpoises and harbour and grey seals in the Eastern Scheldt estuary is not completely proven but it may be plausible, as the two predators show partial dietary overlap in a limited space.

4.3 Is there competition with fisheries?

Many marine mammals, including harbour porpoises, in common with humans operate on the top of the food chain. For this reason it is possible that competition occurs between fisheries and top predators such as harbour porpoises.

The entire overview of both recreational and commercial fishing activity in Eastern Scheldt waters has changed within the last 10 years. Main reasons are the official recognition of the estuary as a natural park and the decrease of fish stock and fish availability year by year. Based on personal communication by interviewees, nowadays only two boats are fishing in the estuary and the main catch does not seem to overlap with harbour porpoises diet. Concerning recreational fisheries, on average 5 boats are going out 3 times per week, while in the past 10 years there were around 100 boats. Looking at the main catch of recreational fisheries, whiting and Atlantic cod overlap with harbour porpoises diet.

Interaction between fisheries and marine mammal concerns usually not only food competition but disturbance of the natural environment of marine mammals by human fishing methods. Human disturbance involves sound pollution, bycatch in nets and incidents with propeller of ships. In the Eastern Scheldt, among the animals analysed by Veterinary centre, only one case of a probable bycatch was identified, meaning that the influence of bycatch in the Eastern Scheldt water is not as significant as it is in the Dutch coast [2].

It can be concluded that, even when there is an overlap in catch and harbour porpoises diet, the competition and interaction with the few fishermen in the Eastern Scheldt is minima and it does not significantly influence the high number of stranded animals in the last 3 years.

5 Conclusions and Recommendations

This research pointed toward the possible causes of starvation of the high number of harbour porpoises found stranded on the Eastern Scheldt shores since the last four years. The condition of the majority of the carcasses led to think of lack of prey availability as a possible scenario in the Eastern Scheldt waters. Data gathered from surveys performed by IMARES and from personal communication by interviewed experts of Eastern Scheldt waters revealed a fluctuating decrease in fish number as well as biomass in the period 2000, till reaching very low values in 2012. This phenomenon is translated in a shortage of food for harbour porpoises resident in the estuary. The lack of the main prey (sand goby, Atlantic and poor cod, herring and whiting) of these animals led some of them to die for starvation, especially juveniles, weaker and less experts in hunting food. The year 2011, when the largest number of individuals was spotted, because of excellent weather condition during counting survey, is thought to be a realistic estimate of number of harbour porpoises present in the area. But at the same time it was the year with the highest number of animals found stranded on the shore.

Shortage of food may also be incremented with the competition for several preys with harbour and grey seals, the others top predators inhabiting of Eastern Scheldt waters. Harbour seals are much more numerous than harbour porpoises and they may influence the prey availability for harbour porpoises. Grey seals are less in number but larger in size and stronger, therefore they can have an higher potential competition for food.

In any area where human activities are present, interactions and influences of these activities on marine mammal's life are present. In the particular case of Eastern Scheldt, where human activities are reduced to minima, commercial and recreational fisheries do not seem to influence significantly the rate of high stranding of harbour porpoises.

This research showed the need to study more the reasons of the fish stock decrease and the possible connection with the decline of phytoplankton. Several questions should be answered in order to understand what are the underlying process behind this phenomenon that can bring changes in the biodiversity of the estuary and be detrimental for some species. Did the construction of barriers in the Eastern Scheldt change the inflow of nutrients causing a lowering of the primary production? What is the role of the Pacific oysters in this decline? What is its role in the food chain and how can it affect the further links of the food chain? Is the decline of fish stock a consequence? Is the estuary arrived to the maximum carrying capacity?

Furthermore, other studies should be done to clarify the competition between seals and harbour porpoises in the area, looking into overlaps in places, techniques and time of foraging of the species. In this study only types of prey which are commonly hunted by both predators were under analysis.

Jansen et al. (2013) proved with their study that harbour porpoises created in the last ten years a sub-population in the Eastern Scheldt, and the presence of calves in the estuary is evidence that it might be also a breeding area. There must also be a continuous influx from the North Sea into the estuary, especially around March and April when the highest density of porpoises is registered along the Dutch coasts (Jansen et al., 2013). The water passing through the shafts create noise which can disturb these animals that are so sensitive to any kind of underwater noise. It is therefore possible that harbour porpoises, moved into the estuary, cannot escape anymore being trapped inside the bay [2]. The storm surge barrier influences the residency of harbour porpoises in the area and is an obstacle for the individuals which have trouble to find prey inside the estuary, increasing the possibility of starvation. Therefore, the presence of the barrier is

a probable cause of high mortality by starvation, and it can be investigated by further research.

In conclusion, more research should be done in order to understand what is happening in the food chain of the Eastern Scheldt waters, which is causing the change in the entire estuary and leading the recent settled down harbour porpoise population in an endangered position. And what is the real role of the artificial coastal protection structures on that, changing the nutrients concentration? How do the massive presence of Japanese oysters might be correlated with decrease of fish stock and how can this problem of uncontrolled growth be faced? The presence of harbour porpoises in this Natural Park is a substantial attraction for inhabitants and tourists which can have opportunities to see these animals in the wild and it can stimulate more fascination for marine mammal species with the luckily effect of more acting contribution into the protection not only in the Eastern Scheldt but in all Dutch coastal waters.

References:

- Hohn A., David S. Rotstein,2 and Barbie L. Byrd1,2013. Unusual Mortality Events of Harbor Porpoise Strandings in North Carolina, 1997–2009. Journal of Marine BiologyVolume 2013, Article ID 289892, 13 pages

- Bijker E., 2002. The Oosterschelde Storm Surge Barrier: A Test Case for Dutch Water Technology, Management, and Politics Technology and Culture, Volume 43, Number 3, July 2002, pp. 569-584

- Bjorge A, Tolley KA (2009) Harbour porpoise – *Phocoena phocoena*. In: Encyclopedia of marine mammals 2nd Ed. (Perrin WF, Würsig B, Thewissen JGM, eds.) Academic Press, Amsterdam, pp. 530-533.

- Boois, I.J de, en M. van Asch. 2013. DFS visgegevens Oosterschelde: IMARES Rapport C188?13

- Bouveroux T, 2014. Direct evidence for gray seal (*Halichoerus grypus*) predation and scavenging on harbor porpoises (*Phocoena phocoena*). Marine mammal science. DOI: 10.1111/mms.12111

- Camphuysen C.J. & M.L. Siemensma. 2011. Conservation plan for the Harbour Porpoise *Phocoena phocoena* in The Netherlands: towards a favourable conservation status. NIOZ Report 2011-07, Royal Netherlands Institute for Sea Research, Texel.

- Feldhamer G.A, Bruce C. Thompson, Joseph A. Chapman JHU Press, 2003. Wild mammals of North America: biology,management, conservation. pp 397

- Geelhoed C.V., Meike Scheidat, S.A. van Bemmelen1 & Aarts, 2013. Abundance of harbour porpoises (*Phocoena phocoena*)on the Dutch Continental Shelf aerial surveys in July 2010-March 2011. Lutra 2013, 56 (1): 45-57

- Jansen, O. E. (2013). Fishing for food: feeding ecology of harbour porpoises Phocoena phocoena and white-beaked dolphins Lagenorhynchus albirostris in Dutch waters, publisher not identified.

- Jefferson TA, Leatherwood S, Webber MA,1993. FAO Species identification guide. Marine mammals of the world. UNEP/FAO, Rome, 320 pp.

- Kastelein R.A et al., 1997. Food consumption and body weight of harbour porpoises (*Phocoena phocoena*). The biology of the harbour porpoises. The Netherlands, pp. 217-233

- Koschinski S, 2001. Current knowledge on harbour porpoises (Phocoena phocoena) in the Baltic Sea. Ophelia 55(3): 167-197.

- Korpelshoek LD, 2011. Resident harbour porpoises *Phocoena phocoena* in the Oosterschelde (Netherlands): their behaviuor compared to the behaviour of migratory harbour porpoises in the southern North Sea. Leiden University and Rugvin Foundation. Msc. Thesis (not published)

- Leopold M.and C.J. Camphuysen. 2006. Bruinvisstrandingen in Nederland in 2006: achtergronden, leeftijdsverdeling, sexratio, voedselkeuze en mogelijke oorzaken. IMARES: C083/06, NIOZ: 2006-5. Pages 1-136.

- Prime J.H, Hammond P.S, 1990. The diet of grey seals from the south-western North Sea assessed from analyses of hard part found in faeces. Journal of Applied Ecology 1990 Vol. 27 No. 2 pp. 435-447

- MacLeod C.D et all., 2007. Linking sandeel consumption and the likelihood of starvation in harbour porpoises in the Scottish North Sea: could climate change mean more starving porpoises? Biology Letters.

- Mees, J & Reijnders P.J.H., 1994. The harbour seal, *Phoca vitulina,* in the Oosterschelde: decline and possibilities for recovery. Hydrobiologia 282/283: pp 547-555.

- Yasui W.Y. & D.E. Gaskin, 1986. Energy budget of a small Cetacean, the harbour Porpoise, *Phocoena Phocoena* (L.) Department of Zoology , University of Guelph, Guelph, Ontario, OPHELIA, 25(3): 183-197

- Reijnders P.J.H., S.M.J.M. Brasseur, T. Borchardt, K. Camphuysen, R. Czeck, A. Gilles, L. Fast Jensen, M. Leopold, K. Lucke, S. Ramdohr, M. Scheidat, U. Siebert, and J. Teilmann. 2009. Marine Mammals. Thematic Report 20 in H. Marencic, and J. de Vlas (eds.), Quality Status Report 2009. Wadden Sea Secretariat, Wilhelmshaven.

- Smaal A.C et all., 2013. Decrease of the carrying capacity of the Oosterschelde estuary (SW Delta, NL) forbivalve filter feeders due to overgrazing? Aquaculture 404-405, 28-34

- Smaal et all.,2009. Introduction, establishment and expansion of the Pacific oyster *Crassostrea gigas* in the Oosterschelde (SW Netherlands). Helgol Mar Res(2009) 63: 75-83

- Spitz, J., Rousseau, Y., Ridoux, V., 2006. Diet overlap between harbour porpoise and bottlenose dolphin: An argument in favour of interference competition for food? Estuarine, Coastal and Shelf Science. Volume 70, Issues 1–2, October 2006, Pages 259–270.

Websites:

[1]: http://www.nationaalpark.org/docs/200512201509594763.pdf , accessed 25/02/2014
[2]: http://ruqvin.nl/, accessed 19/02/2014
[3]: http://www.nmfs.noaa.gov/pr/health/mmume/criteria.htm, accessed 17/02/2014
[4]: http://www.spc.noaa.gov/faq/tornado/beaufort.html, accessed 25/02/2014
[5]: http://www.sportvisserijzwn.nl/ , accessed 25/04/2014
[6]: http://www.deltamilieu.nl/delta/rapporten , accessed 13/05/2014
[7]: http://www.sambah.org/Docs/General/Doktoranduppsats-Ida-Carlen-FINAL.pdf, accessed 14/05/2014
[8]: http://www.fao.org/fishery/species/3022/en, accessed 14/05/2014
[9]: http://www.sportvisserijzwn.nl/zout/delta-tij/delta-tij.html dossier pp.12, accessed 14/05/2014
[10]: http://ruqvin.nl/wp-content/uploads/2012/02/Bruinvisstudie.pdf, accessed 15/04/2014