THE ROLE OF THE JAPANESE OYSTER (*CRASSOSTREA GIGAS*) IN THE MORTALITY OF HARBOUR PORPOISES (*PHOCOENA PHOCOENA*) IN THE EASTERN SCHELDT

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(*img*. EHBZ Zuidwest, 2010)

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The role of the Japanese oyster (*Crassostrea gigas*) in the mortality among harbour porpoises (*Phocoena phocoena*) in the Eastern Scheldt

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12 May 2015

Acknowledgement

I would like to thank everyone I had contact with for helping me with my research, especially the following people. Adrie Hottinga for introducing me to Rugvin in the first place and for lending me maps and books. My supervisors Frank Zanderink from Rugvin and Patrick Bron from Van Hall Larenstein for overall help and explanation. Nynke Osinga from Rugvin for explanation about coordinates and stranded Harbour Porpoises. Jacco Kromkamp from NIOZ for providing me with information and a lot of patient explanation about water temperatures and phytoplankton in the Eastern Scheldt. Karin Troost, Pauline Kamermans and Emiel Brummelhuis from IMARES for providing me information about the Japanese Oyster in the Eastern Scheldt. Jaap van der Hiele from A seal Zeeland for providing me with information about numbers of stranded Harbour Porpoises, and his patience in doing so. Margherita Zorgno for helping me figure out issues and differences in stranded porpoise data.

I am happily surprised how willing to help everyone was!

Larissa Wagenaar,

Wapenveld, 25 February 2015.

Summary

A report, made by M. Zorgno (2014), shows that it could be possible that the Japanese oyster (*Crassostrea gigas*) is a main cause of the high mortality among harbour porpoises (*Phocoena phocoena*) in the Eastern Scheldt which has been occurring in the last decade. The high abundancy and rapid expansion of these bivalves after being introduced in the Eastern Scheldt and possible competition for food with prey species of the harbour porpoise make this presumable. The main question of this research is: How big is the role of the Japanese oyster (*Crassostrea gigas*) in the high mortality of harbour porpoises (*Phocoena phocoena*) caused by starvation in the Eastern Scheldt? The Japanese oyster does well in the conditions of the water of the Eastern Scheldt and could therefor spread rapidly. A "Spearman's rho Correlation test" was conducted for the variables hectares of Japanese oysters and number of stranded harbour porpoises showed that there is no correlation between the variables, possibly due to a low n-value. However the developmental stages of the Japanese oyster has similar food sources, namely phytoplankton, as larval developmental stages of Atlantic cod (*Gadus morhua*), poor cod (*Trisopterus minutus*) and whiting (*Merlangius merlangus*) and the same food source as the adult stage of the sand goby (*Pomatoschistus minutus*) and of all developmental stages of the herring (*Harengus*) which are the main prey species of the harbour porpoise in the Eastern Scheldt. This could result into competition for food. Japanese oysters can also filtrate larvae and eggs of other bivalve species and it was there for thought that this might also be possible with the larvae and eggs of the porpoise-prey species, however this is not the case because the eggs and larvae they filtrate range from 0,07 to 0,2 millimetres while all the eggs and larvae are bigger than this. When only the food intake of the Japanese oyster is taken in account it seems that there would be enough phytoplankton available. However, when all the dominant bivalve species and their food intake are taken in account there could possibly be overgrazing and thus competition and shortage of phytoplankton. This could result in lesser conditions of the prey species of the harbour porpoise or even lower abundancies. This could cause a shortage in food for the harbour porpoise and thus starvation, which is one of the main causes of death in the examined stranded porpoises from the Eastern Scheldt. When overgrazing occurs, which is assumed, the Japanese oyster plays an important indirect role in this and therefor also in the stranding of harbour porpoises.

Samenvatting

Een verslag, gemaakt door M. Zorgno (2014), laat zien dat de Japanse oester (*Crassostrea gigas*) een mogelijke oorzaak is voor de hoge mortaliteit onder bruinvissen (*Phocoena phocoena*) dat zich in het laatste deccenia in de Oosterschelde voordoet. Dit wordt gedacht door hun hoge voorkomen en snelle vermenigvuldiging nadat ze in de Oosterschelde zijn geïntroduceerd en de mogelijkheid voor voedselconcurrentie met de prooi soorten van de bruinvis. De hoofdvraag van dit onderzoek is: Hoe groot is de rol van de Japanse oester (*Crassostrea gigas*) in de hoge mortaliteit onder bruinvissen (*Phocoena phocoena*) door verhongering in de Oosterschelde? De Japanse oester doet het goed in de omstandigheden van het water van de Oosterschelde en kon zich daardoor snel vermenigvuldigen. Een "Spearman's rho Correlatie test" voor de variabelen hectare aan Japanse oesters en aantal gestrande bruinvissen wees uit dat er geen correlatie is tussen de variabelen, wat waarschijnlijk aan de lage n-waarde te wijten is. Er is echter wel overeenkomst in voedselbronnen, namelijk fytoplankton, tussen de levensstadia van de Japanse oester en de larven van de kabeljauw (*Gadus morhua*), de dwergbolk (*Trisopterus minutus*) en de wijting (*Merlangius merlangus*), het volwassen stadia van dikkopjes (*Pomatoschistus minutus*) en alle levensstadia van haring (*Harengus*), wat de hoofd prooien zijn van de bruinvis in de Oosterschelde. Dit kan resulteren in voedselconcurrentie. Japanse oesters kunnen naast fytoplankton ook larven en eieren van andere tweekleppige uit het water filteren, het zou kunnen dat ze misschien ook larven en eieren van prooi soorten van de bruinvis zouden filteren, maar dit is niet het geval. De grote van de larven en eieren die uit het water gefilterd worden rijkt namelijk van 0,07 tot 0,2 millimeter en alle larven en eieren van de bruinvis-prooi soorten zijn groter dan dit. Het lijkt of er genoeg fytoplankton aanwezig is wanneer alleen gekeken wordt naar de voedsel opname van de Japanse oester, maar wanneer er naar alle veel voorkomende tweekleppige wordt gekeken zou er mogelijk overbegrazing plaatsvinden. Dit zou inhouden dat er concurrentie en een tekort is aan fytoplankton. Dit kan resulteren in verminderde conditie van prooi soorten van de bruinvis of zelfs lagere voorkomens wat weer kan leiden tot een tekort aan voedsel voor bruinvissen en dus verhongering. Wanneer er daadwerkelijk sprake is van overbegrazing zoals vermoed wordt, zal de Japanse oester hier een grote rol in spelen, en daardoor ook in de mortaliteit van bruinvissen.

Contents

Chapter 1: Introduction

In a report done in 2013 the possible causes of the high mortality (mainly caused by starvation), of the harbour porpoises (Image 1.) (*Phocoena phocoena*) in the Eastern Scheldt were researched. This report, made by M. Zorgno (2014), shows that it could be possible that the Japanese oyster (*Crassostrea gigas*) (Image 2.) is an indirect cause of the high mortality of harbour porpoises.

Image 1. Harbour porpoise (*Phocoena phocoena*)
(*img*. Rugvin, 2014)

Image 2. Japanese oyster (*Crassostrea gigas*)
(Own photo)

In 1986 a storm surge was built in the Eastern Scheldt to protect the land against floods. This resulted the Eastern Scheldt, which first was openly connected, to be mostly closed off from the North Sea. In 2008 the organisation Rugvin in cooperation with Wereld Natuur Fonds Nederland decided to focus not only on the North Sea but also on the Eastern Scheldt because there was an unknown number of harbour porpoises living here. (Rugvin, 2014[3]) This raised questions, therefore the first counting took place in the Eastern Scheldt in 2009 to determine the number of harbour porpoises. (Rugvin, 2014[2]) Furthermore C-pods, which measure echolocation sounds, were placed in the Eastern Scheldt in 2009 to examine if the harbour porpoises leave the area through the barrier. (Rugvin, 2014[1]) This research showed that they rarely leave the Eastern Scheldt through the storm surge barrier. The counting is done annually and had a peak in 2011 of at least 61 individuals. However the number decreased again after 2011. The number or stranded Porpoises increased after 2009 with a peak in 2011 of 70 animals. Analyses of the carcasses show that the most common cause of death is starvation. The number of Japanese oyster increases strongly in the Eastern Scheldt and because of that it could be a possible cause of the high mortality of Porpoises. The Japanese oyster is an exotic species in the Netherlands and came here in 1964 after they were first introduced by oyster farmers because most of the Flat oyster (*Ostrea edulis*) that were first farmed by them died in the winter. After 1976 they began to disseminate throughout the whole Eastern Scheldt. They could possibly be a cause of the high mortality of harbour porpoises because they feed on phytoplankton and because of their abundancy. This could result in competition for food between them and preys of the harbour porpoise, and thus a decrease of fish as mentioned in the research report of Zorgno (2014). This could lead to starvation of Porpoises when there is a lack of food. (Zorgno, 2014) (F. Zanderink, personal communication, 1 September 2014)

The aim of this research is to find out if the Japanese oyster is a main (indirect) cause of the high mortality of the harbour porpoises. The main question is defined as followed: How big is the role of the Japanese oyster (*Crassostrea gigas*) in the high mortality of harbour porpoises (*Phocoena phocoena*) caused by starvation in the Eastern Scheldt? To find an answer to this question a literature study was done.

1.1 Problem definition

The number of stranded harbour porpoises in the Eastern Scheldt has increased as mentioned in the introduction, and could be called alarming in comparison to the number of Porpoises that have been counted. This could mean that the harbour porpoise in this area might disappear. Furthermore the harbour porpoise could possibly be seen as an indicator species for the whole area because it is on the top of the food chain. This may mean that the number of prey species of the harbour porpoise decreases and lower in the food chain the food of the prey species, because the high mortality of the harbour porpoises is mainly caused by starvation. The decrease could have an impact on the biodiversity in the Eastern Scheldt but also on the fishermen.

1.2 Research questions

The aim of this research is to determine if the Japanese oyster is a cause of the high mortality through starvation of the harbour porpoise in the Eastern Scheldt. If this is ruled out, research could be done to other possible causes. If it turns out that the Japanese oyster does play a big role in this, measures could be made by the organisations that are responsible for it to protect the harbour porpoise population in the Eastern Scheldt.

That is why the following main question has been drafted: How big is the role of the Japanese oyster (*Crassostrea gigas*) in the high mortality of harbour porpoises (*Phocoena phocoena*) caused by starvation in the Eastern Scheldt?

The sub-questions are:

- How can the increase of Japanese oysters in the Eastern Scheldt in the last years be explained?
- Do the various developmental stages of the Japanese oyster have similar food sources as the various developmental stages of prey species of the harbour porpoise?
- How big is the food intake of the Japanese oyster in the Eastern Scheldt?
- Is there a relationship between the hectares of Japanese oysters and the number of stranded harbour porpoises in the Eastern Scheldt?

Chapter 2: Methods

To find an answer to the main question a literature study was done. Other research reports have been used and several people were contacted for additional information and further explanation hereof.

For testing of the sub question: Is there a positive relationship between the number of Japanese oysters and the number of stranded harbour porpoises in the Eastern Scheldt, the Kolmogorov-Smirnov normality test was used to see if the two variables hectares of Japanese oysters and the number of stranded harbour porpoises are normally distributed. Furthermore the Spearman's rho Correlation test was used to find out if there is a correlation between the variables and thus a relationship. This was possible because both variables are ratio scaled. Both tests were conducted with a significance level of α=0,05.

Chapter 3: Results

3.1 Increase of Japanese oysters in the Eastern Scheldt

When the Japanese oyster was first introduced in the Eastern Scheldt it was thought that the water would be too cold for them to reproduce and spread. Even if the Japanese oyster would spread it would not turn out to be a problem because plans were made to close the Eastern Scheldt off from the North Sea which would make the water fresh or brackish without tide, which would make it impossible for the oysters to grow in this area. However, this never happened and the Japanese oyster did spread through the Eastern Scheldt rapidly to now exist of a population of about 780 hectares of oyster reefs. Figure 1 shows the increase of Japanese oysters in the last decades. The littoral reefs were measured for this, which is the zone between the high and low water line. Only the data of the littoral reefs has been used because the sublittoral data was not available for all years. (Troost, 2010)

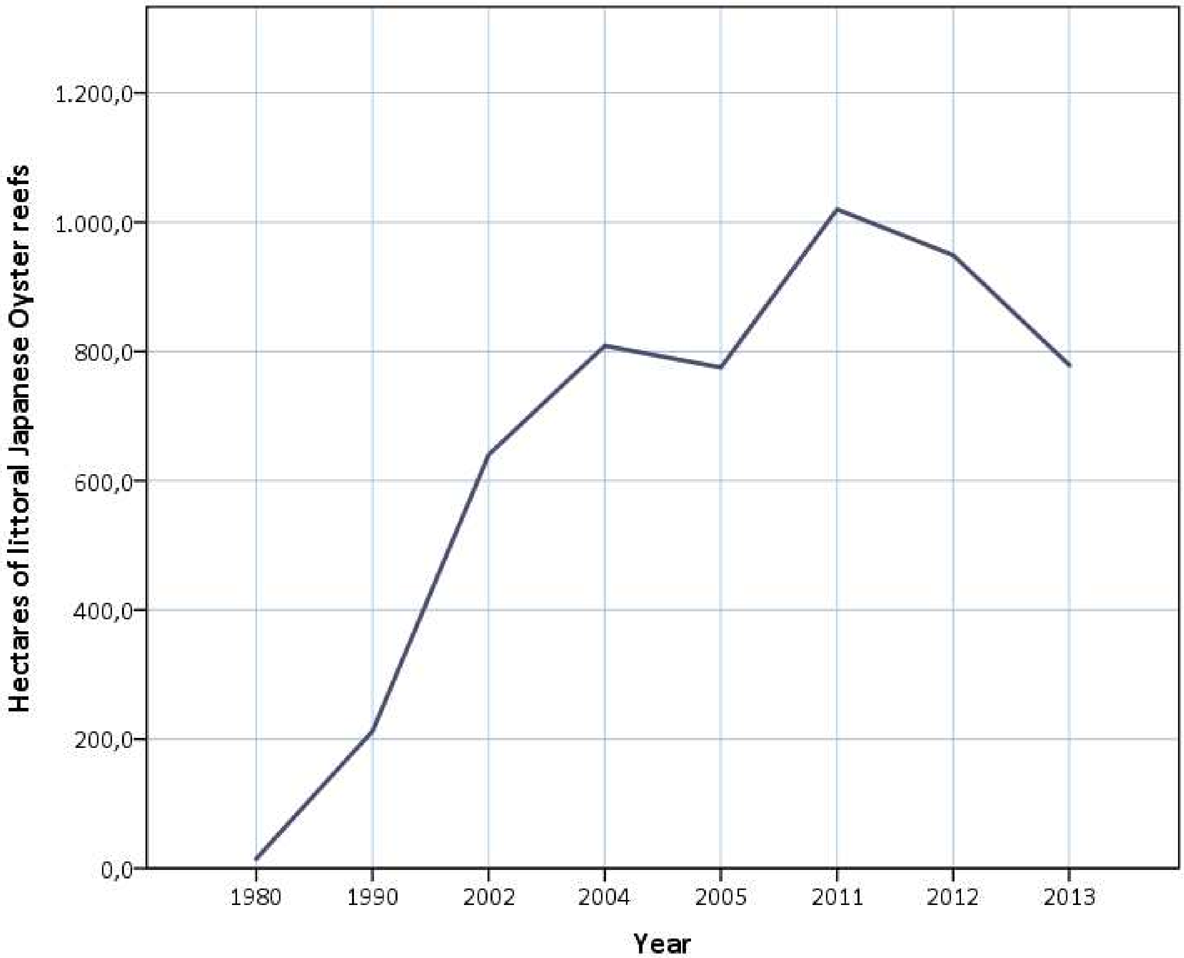

Figure 1. The Hectares of Japanese oysters reefs in the littoral zone of the Eastern Scheldt per year. Graph by L. Wagenaar. Information from: (Brummelhuis et al., 2011) (Brummelhuis et al., 2012) (Brummelhuis et al., 2013) (Smaal et al., 2005) (Smaal et al., 2008)

The species reproduces in July and August from temperatures of 16 degrees Celsius and higher with an optimum temperature between 20 and 25 degrees Celsius. A water temperature of -5 degrees Celsius and lower is deadly for the Japanese oyster and for juveniles, whom occur from July till around December, temperatures of 3 degrees Celsius and lower are deadly. (Troost, 2010) The lowest water temperature recorded by Dr J. Kromkamp in the Eastern Scheldt from January 2002 till December 2013 is 0,07 degrees Celsius on 13 January 2010 (Kromkamp, 2015). The lowest water temperature recorded from July to December (from January 2002 till December 2013) when juveniles occur is 2,06 degrees Celsius on 15 December 2010 (Kromkamp, 2015), however the next following lowest water temperature recorded is 3,22 degrees Celsius on 16 December 2002 (Kromkamp, 2015). Therefore temperature is not a limiting factor in the spreading of Japanese oysters as was first thought.

The oysters themselves create a hard substrate for new oysters to grow on, and so by growth of the population it stimulates the growth of new oysters and thus further growth of the population. Furthermore the Japanese oyster has very few natural enemies in the Eastern Scheldt. The oysters that mostly become prey are loose ones, oyster reefs usually remain untouched by predators. (Dankers *et al.*, 2006)

3.2 Similarity in food sources between various developmental stages

To see if the Japanese oyster is a cause of the high mortality of harbour porpoises the competition for food between the Japanese oyster and the main prey species of the harbour porpoise in the Eastern Scheldt has been studied. This because the main cause of death of the stranded harbour porpoises is starvation. (Zorgno, 2014)

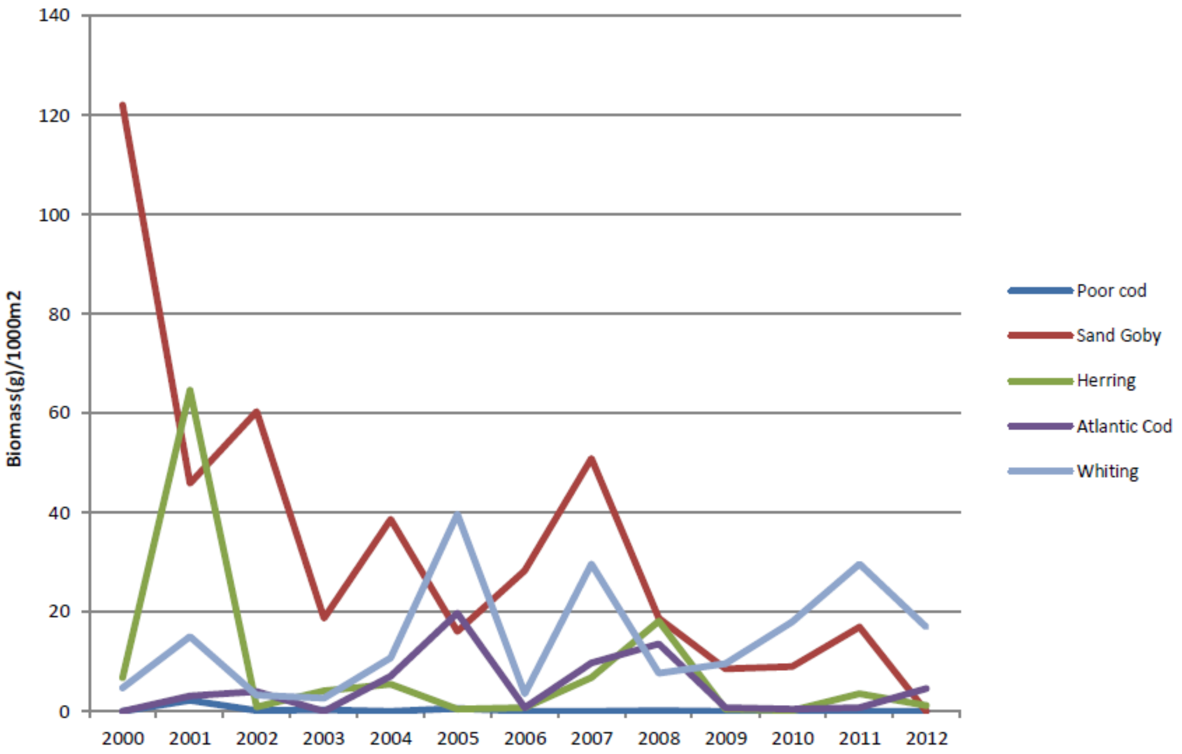

Figure 2. Grams of biomass per 1000 m^2 from 2002 till 2012 for poor cod, sand goby, herring, Atlantic cod and whiting in the Eastern Scheldt. Poor cod has a biomass close to 0 for all years, goby decrease in biomass from the year 2000, Atlantic cod and herring biomass varies through all years but appears to stay low from the year 2008 on and whiting does not show a decrease in biomass. (Zorgno, 2014) Graph from: (*fig.* Zorgno, 2014)

The main prey species of the population in the Eastern Scheldt were collected by analyses of stomach contents of stranded Porpoises done by M. Leopold & O. Jansen (Korpelshoek, 2011). The five main prey species of harbour porpoises according to the stomach analysis are: Atlantic cod (*Gadus morhua*), poor cod (*Trisopterus minutus*), whiting (*Merlangius merlangus*), sand goby (*Pomatoschistus minutus*) and herring (*Harengus*) (Zorgno, 2014). M. Zorgno (2014) shows that there is a decline in biomass of some of these porpoise-prey species as shown in figure 2.

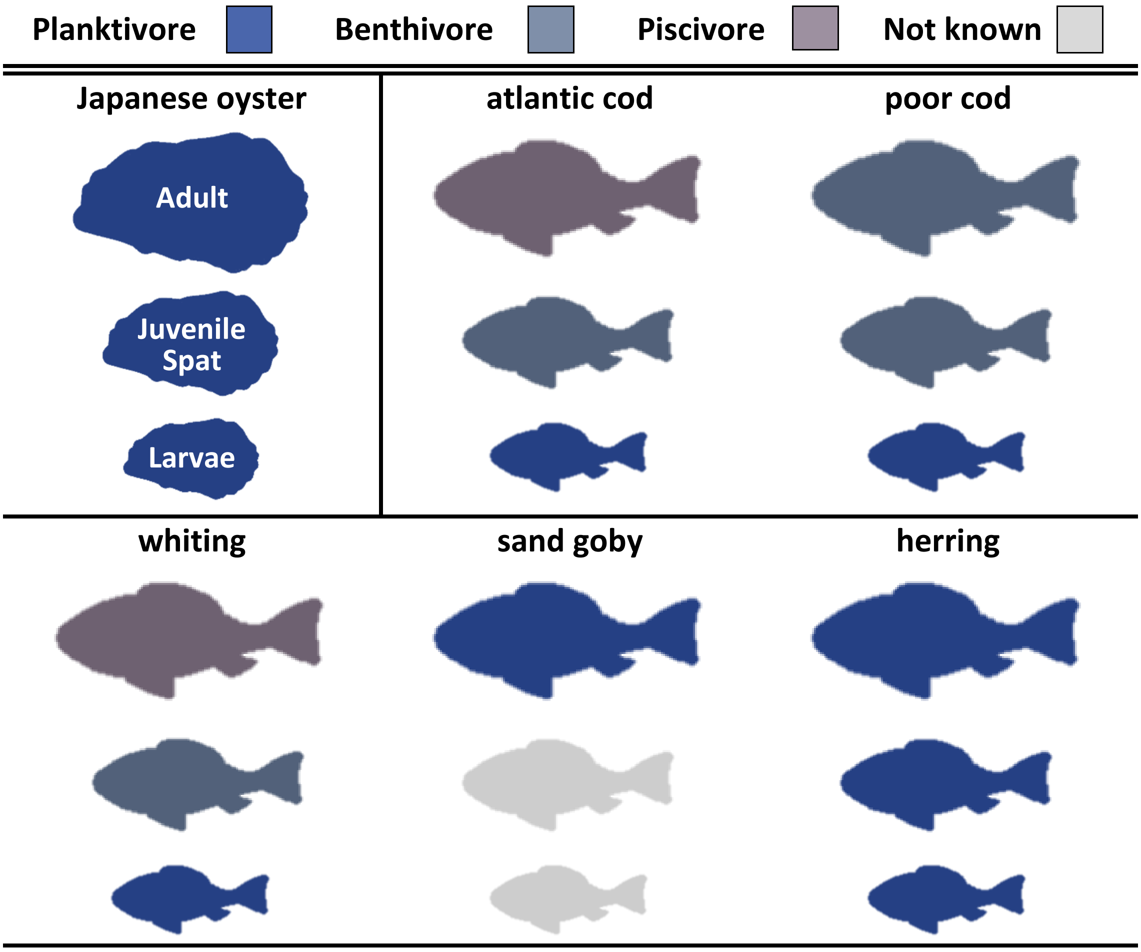

Figure 3. Comparason of the diet for the lifestages of Japanese oysters (*Crassostrea gigas*) and the main prey of harbour porpoises (*Phocoena phocoena*) in the Eastern Scheldt.
Figure by L. Wagenaar. Information from: (Boer, 1967) (Bos *et al.*, 2009) (Dankers *et al.*, 2006) (Hehir, 2003) (ICES, 2015) (Magnussen & Magnussen, 2009) (Nameless, 2009) (Pilling *et al.*, 2015) (Tangelder *et al.*, 2012) (Teal *et al.*, 2009) (Troost, 2010) (U. S. Department Of Commerce, 1999) (Vallisner *et al.*, 2006) (BIOTIC, 2015[1,2]) (Ecomare, 2015[1,2]) (Marine Species identification portal, 2015[1,2]) (The Scottish Government, 2010) (Waddenzee Vismonitor, 2015) (Zorgno, 2014)

To figure out whether there is competition for food between the Japanese oyster and these species the diet for all the developmental stages that depend on external food sources of all the organisms have been investigated. The diet of the developmental stages of the main prey species were compared to the diet of the developmental stages of the Japanese oyster. All the developmental stages of the Japanese oyster feed on plankton (Figure 3). As figure 3 Shows all the larvae of the main prey species of the harbour porpoise in the eastern Scheldt (of which information is available) feed on plankton as well. The same goes for adult and juvenile herring and adult sand goby's. To all those developmental stages the Japanese oyster is a possible competitor. To be a competitor the organisms should feed on the same size of plankton as the Japanese oyster. The Japanese oyster does not consume phytoplankton smaller than 3 micrometre, the upper limit in size of phytoplankton they can consume is not known (P. Kamermans, personal communication, 19 January 2015). According to P. Kamermans (personal communication, 19 January 2015) it is very likely that Japanese oysters are competitors to fish that consume phytoplankton. Fish larvae in general would feed on both phytoplankton and zooplankton. (Das *et al.*, 2012) Though the Japanese oyster mainly feeds on phytoplankton (Troost, 2010), it would also be possible that they filtrate small zooplankton. This because they also filtrate eggs and larvae according to K. Troost (2014) (see Appendix I).

Since the Japanese oyster filtrates eggs and larvae from other bivalve species according to K. Troost (2014) (see Appendix I), it could be possible that they filtrate fish larvae and eggs as well. However, the size of the eggs and larvae they filtrate range from about 0,07 to 0,2 millimetres (P. Kamermans, personal communication, 19 January 2015), whereas the eggs and larvae of the prey of the harbour porpoise range from 0,85 to 70 millimetres as seen in Figure 4. Therefor filtration of eggs and larvae from the main prey species of the harbour porpoise is not the case.

	Larvae	Eggs
Atlentic cod	< 70 mm	1,2-1.7 mm
Poor cod	2,3-17 mm	0,85-1 mm
Whiting	+/- 2,4 mm	1,0-1,3 mm
Sand Goby	< 18 mm	3-18 mm
Herring	8-50 mm	?

Figure 4. The sizes of larvea and eggs for the prey species of the harbour porpoise (*Phocoeana phocoena*) in the Eastern Scheldt.

Figure made by L. Wagenaar Information from:(Boer, 1967) (Bos et al., 2009) (Hehir, 2003) (ICES, 2015) (Magnussen & Magnussen, 2009) (Nameless, 2009) (Pilling et al., 2015) (Tangelder et al., 2012) (Teal et al., 2009) (U.S. Department Of Commerce, 1999) (Vallisner et al., 2006) (BIOTIC, 20151,2) (Ecomare, 20151,2) (Marine Species identification portal, 20151,2) (The Scottish Government, 2010) (Waddenzee Vismonitor, 2015) (Zorgno, 2014)

3.3 Impact of the food intake of Japanese oysters in the Eastern Scheldt

To find out what the food intake of the Japanese oyster in the Eastern Scheldt is and what its impact is it has been searched into what the amount of water that the organism filtrates is, what its clearance rate is and the period of time it takes the phytoplankton in the Eastern Scheldt to replace its own population, also called turnover time.

The Japanese oyster can filtrate 10 to 25 litres of water per hour (Dankers *et al.*, 2006) with a clearance rate of 2 to 10 litres per hour per gram dry tissue weight (P. Kamermans, personal communication, 19 January 2015). The total amount of water in the Eastern Scheldt is 2750.10^6 cubic meter or 2750.10^9 litre (Huisman & Luijendijk, 2009). The estimated number of Japanese oyster in the littoral area of the Eastern Scheldt in 2013 is 330.10^6 (Brummelhuis *et al.*, 2013). The littoral part contains most of the whole population (E.B.M. Brummelhuis, personal communication, 6 January 2015). With an average dry tissue weight (DTW) of 3,80 g (Troost *et al.*, 2009), this would make it an estimated population of 1254.10^6 gram DTW. This would mean that the estimated filtration speed is 9 to 46 days and thus that is how long it would take to clear the entire water column of the Eastern Scheldt. The turnover time of phytoplankton in the Eastern Scheldt ranges between 0,5 days in the summer and 9 days in the winter (J. Kromkamp, personal communication, 13 March 2015) (Kater, 2003). Therefore, when comparing phytoplankton turnover time to the mean filtration speed of the littoral oysters of 27 and a half day, it can be concluded that the clearance time of the littoral oysters is not high enough to remove all the phytoplankton. (See calculations in Appendix II)

Though, more bivalve species occur in the Eastern Scheldt, meaning that the grazing pressure is higher than estimated based on Japanese oyster grazing rates alone. An article by Smaal *et al*. (2013) takes the dominant bivalve species from the Eastern Scheldt, consisting of Japanese oysters (*Crassostrea gigas*), cockles (*Cerastoderma edule*) mussels (*Mytilus edulis*), and razor clams (*Ensis americanus*) in account. The article shows that the primary production has halved in period from 1995 till 2009 (Smaal *et al.*, 2013). This together with the increase of oysters would indicate that overgrazing is occurring in the Eastern Scheldt (Smaal *et al.*, 2013). The Japanese oyster is the dominant bivalve species in the Eastern Scheldt and have a high filtration capacity compared to other bivalve species and therefor most likely would play a big role in overgrazing. (Smaal *et al.*, 2013) Overgrazing would result in shortage in phytoplankton and competition not only between bivalve species but also the prey species of the harbour porpoise.

3.4 Relationship between Japanese oysters and stranded harbour porpoises

There is a possible relationship between the hectares of Japanese oysters and the number of stranded harbour porpoises because the Japanese oysters could cause competition in diet with prey of the harbour porpoise. Furthermore there has been an increase in numbers of stranded harbour porpoises as shown in figure 5, while there has also been an increase in Japanese oysters after 2009 as shown in figure 1 from chapter 3.1. A list with this information is shown in Appendix III for the years of which information of both variables was available. The estimated hectares of Japanese oysters have been obtained from three researches of IMARES on the Japanese oyster reefs in the Eastern Scheldt and the Waddenzee (Brummelhuis, 2011/2012/2013), an article by Smaal *et al.* (2008) about the introduction, establishment and expansion of the Japanese oyster in the Eastern Scheldt and a research on the manageability's of the Japanese oyster in the Eastern Scheldt by Smaal *et al.* (2005).

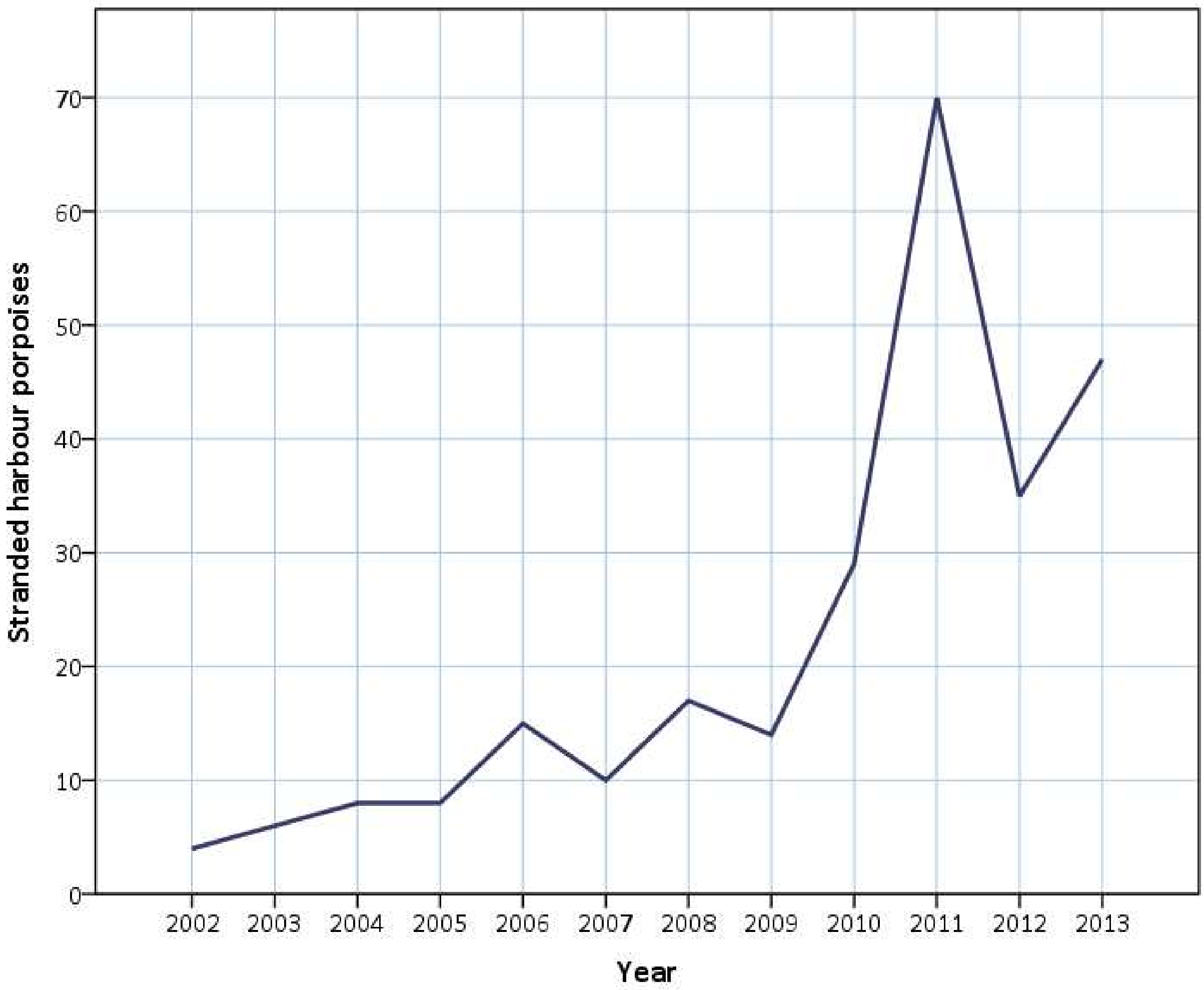

Figure 5. Number of stranded harbour porpoises per year in the Eastern Scheldt.
Graph by L. Wagenaar. Information from: (M. Zorgno, personal communication, 11 December 2014) (van der Hiele, 2015)

The number of stranded Porpoises for 2006 till 2013 has been obtained in personal communication with M. Zorgno (personal communication, 11 December 2014) and the additional number of stranded Porpoises for the years 2002 till 2005 have been obtained from personal communication with J. van der Hiele (van der Hiele, 2015). The numbers are an indication because it is possible that more harbour porpoises have stranded, but have not been recorded by J. van der Hiele.

To find out if there is a relationship between the hectares of Japanese oysters and the number of stranded harbour porpoises the following hypothesis has been formulated.

"There is a positive relationship between the hectares of Japanese oysters and the number of stranded harbour porpoises in the Eastern Scheldt."

To test this hypothesis a Spearman's rho correlation test was conducted with a significance level of α=0,05 (see Appendix III). The test showed that there is no correlation between the hectares of Japanese oysters and the number of stranded harbour porpoises, p=0,066. Figure 6 shows the distribution of the number of stranded harbour porpoises plotted against the hectares of Japanese oyster reefs in the Eastern Scheldt.

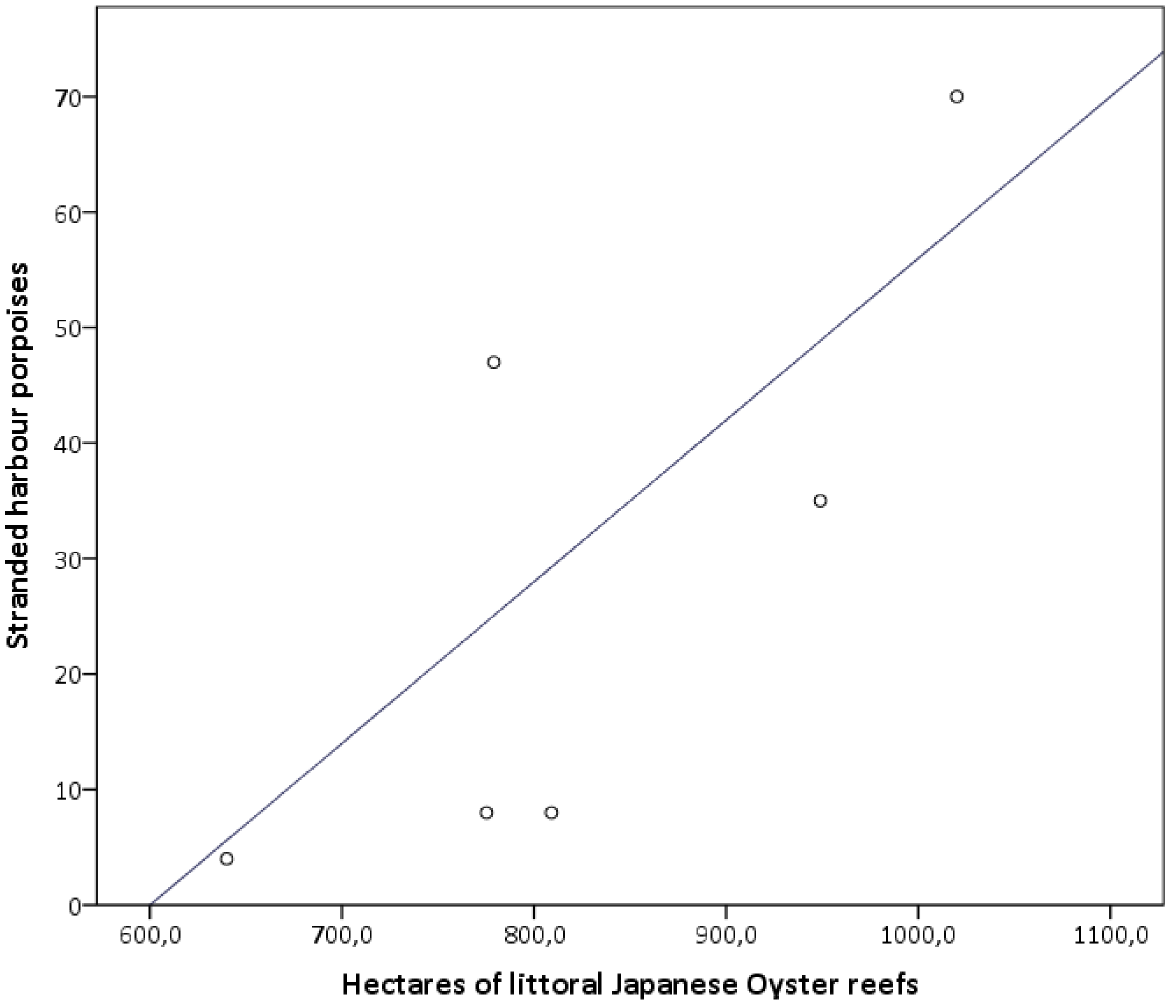

Figure 6. Regression line of the number of stranded harbour porpoises and the hectares of littoral Japanese oyster reefs in the Eastern Scheldt.

Graph by L. Wagenaar. Information from: (Brummelhuis et al., 2011) (Brummelhuis et al., 2012) (Brummelhuis et al., 2013) (M. Zorgno, personal communication, 11 December 2014) (van der Hiele, 2015)

Chapter 4: Discussion

For this research the numbers of hectares of Japanese oyster reefs are only of the littoral population, more oysters may occur in deeper parts of the Eastern Scheldt. Though the reefs in the littoral contain the biggest part of the population. Therefor this can be used as an indication for the whole population and its growth and would also represent the most of the populations food intake.

Furthermore no information could be found on the diet of the larval and juvenile developmental stages of the sand goby and the size of herring eggs. The diet for the adult sand goby and the other prey species are available, as are the egg and larval sizes of all the other species. Therefore, this most likely does not influence the final conclusion much.

This report is about the role of the Japanese oyster on the mortality of harbour porpoises, whereas more bivalve species occur in the Eastern Scheldt who also rely on phytoplankton for diet. The reason for this is that the Japanese oyster has expanded rapidly after being introduced in the Eastern Scheldt. When the other dominant bivalve species are taken in account as in chapter 3.3, it shows that competition would occur whereas there wouldn't be when only looked at the Japanese oyster. Nevertheless the Japanese oyster is the dominant species in this area and would therefore play a big role in the possible overgrazing.

There is only data from 8 different years available for the hectares of Japanese oysters in the Eastern Scheldt, and for the years 1980 and 1990 there is no data available of the number of stranded harbour porpoises. This results in a low n
value of 6. This low N value could have also influenced the outcome of the Spearman's rho Correlation test. The significance of the outcome of test ($p=0{,}066$) is only 0,016 higher than the significance level of $\alpha=0{,}05$ used for this test. Therefore it would be possible that a test with a higher N value would show a different outcome and that there might be a correlation between the hectares of Japanese oysters and the number of stranded harbour porpoises.

Chapter 5: Conclusion

The main question of this research is: How big is the role of the Japanese oyster (*Crassostrea gigas*) in the high mortality of harbour porpoises (*Phocoena phocoena*) caused by starvation in the Eastern Scheldt? Even though the Japanese oyster alone would not cause the overgrazing that might be occurring according to the signs mentioned in Smaal *et al*. (2013), all the dominant bivalve species together do. The Japanese oyster has a high filtration capacity and is the dominant species in the Eastern Scheldt, and therefor would play a big role in possible overgrazing. Overgrazing would result in shortage of phytoplankton and competition for phytoplankton and as shown in chapter 3.3 the prey species of the harbour porpoise have similar food sources for larval developmental stage and for herring for all developmental stages as the Japanese oyster. Competition could result into shortage of food for the prey species of the harbour porpoise and thus lesser conditions and even lower occurrence. This could lead to starvation of harbour porpoises, which is one of the main causes of death for the stranded Porpoises that have been examined. Though in the end overgrazing would not only affect harbour porpoises and its prey species but most of the organisms in this area because it is at the base of the food cycle. Therefore it could be assumed that the Japanese oyster plays an important role in the mortality of harbour porpoises in the Eastern Scheldt, however this is together with the other dominant bivalve species. Though this is not yet detectable, the Spearman's rho Correlation test showed no correlation between the number of stranded harbour porpoises and the hectares of Japanese oysters. It is assumable that this is due to the low n-value and that there might possibly be a relationship when a higher n-value is used. It cannot be said with certainty that the Japanese oyster is a main indirect cause of the mortality of harbour porpoises in the Eastern Scheldt. To be certain that there is a relationship or not further research should be done. This research should focus on collecting more data on the number of stranded harbour porpoises and the hectares of Japanese oysters in the Eastern Scheldt. Furthermore it is recommended to include grazing and clearance rates of all bivalves in the Eastern Scheldt to get a more realistic view of the grazing pressure on phytoplankton.

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Appendix

Appendix I: 3.2 Similarity in food sources between various developmental stages

Part of an email from K. Troost to L. Wagenaar (Troost, 2014)

"Bijgevoegd ook een ander artikel waar je mogelijk wat aan hebt. Troost 2010 is een verder uitgewerkte versie van het discussiehoofdstuk in mijn proefschrift. Mochten de vermeende effecten op bruinvissen te maken hebben met het filtreren van larven door oesters, zie dan ook de stukken die ik heb geschreven over filtratie van schelpdierlarven door oesters, mosselen en kokkels. In de Oosterschelde liggen ook veel mosselen op de kweekpercelen en ook deze mosselen filtreren larven."

Appendix II: 3.3 Impact of the food intake of Japanese oysters in the Eastern Scheldt

Calculation of the filtration speed of the Japanese oyster population in the Eastern Scheldt

<u>Fr= (Cr.Pweight).24hours</u>

Cr= Clearance rate of the Japanese oyster

Pweight= Population weight in grams Dry Tissue Weight (estimation)

Fr= Filtration rate in litres per day

$(2x1254.10^{6})$ x24= $6{,}0192.10^{10}$ L/day

$(10x1254.10^{6})$ x24= $3{,}0096.10^{11}$ L/day

<u>Fs= TotalW/Fr</u>

Fs= Filtration speed of Japanese oysters in the Eastern Scheldt in days

TotalW= Total amount of water in the Eastern Scheldt in litres

Fr= Filtration rate in litres per day

$2750.10^{9}/6{,}0192.10^{10}$= 46 days

$2750.10^{9}/3{,}0096.10^{11}$= 9 days

Appendix III: 3.4 Relationship between Japanese oysters and stranded harbour porpoises

Variables hectares of Japanese oysters and number of stranded harbour porpoises per year (with information available from both variables)

Year	Hectares of littoral Japanese oyster reefs	Number of stranded harbour porpoises
2002	640	4
2004	809	8
2005	775,2	8
2011	1020	70
2012	949	35
2013	779	47
(Brummelhuis *et al.*, 2011) (Brummelhuis *et al.*, 2012) (Brummelhuis *et al.*, 2013) (M. Zorgno, personal communication, 11 December 2014) (van der Hiele, 2015)		

Test of Normality: Kolmogorov-Smirnov for variable hectares of Japanese oysters

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
AcresOysterReefs	,224	6	,200*	,947	6	,714

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Test of Normality: Kolmogorov-Smirnov for variable number of stranded harbour porpoises

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
AcresOysterReefs	,224	6	,200*	,947	6	,714
NumberStrandedPorpoises	,281	6	,150	,877	6	,254

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Spearman's rho Correlation test for variables hectares of Japanese oysters and number of stranded harbour porpoises

Correlations

			AcresOysterReefs	NumberStrandedPorpoises
Spearman's rho	AcresOysterReefs	Correlation Coefficient	1,000	,783
		Sig. (2-tailed)	.	,066
		N	6	6
	NumberStrandedPorpoises	Correlation Coefficient	,783	1,000
		Sig. (2-tailed)	,066	.
		N	6	6