Impact of wind farms on porpoises

Study on the effect of the construction and presence of wind farms on the harbor porpoise population in the southern North Sea

Research report

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Study on the effect of the construction and presence of wind farms on the harbor porpoise population in the southern North Sea

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Summary

Construction of offshore farms with high wind turbines has increased due to the demand for renewable energy. Many more wind farms are being planned to be built in the near future, this growth of offshore wind farms raised concerns about their impact on their surroundings. Marine mammals use echolocation to find their food but also to communicate with others and navigate. Sound therefore plays an important role in the life of marine mammals. Assessing the effects of building noise is therefore crucial. The noise made by the offshore windfarm including, operational noise, shipping and construction of nearby wind turbines, are much greater than expected, even if pile driving is below the hearing threshold of porpoises. And that is a big concern for the future knowing that many more offshore wind farms are planned for construction. This study examined the potential effects of wind farms on harbor porpoises in the southern North Sea. The installation of foundations using impact pile driving has an impact on porpoises in an area several hundred kilometres around the construction site and are therefore possibly susceptible to negative effects of man-made noise generated from constructing and operating these large offshore wind turbines. The wind farms involved in this study are East Anglia, Galloper and Thorntobank. These are relatively close to the Stena Line shipping route where all porpoises have been observed by Stichting Rugvin from 2005 to 2019. During the study, both the distance from the wind farm, and the years of construction were considered to have an effect on the porpoise population. This study found that the general trend in number of porpoises has increased over the last years. both presence and distance from wind farm East Anglia have an effect on porpoises. Wind farms Galloper and Thorntobank were probably too far from the Stena Line route to draw any conclusions. However it is difficult to draw conclusions during this study because there are many factors involved and it is hard to include them all. Once a number of variables are examined that may have an effect on the harbor porpoise population, such as in this study the distance to the wind farm and the years of construction, all other conditions must be proven to have remained the same, only then will it be possible to conclude an effect of the distance and the years of construction.

1. Introduction

The North Sea is the habitat for the harbour porpoise (*Phocoena phocoena*), it is estimated that about half of all common porpoises in the world live in the North Sea (World Wildlife Fund, n.d.). It is suggested that these animals are negatively disturbed by noise pollution and loss of habitat by the offshore wind farms (Gilles et al. 2009). Porpoises use echolocation to find their food but also to communicate with each other and navigate. Sound therefore plays an important role in the life of porpoises. Assessing the effects of building noise is therefore crucial (University of Aarhus, 2018).

Ocean noise is a growing concern. Sound travels about 4.3 times faster underwater than in the air, this combined with relatively poor underwater visibility means that many marine animals use sound primarily for vital life functions. Most of the ocean noise pollution comes from the offshore industry in coastal areas, which are generally heavily influenced by human activities (Kaiser et al. n.d).

Offshore wind energy is a growing activity in Europe. These wind farms play a major role in making our energy system more sustainable (Milieu centraal, s.d.). The rapid increase in the development of offshore wind energy has led to concerns about the potential environmental impact of wind farms (Scheidat et al. 2011). A lot of underwater noise is generated during the construction of the wind farms. The resulting noise can cause problems (Attachment I). In several marine mammals and fish, this noise exceeds the hearing damage threshold (Hastie et al. 2015).

The harbour porpoise audiogram is U-shaped with the range of best hearing from 16 kHz to 140 kHz. Some individuals have a reduced sensitivity around 64 kHz. The maximum hearing range occurs between 100 kHz and 140 kHz (de Haan et al. 2005). During the construction of wind farms it usually takes several hours to drive one pile into the bottom. This activity creates high levels of sound pressure and acoustic particle motion that are transferred through the pile into the water and seabed. Noise is radiated from the pile itself, but it could also radiate back from the seabed into the water column (Andersson, 2011). Kastelein et al. (2015) showed that impulsive pile driving sounds with most of their energy in the low frequencies (500-800 HZ) can cause reduced hearing at higher frequencies in harbour porpoises.

Earlier research into the effects of wind farms on porpoises shows that it is mainly the construction of these farms that affects the porpoises. In particular, the installation of foundations using impact pile driving has an impact on porpoises in an area several hundred kilometres around the construction site (Carstensen et al. 2006). The pathological effect on the ears is difficult to determine, this can only be done on animals that have died and is very expensive. In any case, noise disturbance has major indirect consequences. They migrate to areas where the noise is less, this costs a lot of energy. And it is precisely with this energy management that porpoises are very busy. This is important because about 95% of the time porpoises are busy searching for food and hunting (Zanderink & Osinga, 2020).

Potential positive effects of offshore wind farms have also been discussed. After construction they can increase biodiversity and possibly also the biomass of prey species. This is due to the addition of hard substrates that replace the monotonous sandy soil (Petersen & Malm 2006). These positive effects could perhaps cause an increase in porpoises after construction (Attachment II). Fishing is often banned in wind farms, which could lead to less disturbance of the bottom fauna. In addition, the exclusion of shipping activities could play a role.

In the southern North Sea, Stichting Rugvin has been observing the route of the Stena Line ferries Hollandica and Britannica for 15 years (Stichting rugvin, 2020There are several wind farms close to the Stena Line ferry route, two on the coast of England and one on the coast of both Belgium and the

Netherlands, which may have an effect on the number of porpoise sighted on the survey route. It is important to find out whether the frequency of porpoises is affected by these 3 wind farms.). The observations are used in this study to find out whether there is a significant difference in the number of sightings of porpoises close to the construction locations of wind farms. During the study, both the distance from the wind farm, and the years of construction are considered to have an effect on the porpoise population.

2. Material and Method

2.1. Location

All observations of porpoises were taken from the Stena Hollandica and the Stena Britannica ferries. These are ferry crossings between Hook of Holland and Harwich in England (Figure 1). There are 3 wind farms close to this route two of which are on the coast of England and one on the coast of both Belgium and the Netherlands. The wind farms are represented in figure 1 by a red dot, this dot is the centre of the wind farm.

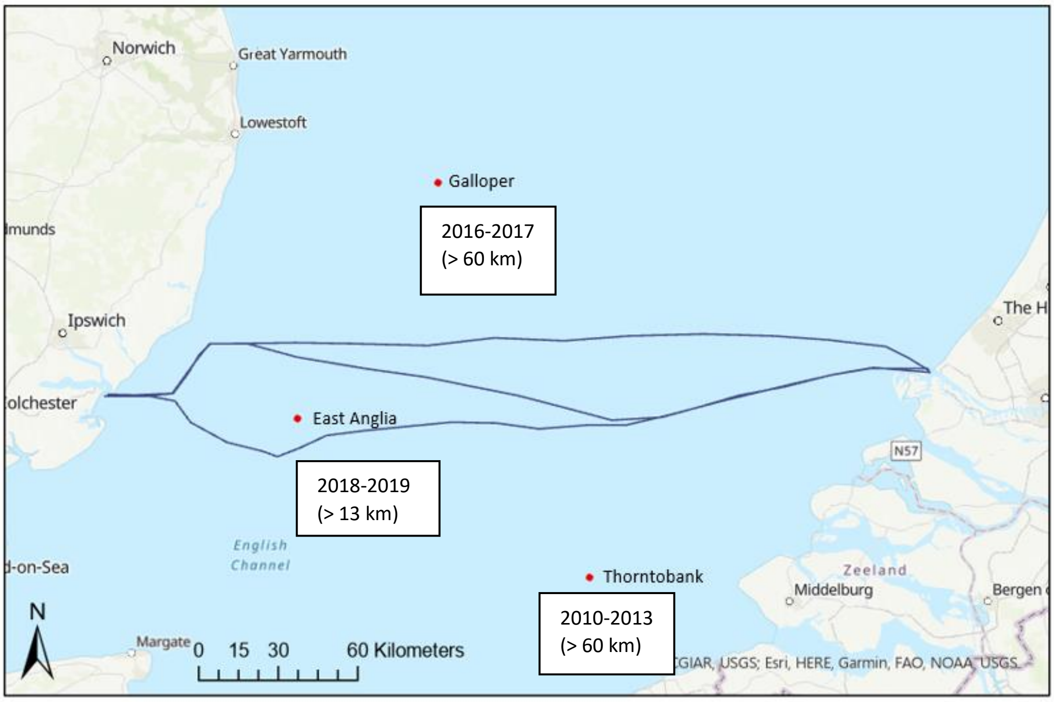

Figure 1: Stena Hollandica and Stena Britannica ferry routes and the three wind farm locations

East Anglia One wind farm is located in the southern part of the East Anglia Zone, about 43 km from the coast of Suffolk. The windfarm consists of 102 wind turbines, each with a capacity of 7 MW. The wind farm is 300 km2 in size and is shaped like a narrow upright rectangle. The construction of this wind farm on land started in 2017, the offshore construction started in June 2018, the first turbine was completed in June 2019. The offshore sub-station of the wind farm was installed in August 2018. The first power was generated in September 2019, the installation of all turbines was completed in April 2020. The commercial operations began in July 2020.

The second wind farm on the coast of England is Galloper. The windfarm is located 27 km off the coast of Suffolk and consists of 56 turbines with a total capacity of 353 MW. Construction of the Galloper wind farm began in late 2015 with onshore work and offshore construction began in the summer of 2016. The first power was generated by the wind farm in November 2017 and became fully operational in March 2018.

The wind farm on the coast of Belgium and the Netherlands is Thorntobank. The wind turbines are located on a sandbank, which rises about 25 meters above the surrounding channels and is about 20 km long. The sandbank runs parallel to the coast. Construction began in May 2007. The first 6 wind turbines were finished in 2008. In 2010, construction of 24 wind turbines started. In 2012, 54 wind turbines were added. In the final phase of construction, 24 more wind turbines were added. The wind farm was completed in July 2013.

2.2. Data collecting

Between 2005 and 2020, data was collected by Stichting Rugvin regarding the porpoise population in the Southern North Sea from within the Stena Line ferries. Two observers were present on the boat each time, one on the port side and one on the starboard side. Surveys were conducted on a monthly basis and each survey consisted of two days only during daylight. In some months surveys had to be cancelled due to continues bad weather conditions or due to ships not sailing because of maintenance. It has to be noted that during the first survey day (sailing from NL to UK), the hours of observation were limited by the hours of daylight in winter.

Whenever a porpoise was sighted it was noted, also the environmental conditions on board were noted every half hour. The latitude and longitude coordinates of the vessel, the sighting distance, the time, number and direction in which the porpoises were swimming. Also abiotic variables where noted, factors such as wind speed, wind direction, visibility, sea state, sea water temperature and swell height.

Sea state is a measurement of how disturbed the sea surface is, and is measured by wave size and behaviour. These are measured in whole numbers that can vary between 0 and 9. To optimise sighting conditions, the observers aimed at planning surveys at dates with lowest Sea State. Surveys were cancelled when sea state was predicted to be 6 Bft or more.

Swell height is the height difference of the waves between the two consecutive swells and the top of the next swell. There were 4 options here, absent, light (swell height <1m), moderate (swell height between 1-2m), heavy (swell height is greater than 2m).

To determine the direction in which the porpoises swim, several methods were used, polling by sighting and sighting distance. In the first method mentioned, this is the survey of the group of animals at the first sighting. This has been measured in degrees relative to North. The sighting distance is a measurement of the distance to the group of animals at the first sighting, this has been measured in meters.

2.3. Data analysis

To map the exact location of all porpoises, the X and Y coordinates were exported in a GIS map (Attachment III), In addition, the route of the Stena Line ferries were also mapped. These were then divided into boxes of 5 by 5 kilometres each. The number of porpoises observed in each box was then counted. The distance from each box to the three wind farms was then calculated.

The data had been compared from year to year to see how many porpoises were in these areas. This allows a distinction to be made between the number of porpoises during construction and during full operation of the parks.

To find out if there is a correlation between the frequency porpoise presence and the distance of the windmills, a *poisson regression test* has been performed through Jamovi 1.2.27. Multiple *lineair regression analyses* were also performed with interaction between distance and year.

H0: There is no correlation between the frequency of porpoises and the distance from the windmills.
H1: There is a correlation between the frequency of porpoises and the distance from the windmill

The hypothesis from attachment II has not been tested.

3. Results

3.1. Trend of porpoises

An increase in porpoises has been observed in porpoises between the years 2005 and 2019 (Figure 2).

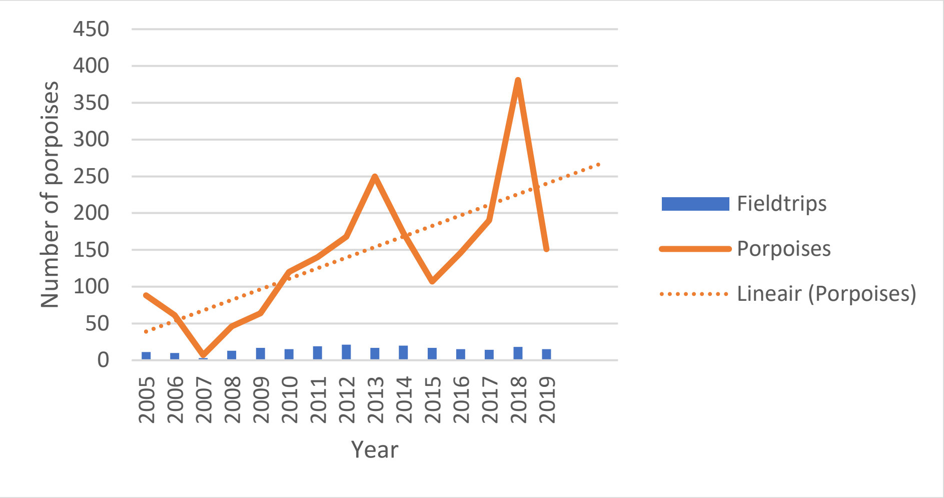

Figure 2: Sum of porpoises from 2005 to 2019 with sum of field visits per year

3.2. Distribution of porpoises

Aast Anglia and Galloper wind farms, scatter diagrams of porpoise abundance were made before and during construction. At Thorntobank wind farm, scatter diagrams were also made after construction.

3.2.1 Distribution of porpoises at East Anglia wind farm

The scatter plot of the years 2018 and 2019 shows that the number of porpoises increases with the distance from the wind farm. The trend lines of 2018 and 2019 increase linearly. The year 2019, shows a decrease in porpoises close to the park, under the range of 100 km (Figure 4). The scatter diagram of the years 2010 and 2011 is more evenly distributed and a slighter increase was observed (Figure 3). The linear regression test shows a significant effect of distance from the park and the years 2010 and 2011 (0.039 < 0.05). This is also the case for the years 2018 and 2019 (0.045 < 0.05) (Attachment IV).

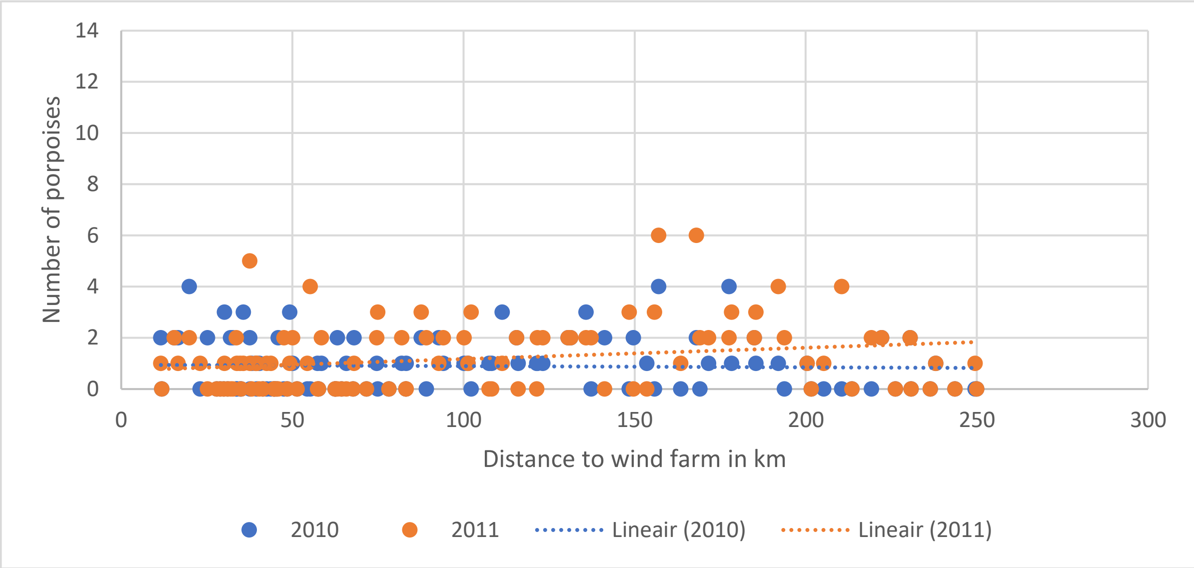

Figure 3: Porpoise scatter diagram before construction around East Anglia wind farm in 2010 and 2011

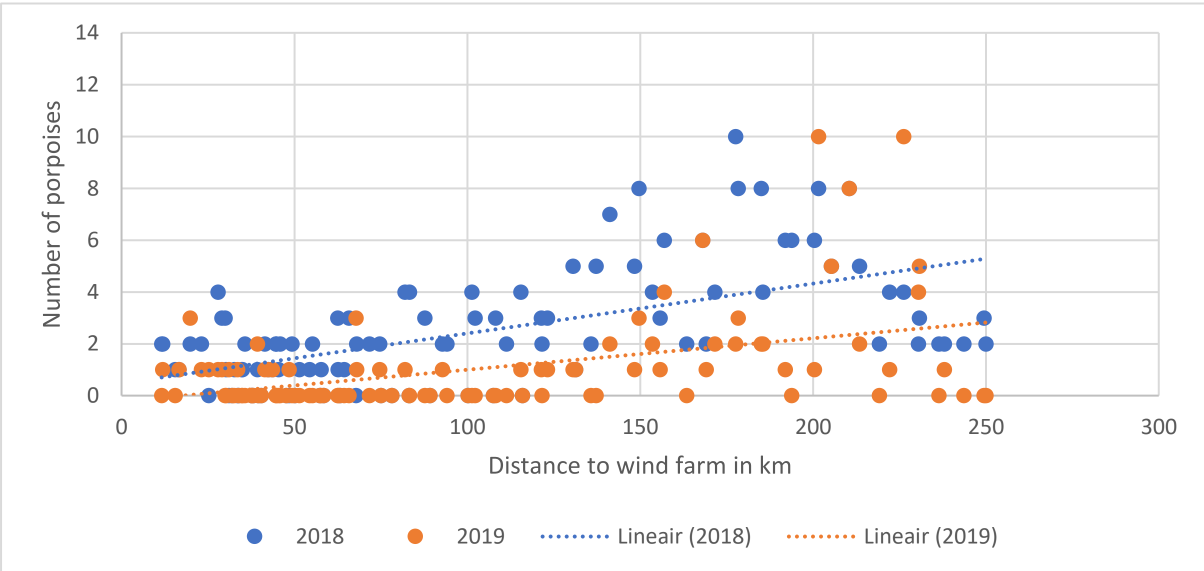

Figure 4: Sum of porpoises during the construction phase around East Anglia wind farm in 2018 and 2019

3.2.2. Distribution of porpoises around wind farm Galloper

The scatter diagram of wind farm Galloper shows an increase in porpoises further away from the farm in the year 2018. A slight increase was observed for the years 2016 and 2017 (Figure 6). No increasing trend was observed in the years 2010 and 2011, porpoises are more evenly distributed in these years (Figure 5). The linear regression test does not give a significant effect of distance from the park and the years 2010 and 2011 (0.382 < 0.05). This is also the case for the years 2016, 2017 and 2018 (0.514 > 0.05 & 0.079 > 0.05) (Attachment IV).

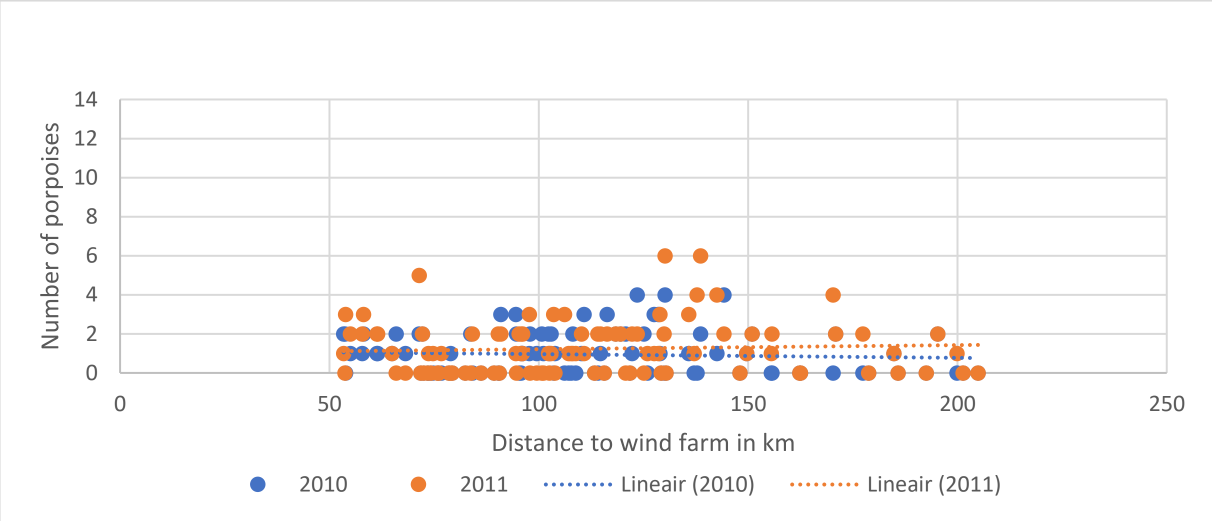

Figure 5: Scatter diagram of porpoises before construction around Galloper wind farm in 2010 and 2011

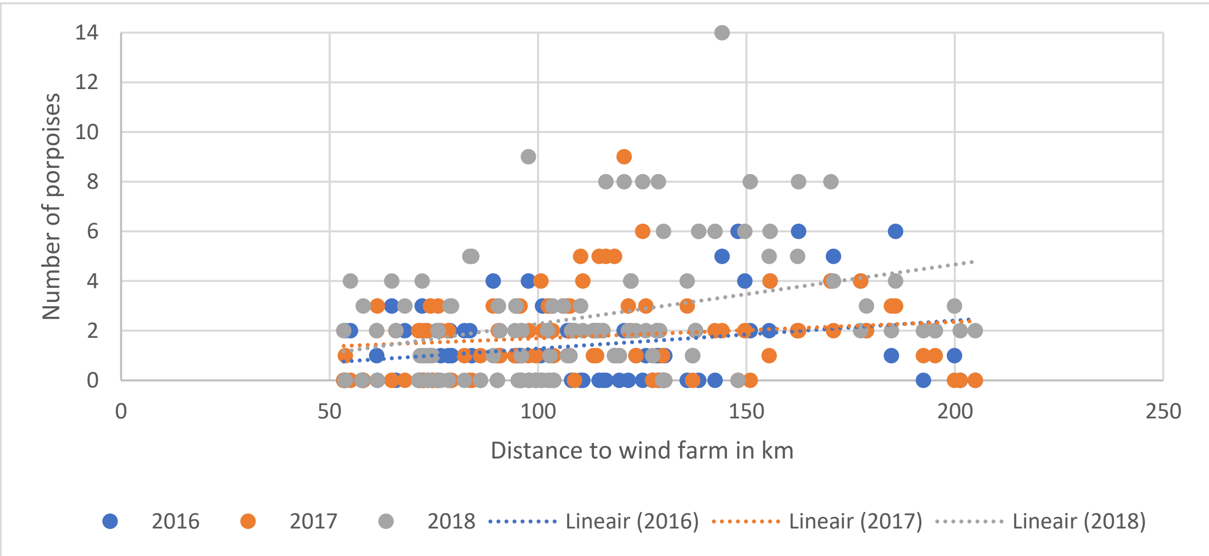

Figure 6: Scatter diagram of porpoises during the construction phase around Galloper Wind Farm in 2016, 2017 and 2018

3.2.3. Distribution of porpoises around wind farm Thorntobank

There is little to no difference between the distribution diagrams of 2005-2006, 2010-2011 and 2012, 2013 (Figures 7, 8 and 9). In the scatter diagram of 2018-2019, the distribution of the number of porpoises is much higher (Figure 10). The linear regression test gives no significant effect of distance from the park and the years 2005 and 2006 (0.403 > 0.05). This is also the case for the years 2010 and 2011 (0.557 > 0.05), 2012 and 2013 (0.132 > 0.05) and for the years 2018 and 2019 (0.096 > 0.05) (Attachment IV).

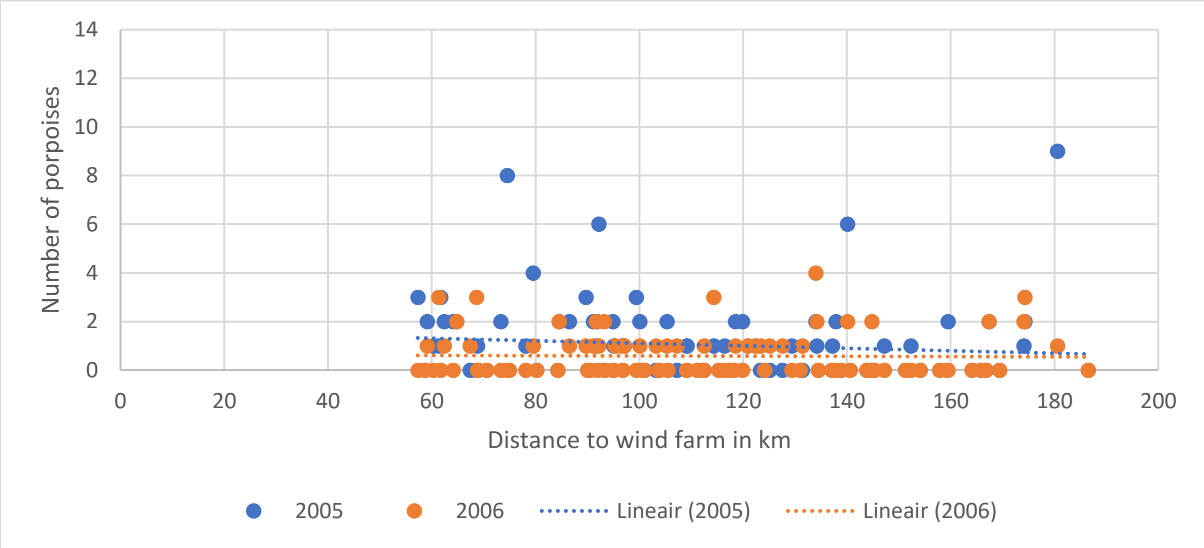

Figure 7: Scatter diagram of porpoises before the construction around Thorntobank wind farm in 2005 and 2006

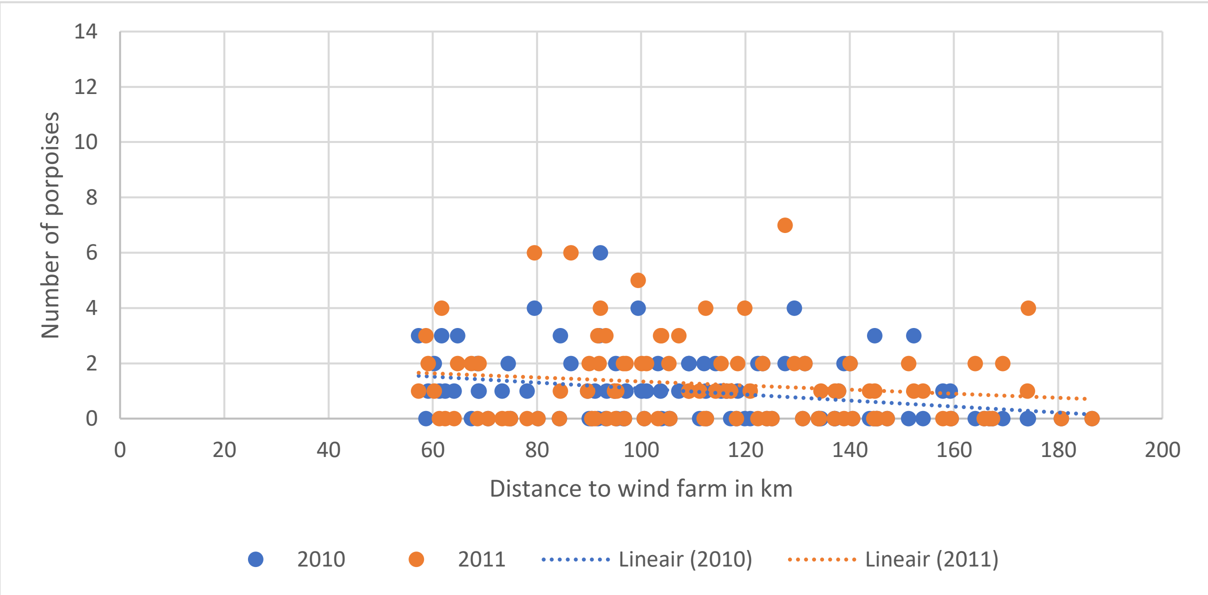

Figure 8: Scatter diagram of porpoises during construction around Thorntobank wind farm in 2010 and 2011

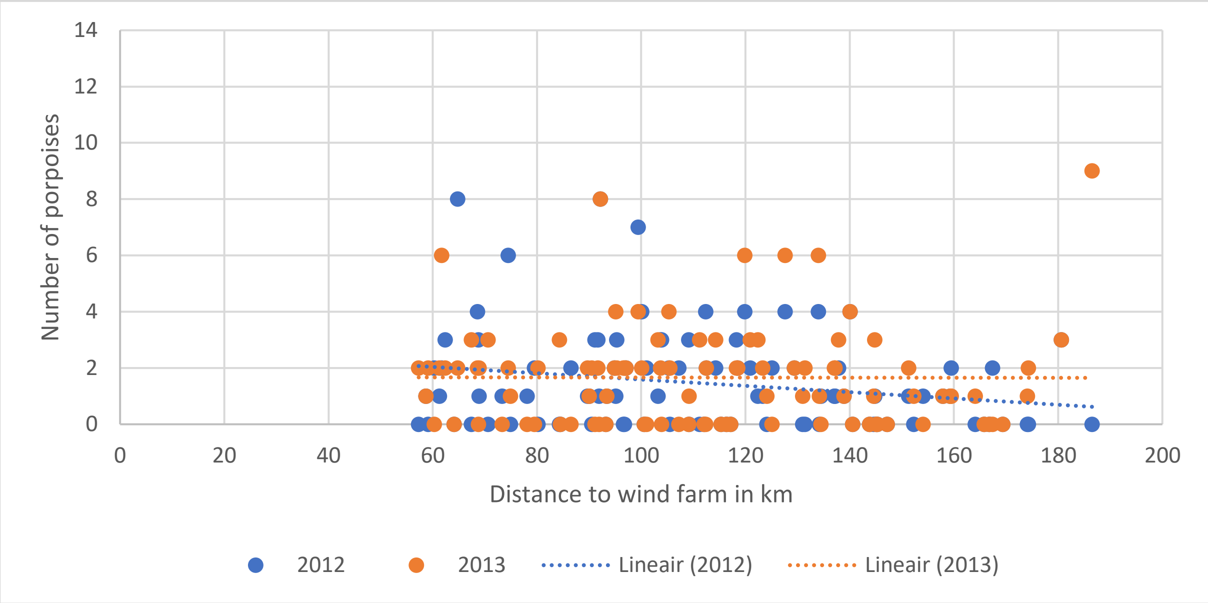

Figure 9: Scatter diagram of porpoises during the construction phase around Thorntobank wind farm in 2012 and 2013

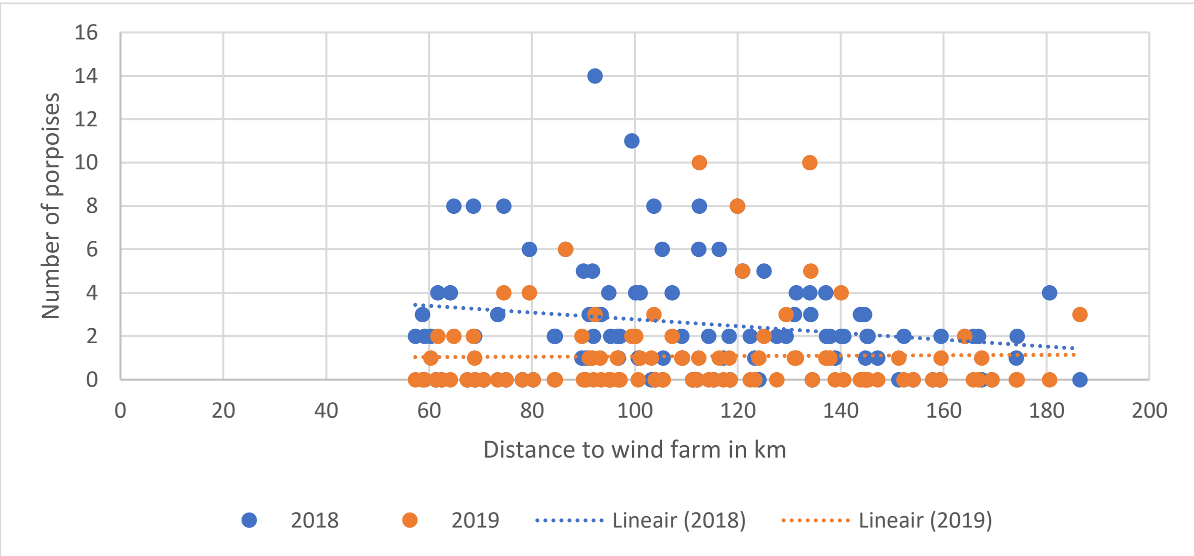

Figure 10: Scatter diagram of porpoises after the construction around Thorntobank wind farm in 2018 and 2019

3.3. Seasonal impacts

A strong seasonal impact was observed on porpoise abundance during the years 2005 to 2019. In the months of January through May, almost double the number was observed compared to the months of June through December (Figure 11).

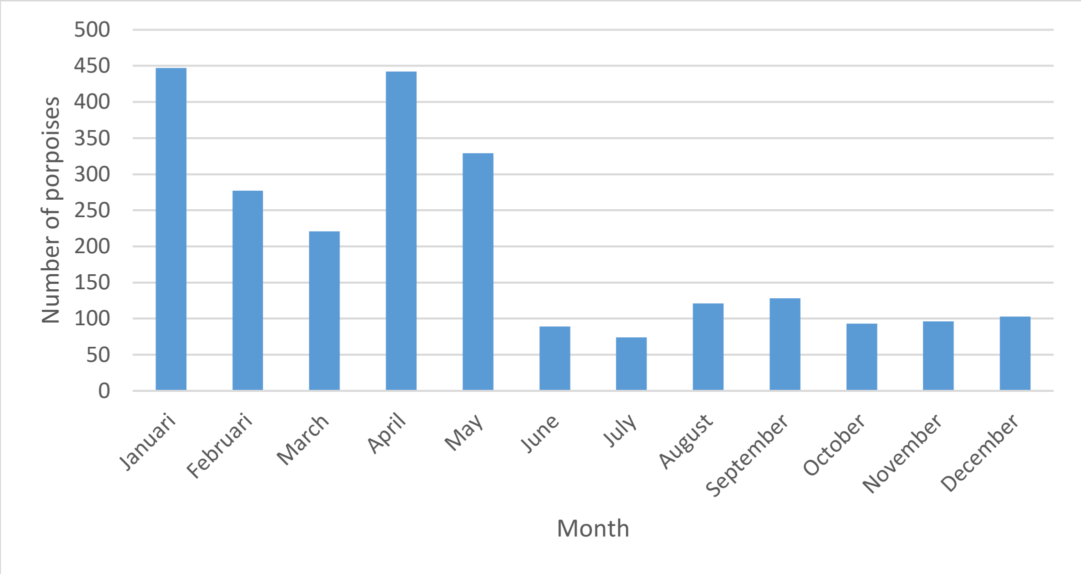

Figure 11: Average amount of porpoises by month in the years 2005 to 2019

3.4. Statistical tests

The *Poisson Regression test* showed a significant effect of the distance from the Thorntobank wind farm on the number of porpoises (0,001 < 0,05). Interaction of wind farm construction and porpoise distance does not have a significant effect on porpoises at Galloper and Thorntobank wind farms (0,880 > 0,05 and 0,124 > 0,05). However, a significant effect was found for this interaction at East Anglia wind farm (0,001 < 0,05). Time also has a significant effect on porpoise abundance (0,001 < 0,05).

Table 1: ANOVA Omnibus tests results with P value and significance

	SS	**df**	**F**	**P value**	**Significance**
Model	2216.1628	22	95.0872	< .001	yes
East Anglia distance	3.4023	1	3.2115	0.073	no
Galloper distance	3.3630	1	3.1745	0.075	no
Thorntobank distance	31.5315	1	29.7637	< .001	yes
Year	1805.8680	14	121.7589	< .001	yes
Thorntobank construction	1.0813	1	1.0207	0.312	no
East Anglia construction x East Anglia distance	88.4549	1	83.4959	< .001	yes
Galloper construction x Galloper distance	0.0240	1	0.0227	0.880	no
Thorntobank construction x Thorntobank distance	2.5112	1	2.3704	0.124	no

4. Discussion

The general trend in number of porpoises has increased over the last years. The results show a clear linear increase in porpoises along the Stena Line ferry route from 2005 till 2019. This could be a result of an increase in porpoises in general. In the Southern part of the North Sea is a reported increase in porpoises due to a shift of animals from the Northern part of the North Sea. The displacement may be related to a reduced food supply in the Northern North Sea (Rijksoverheid 2020).

The construction of windfarms involves many types of activities that can generate high sound pressure levels. The level of impact can be separated into construction activities, such as pile-driving, where there is indeed reason for concern, and operational effects, where the level of impact is small most of the time. Pile-driving seems to be the noisiest of all. Both the literature and modelling show that pile-driving and other activities generate intense impulses during construction and are likely to change the behaviour of marine mammals, and may induce hearing impairment at close range (Madsen et al. 2015). However in this research it has only been established that there seems to be a statistical relationship with the distance.

A windfarm's lifecycle can be split into four phases: the pre-construction phase, the construction phase, the operational phase and the decommissioning phase (Nedwell & Howell 2004). Throughout the lifecycle of a windfarm there will be an increase in vessel traffic. Before construction, survey vessels will be used to plan for the development. During construction, small and large vessel support will be required and this will continue throughout the operational phase in order for regular maintenance.

On the other hand, all fishing activities and shipping are prohibited in wind farms and in a marginal buffer zone of 500 meters (except for smaller vessels). These positive factors may outweigh possible negative factors, such as underwater noise from turbines and the service vessels (Vallejo et al. 2017). This does not mean that other less noisy sound sources can be ignored, but the problems associated with the piledriving represent worse case scenarios that may be applicable for assessing the impact of a range of less noisy construction activities. At the offshore wind farm Egmond aan Zee, porpoises were more frequently seen near the operational wind farm compared to measurements from reference areas outside the wind farm (Scheidat et al. 2011). The increased activity of porpoises near the wind farms may be related to increased food availability and the decrease in shipping traffic.

During the construction phase of a wind farm, many factors affect the amount of sound produced and how far the sound propagates. These include the size and technology of the turbine, the type of foundation, and the number and placement of turbines within the farm, as well as propagation conditions and ambient noise. Also, substrate type, local marine communities, and human activities before and after construction of wind farms are highly variable. All of these factors may be different for each wind farm and thus have different effects on porpoises. In addition, cumulative effects may also occur due to multiple wind farms located close to each other.

All data collected of porpoises for this report stopped in 2019. Galloper and East Anglia wind farms did not begin the operational phase until shortly before 2019, this means there are no results of amount of porpoises after the construction. Thorntobank windfarm went into business in 2013 which means there is more data after construction for this wind farm. The amount of porpoises before, during and after construction have remained almost the same around the farm. One explanation for this would be the return of porpoises when the pile-driving noise is over. Although it has been shown that during construction, porpoises, seals and dolphins avoid areas with offshore wind farms, this displacement appears to be temporary (Teilmann & Carstensen 2012). Studies have shown that most animals return to a wind farm once construction has stopped and the farm is operational. Once wind farms are built, the potential problem of their hearing damage is largely over. In fact, the sound of wind turbines in the operational phase is not harmful to the porpoise. (Wageningen University, n.d.). Another thing to keep in mind is that the park may be too far from the Stena Line route to measure effects.

In the case of the East Anglia and Galloper windfarm, the results shows an increase in porpoises at a distance further away from the wind farms during the construction phase. At Thorntobank, an increase in porpoises further away from the wind farm can also be seen, but only later. In al cases this increase is around 2018. The fact that more porpoises have been observed further away from the wind farms may have several causes. The noise of the pile-driving may be a factor, but other factors should also be taken into account. Oil, gas, sand and gravel are extracted from the bottom of the North Sea, fishing takes place there, as well as military training grounds and a number of very busy shipping routes. but the research design and data are not sufficient to make a distinction here.

The strongest significant effects of construction on porpoises was seen at East Anglia. This park is the closest to the Stena Line routes, porpoises have been observed at a distance of 13 kilometres while for Galloper and Thorntobank this was at 60 kilometres. According to research, the sound of pile-driving can be detected up to at least 80 km, behavioural changes occur mainly within the 20 km of pile-driving. It can be seen that pile-driving noise decreases with distances and that higher frequencies are more rapidly attenuated than lower ones. However, even at 80 km distance, the sound pressure levels are well above background noise (Thomsen et al. 2006). Because East Anglia is close to the Stena Line route, many porpoises have been observed within 20 km of the piling which may explain why there is a significant effect of interaction of wind farm construction and porpoise distance at this park. Because the other wind farms, Galloper and Thorntobank, are further away from the route and therefore less data is available near these farms, it is more difficult to draw conclusions based on the data available.

4.1 Conclusion & recommendation

Knowledge is limited of the effects on marine mammals from constructing and operating offshore wind farms. The underlying issue is the lack of data on behavioural reactions of the exposed animals and the short- and long-term consequences of exposure. Especially in this report, data from the Stena Line shipping routes can be collected but they remain limited.

This study found that both presence and distance from wind farm East Anglia have an effect on porpoises, wind farms Galloper and Thorntobank were probably too far from the Stena Line route to draw any conclusions. But it is difficult to draw conclusions during this study because there are many factors involved and it is hard to include them all. Once a number of variables are examined that may have an effect on the harbor porpoise population, such as in this study the distance to the wind farm and the years of construction, all other conditions must be proven to have remained the same, only then will it be possible to conclude an effect of the distance and the years of construction. However, it can be said with certainty that the porpoise population in the southern North Sea has increased in recent years.

Literature also tells us noise will undoubtedly increase, given that even during the operational phase, repairs and maintenance will take place. Continued increase of shipping back and forth to the turbines will also increase noise. This together with operational noise, shipping and construction of nearby wind turbines could mean that the effects of noise are much greater than expected, even if pile driving is below the hearing threshold of porpoises. And that is a big concern for the future knowing that many more offshore wind farms are planned for construction.

To reduce pile driving noise as much as possible, more ways of pile driving with lower pile driving noise should be studied. Mitigation techniques used to date include bubble curtains, which reduce the source Level of the piling noise, and acoustic deterrents, which 'scare' marine species from the immediate vicinity of construction activity. Alternatively, piles can be "shuffled" into the sediment by vibratory pile driving, which produces a continuous low-frequency noise.

If the power companies could make a small effort financially, setting up a monitoring program from within themselves or any other organization, would be very helpful. Including acoustic and human observation techniques, to ensure species are not within the area during pile driving. In that way every time a wind farm is planned to be constructed, a research study into the effects on the ecology and the environment takes place in the period before, during and after the construction. Monitoring has been conducted to measure behavioural effect, but it has not been used to prevent possible harm to marine species.

In a follow-up study, the effects of the East Anglia wind farm on porpoises could be further investigated once post-construction data is available.

5. Literature cited

Andersson, M. H. (2011). Offshore wind farms – ecological effects of noise and habitat alteration on fish. US-AB, Stockholm, 48 p.

Carstensen, J., Henriksen, O. D., & Teilmann, J. (2006). Impacts of offshore wind farm construction on harbour porpoises: acoustic monitoring of echolocation activity using porpoise detectors (T-PODs), Marine ecology progress series 321: 295-308.

de Haan, D., von Benda-Beckmann, S., Geelhoed, S., & Lagerveld, S. (2015). Potential effects of seismic surveys on harbour porpoises C126/15. IMARES Wageningen UR, The Hague, 57 p.

Gilles, A., Scheidat, M., & Siebert, U. (2009). Seasonal distribution of harbour porpoises and possible interference of offshore wind farms in the German North Sea, Marine ecology progress series 383: 295–307.

Hastie, G. D., Russell, D. J. F., McConnell, B., Moss, S., Thompson, D., & Janik, V. M. (2015). Sound exposure in harbour seals during the installation of an offshore wind farm: predictions of auditory damage. Journal of Applied Ecology 52: 631-640.

Kaiser, M. J., Attrill, M. J., Jennings, S., Thomas, D. N., & Barnes, D. K. A. (n.d). Marine Ecology: Processes, Systems, and Impacts. Oxford university press, Oxford, 489 p.

Kastelein, R., Hoek, L., Covi, J., & Gransier, R. (2015). Effect of exposure duration to pile driving sounds on temporary hearing threshold shift in harbor porpoises. SEAMARCO, Harderwijk, 17 p.

Madsen, P. T., Wahlberg, M., Lucke, K,. & Tyack, P. (2015). Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs, Marine ecology progress series 309: 279-295.

Milieu centraal. (n.d.). Windenergie. https://www.milieucentraal.nl/klimaat-en-aarde/energiebronnen/windenergie/ Retrieved : 11-11-2021.

Nedwell, J., & Howell, D. (2004). A review of offshore windfarm related underwater noise sources no 544 R 0308. COWRIE, London, 63 p.

Rijksoverheid (2020). Bruinvis in de Noordzee, 1991 - 2019 | Compendium voor de Leefomgeving. https://www.clo.nl/indicatoren/nl1250-bruinvis-langs-de-nederlandse-kust Retrieved : 20-2-2021

Scheidat, M., Tougaard, J., Brasseur, S., Carstensen, J., van Polanen Petel, T., Teilmann, J., & Reijnders, P. (2011). Harbour porpoises (Phocoena phocoena) and wind farms: a case study in the Dutch North Sea. Environmental Research Letters 6: 025102.

Stichting Rugvin (2020). Monitoringsresultaten Noordzee. https://rugvin.nl/noordzee/monitoringsresultaten-noordzee/ Retrieved : 30-9-2020

Teilmann, J., & Carstensen, J. (2012). Negative long term effects on harbour porpoises from a large scale offshore wind farm in the Baltic—evidence of slow recovery. Environmental Research Letters 7: 045101

Thomsen, F., Lüdemann, K., Kafemann, R., & Piper, W. (2006). Effects of offshore wind farm noise on marine mammals and fish. COWRIE Ltd, Hamburg, 62 p.

Vallejo, G. C., Grellier, K., Nelson, E. J., McGregor, R. M., Canning, S. J., Caryl, F. M., & McLean, N. (2017). Responses of two marine top predators to an offshore wind farm. Ecology and Evolution, 7: 8698–8708.

Wageningen University. (n.d.). Bruinvissen en gehoorschade door bouw windmolens. https://www.wur.nl/nl/Onderzoek-Resultaten/Onderzoeksinstituten/marine-research/show-marine/Bruinvissen-en-gehoorschade-door-bouw-windmolens.htm Retrieved : 21-2-2021

Zanderink, F., & Osinga, N. (2020). DE BRUINVIS De kleinste walvis van de Noordzee. WWF & Stichting Rugvin, Zeist, 22p.

Attachment I Effects from underwater noise on porpoises

Table 1: The effects from underwater noise on porpoises divided into different categories of effects

	Effects from underwater noise on porpoises
Indirect effects	Reduced prey availability
Chronic effects	Stress that leads to reduced disease or viability
Behavioural effects	Disruption of normal behaviour such as changes in dive. Avoiding an area, changes in dive and disruption of feeding
Perceptual effects	Masking of biologically significant noises by man-made noise (including echolocation, and sounds related with finding prey or avoiding predators or human threats such as shipping)
Physical effects	Damage to body tissues, for example crushing, fracturing, and rupture of body tissues Permanent threshold shift (PTS: reduction in auditory sensitivity, in this case there is no recovery) Temporary threshold shift (TTS: reduction in auditory sensitivity in this case recovery could eventually be possible)

Attachment II Model of the effect of construction on porpoises

Figure 1 shows a model made with the hypothesis that after the construction of a wind farm, porpoises return. It shows a large decrease in porpoises when the wind farm is built, in 2010. Suppose this lasts for 3 years the porpoises will stay away because of the pile driving noise. When the noise is over the porpoises will return. Suppose the conditions are improved by the wind turbine towers the number of porpoises will even increase and be higher than before the construction.

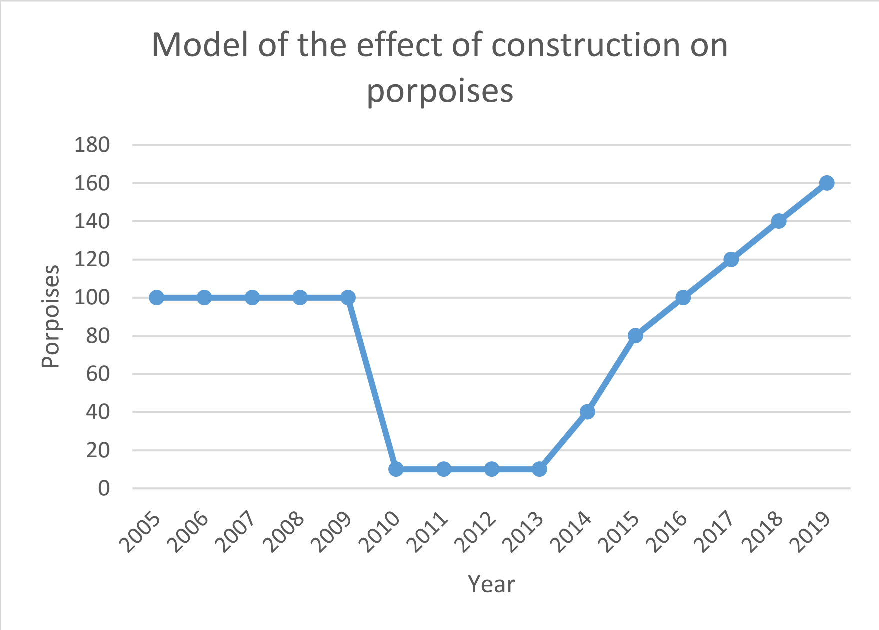

Figure 1: model on how porpoises might decrease and increase before, during and after construction of a wind farm

Attachment III Map with all observed porpoises

Figure 1 shows all porpoises observed by the Harbour Porpoise Foundation on the Stena Line shipping routes between 2005 and 2019.

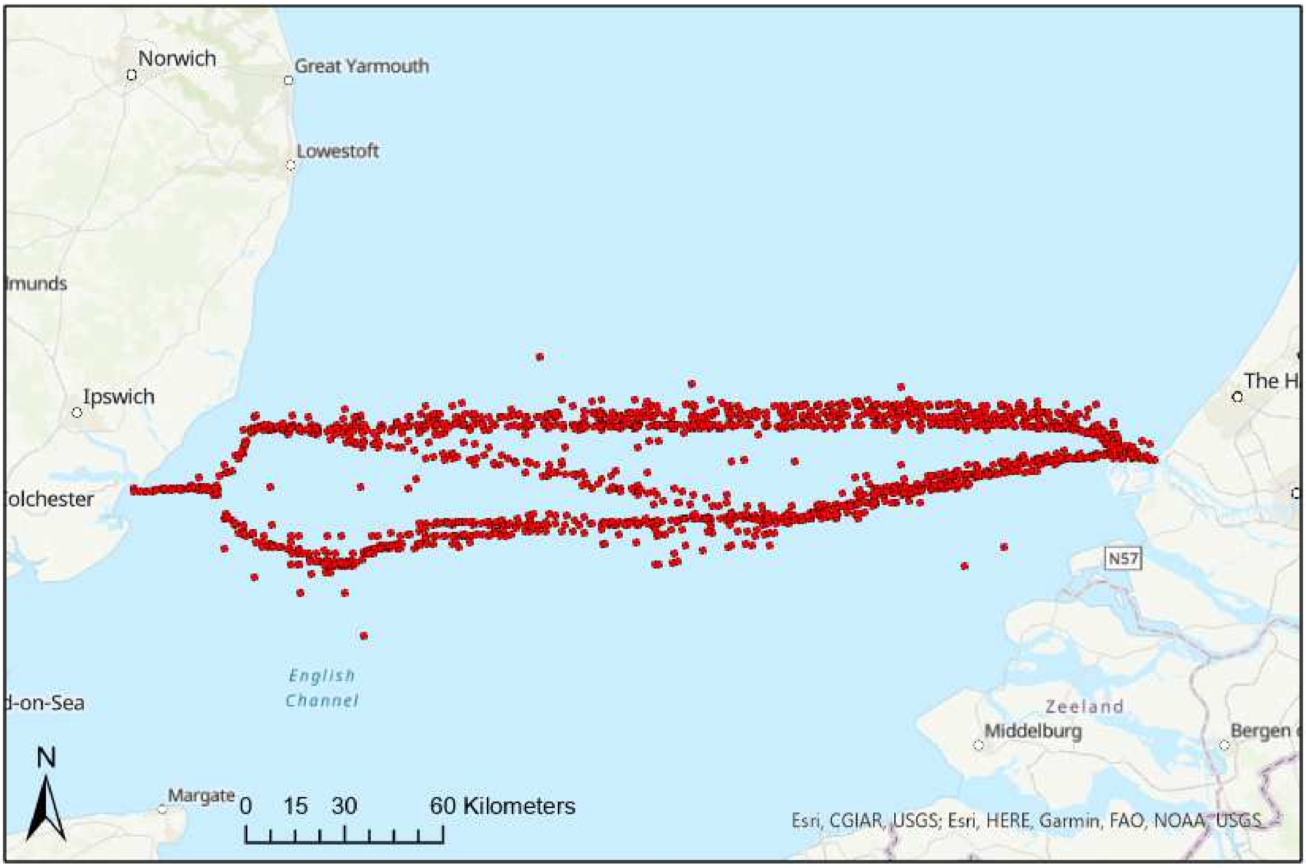

Figure 1: All porpoises observed by the Rugvin Foundation between 2005 and 2019 plotted in a map

Attachment IV Output linear regression tests

Model Fit Measures

Model	R	R^2
1	0.215	0.0462

Model Coefficients - Porpoises10-11EA

Predictor	Estimate	SE	t	p
Intercept [a]	0.94545	0.20534	4.604	< .001
DistanceEA	−4.86e−4	0.00167	−0.290	0.772
Year10-11EA:				
2011 – 2010	−0.21528	0.29039	−0.741	0.459
DistanceEA ✻ Year10-11EA:				
DistanceEA ✻ (2011 – 2010)	0.00492	0.00237	2.077	0.039

[a] Represents reference level

Figure 1: Output from the Linear Regression test showing the effects of distance and years 2010 and 2011 on porpoises around East Anglia

Model Fit Measures

Model	R	R^2
1	0.602	0.363

Model Coefficients - Porpoises18-19EA

Predictor	Estimate	SE	t	p
Intercept [a]	0.49065	0.30345	1.62	0.107
DistanceEA	0.01919	0.00248	7.75	< .001
Year18-19EA:				
2019 – 2018	−0.70009	0.42914	−1.63	0.104
DistanceEA ✻ Year18-19EA:				
DistanceEA ✻ (2019 – 2018)	−0.00706	0.00350	−2.02	0.045

[a] Represents reference level

Figure 2: Output from the Linear Regression test showing the effects of distance and years 2018 and 2019 on porpoises around East Anglia

Model Fit Measures

Model	R	R^2
1	0.372	0.138

Model Coefficients - Porpoises16-17-18Gal

Predictor	Estimate	SE	t	p
Intercept [a]	0.16040	0.59564	0.269	0.788
DistanceGal	0.01130	0.00508	2.225	0.027
Year16-17-18Gal:				
2017 – 2016	0.87749	0.84236	1.042	0.298
2018 – 2016	−0.26953	0.84236	−0.320	0.749
DistanceGal ✻ Year16-17-18Gal:				
DistanceGal ✻ (2017 – 2016)	−0.00469	0.00718	−0.653	0.514
DistanceGal ✻ (2018 – 2016)	0.01267	0.00718	1.765	0.079

[a] Represents reference level

Figure 3: Output from the Linear Regression test showing the effects of distance and years 2016, 2017 and 2018 on porpoises around Galloper

Model Fit Measures

Model	R	R^2
1	0.136	0.0185

Model Coefficients - Porpoises10-11Gal

Predictor	Estimate	SE	t	p
Intercept [a]	1.15319	0.38145	3.023	0.003
Year10-11Gal:				
2011 – 2010	−0.15100	0.53945	−0.280	0.780
DistanceGal	−0.00191	0.00325	−0.588	0.557
DistanceGal ✻ Year10-11Gal:				
DistanceGal ✻ (2011 – 2010)	0.00403	0.00460	0.877	0.382

[a] Represents reference level

Figure 4: Output from the Linear Regression test showing the effects of distance and years 2010 and 2011 on porpoises around Galloper

Model Fit Measures

Model	R	R^2
1	0.197	0.0387

Model Coefficients - Porpoises5-6Th

Predictor	Estimate	SE	t	p
Intercept [a]	1.61512	0.46421	3.479	< .001
DistanceTh	−0.00513	0.00398	−1.291	0.198
Year5-6Th:				
2006 – 2005	−0.98759	0.65650	−1.504	0.134
DistanceTh ✻ Year5-6Th:				
DistanceTh ✻ (2006 – 2005)	0.00471	0.00562	0.837	0.403

[a] Represents reference level

Figure 5:Output from the Linear Regression test showing the effects of distance and years 2005 and 2006 on porpoises around Thorntobank

Model Fit Measures

Model	R	R^2
1	0.247	0.0609

Model Coefficients - Porpoises10-11Th

Predictor	Estimate	SE	t	p
Intercept [a]	2.16267	0.47905	4.514	< .001
Year10-11Th:				
2011 – 2010	−0.08277	0.67748	−0.122	0.903
DistanceTh	−0.01082	0.00410	−2.638	0.009
DistanceTh ✻ Year10-11Th:				
DistanceTh ✻ (2011 – 2010)	0.00342	0.00580	0.589	0.557

[a] Represents reference level

Figure 6: Output from the Linear Regression test showing the effects of distance and years 2010 and 2011 on porpoises around Thorntobank

Model Fit Measures

Model	R	R^2
1	0.123	0.0150

Model Coefficients - Porpoises12-13Th

Predictor	Estimate	SE	t	p
Intercept [a]	2.08980	0.45785	4.564	< .001
Year12-13Th:				
2013 – 2012	0.21000	0.24766	0.848	0.398
DistanceTh	−0.00571	0.00377	−1.512	0.132

[a] Represents reference level

Figure 7: Output from the Linear Regression test showing the effects of distance and years 2012 and 2013 on porpoises around Thorntobank

Model Fit Measures

Model	R	R^2
1	0.345	0.119

Model Coefficients - Porpoises18-19Th

Predictor	Estimate	SE	t	p
Intercept [a]	4.3352	0.81570	5.31	< .001
Year18-19Th:				
2019 – 2018	−3.3493	1.15357	−2.90	0.004
DistanceTh	−0.0157	0.00698	−2.24	0.026
DistanceTh ✻ Year18-19Th:				
DistanceTh ✻ (2019 – 2018)	0.0165	0.00988	1.67	0.096

[a] Represents reference level

Figure 8: Output from the Linear Regression test showing the effects of distance and years 2018 and 2019 on porpoises around Thorntobank