31-1-2017

Sea level rise in the Wadden Sea

A report on the effect of sea level rise on the breeding habitat of Thalasseus sandvicensis in the Wadden Sea

van hall larenstein
university of applied sciences

Littoral 2016
Biarritz, 25-29 October

Sea level rise in the Wadden Sea

A report on the effect of sea level rise on the breeding habitat of Thalasseus sandvicensis in the Wadden Sea

University of Applied Science – Van Hall Larenstein

Agora 1, Leeuwarden, the Netherlands

2016

Young Professional Coastal Community

Biarritz, France

2016

Authors

Mathilde Hoogerwerf
Sarina Martis
Manon van Rossum
Marrit Starkenburg

Preface

This final product has been a process of 1,5 years, first we needed to apply for Littoral and be accepted. Our first meeting as a team was 1 year ago, this was the first time the Coastal and Marine Management students (Mathilde Hoogerwerf and Marrit Starkenburg) and Environmental Sciences students (Sarina Martis and Manon van Rossum) met. In the first couple of meetings brainstorm sessions were the beginning of this end report. To decide what subject, we were going to research, to bring two different studies together. Very quickly it was decided what we wanted to research. On NAM weekend on Ameland the proposal of our research was presented by Mathilde and Manon. At a later stage the process was presented once again on Ameland by Sarina and Marrit. During these two weekends we got feedback and tips from different experts on the Wadden Sea area. We would like to thank these people for helping us. Joop Marquenie for the organization of the NAM weekends, Johan Krol for the suggestions and the positive feedback, Rob Mesdorp and André Dijkstra for the YPCC guidance, feedback on GIS and the research. Lastly we would like to thank Leo Bentvelzen and Ruben de Vries, for the guidance during this process and giving us the change to go to Biarittz to present at the YPCC. Without them this would not have been possible.

Mathilde Hoogerwerf, Sarina Martis, Manon van Rossum & Marrit Starkenburg
January 2017
Leeuwarden, The Netherlands

Abstract

The Wadden Sea is an UNESCO natural world heritage site, it is a shallow sea situated within the borders of The Netherlands, Germany and Denmark. The Wadden Sea is a dynamic intertidal area that was created during the last ice age. It is an important area for many different plant and animal species. It is also an important area for migratory birds, one of these birds is the Sandwich tern *(Thalasseus sandvicensis). T. Sandvicensis* uses this area to breed and forage. The habitat of T. sandvicensis in this area might be threatened by climate change, in particular by sea level rise. Therefore the main focus of this report is to analyse the effects of sea level rise on the breeding habitat of *T. Sandvicensis* in the Wadden Sea. Only the effects on the Dutch part of the Wadden Sea have been analysed. Furthermore this report will look into the history and current situation of *T. sandvicensis* in the Wadden Sea. The first documentation of the presence of *T. sandvicensis* in the Netherlands comes from round 1900. From this knowledge until the 1970's it is clear that *T. sandvicensis* is a resilient species. From the 1970's there is also knowledge of the breeding location throughout the Netherlands. In the last couple of years there has been a shift from certain breeding locations to others. The future is not entirely clear, the sea level rise does not directly affect the breeding grounds of *T. sandvicensis*, but that is only when the Wadden Sea stays like it is today. It is more likely that the Wadden Sea will change due to other factors than just Sea Level Rise, one of such fact might be human interference like gas extraction.

Table of Contents

1 Introduction

The Wadden Sea is a shallow sea situated within the borders of The Netherlands, Germany and Denmark. It is the world largest intertidal ecosystem. The area consists of multiple mudflats, gullies sandbanks and mussel banks (UNESCO). The Wadden Sea is continually changed by sea currents and tidal influences. During low tide some parts of the Wadden Sea run dry creating unique ecosystems which attract many rare plant and animal species (World heritage). For example, the following common breeding birds: Gulls, Terns, Ducks, Stilts, Spoonbills and many passerines (InterWad, 2010).

Currently sea-level rise is occurring worldwide due to the effect of climate change. The Intergovernmental Panel on Climate Change (IPCC) has published four scenarios for global sea-level rise. The sea level rise may affect the habitat for the breeding birds in the Wadden Sea. The aim of this report to find out what the effects of sea level rise will be on the breeding grounds of the Sandwich tern (*Thalasseus sandvicensis*), and how the sea level rise will affect the population.

T. sandvicensis is a common bird in the Netherlands, that uses the Wadden Sea as a breeding, foraging and roosting area (Ens, Piersma, Zwarts, & Kam, 2004). Over the past 30 years' scientist have monitored several bird species in the Wadden Sea. This data can be used to derive trends in the bird population. In the past century the global mean sea level has risen for about 20 centimetres. However, there has been an increase in the annual rate of rise over the past 20 years (National Geograpic, 2008).

The main focus of this report is *T. sandvicensis*, and how the current sea-level rise is affecting their habitat.

2 Area description

The Wadden Sea has been a shallow sea since the old ice ages (approximately 150.000 years ago). The formation of the intertidal ecosystem started during the last ice age (approximately 10.000 years ago). The strong westerly wind blew sand in the direction of the Danish, Dutch and German coast. When the ice melted the strong sea current created large gullies. During flood the sand and silt from the North Sea landed in the area. These sediments remain during low tide and sandbanks and estuaries were formed elsewhere. The effects of alluvial erosion and gully formation are still visible in the Wadden Sea Area (Burbridge, et al., 2012). Another factor in the formation of the Wadden Sea is temperature. The rising temperature caused an increased plant growth. Plant material was degraded slowly and/or incomplete because of the high water level. This created large peat areas which were continuously covered by silt. Saltmarshes formed on the silted area, this caused new plant growth. (World heritage)

2.1 Dutch Wadden Sea

The Wadden Sea is the largest intertidal system in the world, containing gullies, mudflats and islands created by the sea. The Wadden Sea is stretched from the Netherlands, Germany and Denmark (see Figure). On June 2009 UNESCO included the Wadden Sea on the list of Natural World Heritage Sites and therefor became at that moment the only natural environment in the world with this title. The Wadden Sea has a rich and diverse biodiversity and many species depend on the Wadden Sea for survival. But before it became a World Heritage Site it had to become the intertidal system as it is today. (Reise, 2013; Burbridge, et al., 2012)

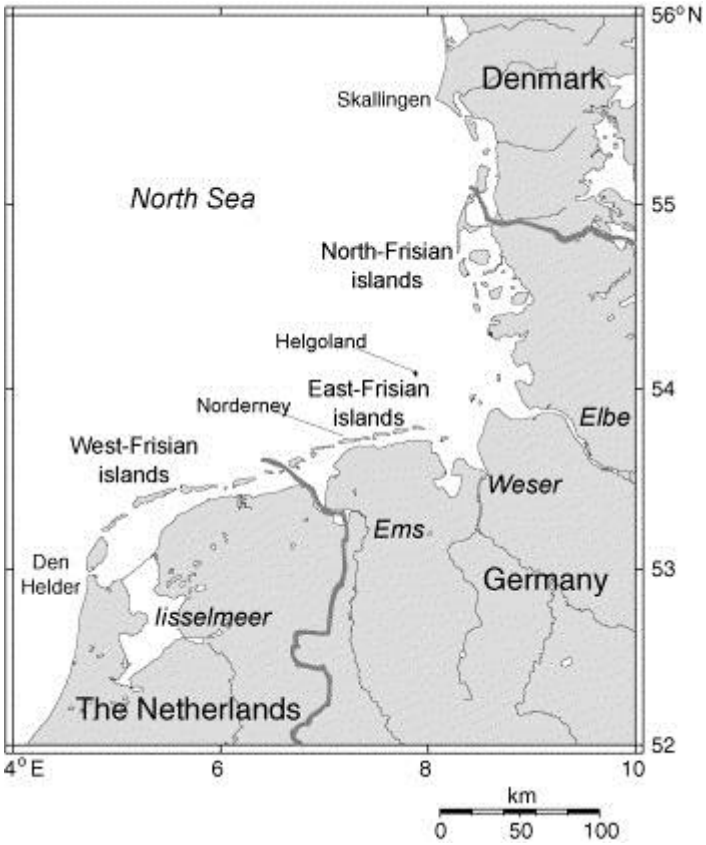

Figure 1. Wadden Sea from The Netherlands, Germany and Denmark. (Lotze, 2007)

The end of the Ice-age (20,000 to 18,000 years ago) was the beginning of the Wadden Sea. During the Ice-age the global sea level was 120m lower than it is today, due to the fact that so much frozen water covert the North. The North Sea and big parts of the coastal areas of the Netherlands,

Germany and Denmark were covered with big pack-ice. After the peak of the Ice-age the sea level started to rise quickly. Sea level rose about 100m in 10,000 years. The North Sea was submerged, a channel opened between England and the continent and the Doggers Bank was drowned. (Reise, 2013) In average the sea level was rising one meter per century, the same rise expected to continue until the end of our century, triggered by burning fossil carbon and the warming atmosphere. However, the sea level rise was in the beginning high, it began to slow down. 8,000 years ago it had slowed down to 15cm per century (Vink, Steffen, Reinhardt, & Kaufmann, 2007). With a sea level rise of 15cm per century the Wadden Sea was able to be formed. 8,000 years ago small islands with dunes started to appear. High tide took sand and silt to the shallow coast which was deposited with low tide. The Wadden Sea became a constantly moving area (Burbridge, et al., 2012). (Reise, 2013)

The geographical position of the Wadden Sea is ideal for coastal birds breeding in the high Arctic and wintering in western Africa. The Wadden Sea is located approximately halfway between breeding and wintering sites (van de Kam, Ens, Piersma, & Zwarts, 2006). Within a radius of 4,000 to 5,000km, the perfect place for long-distance flyers, situated in the middle of the flyway. This location had presumably a major effect on the evolution of migration strategies. (Reise, 2013)

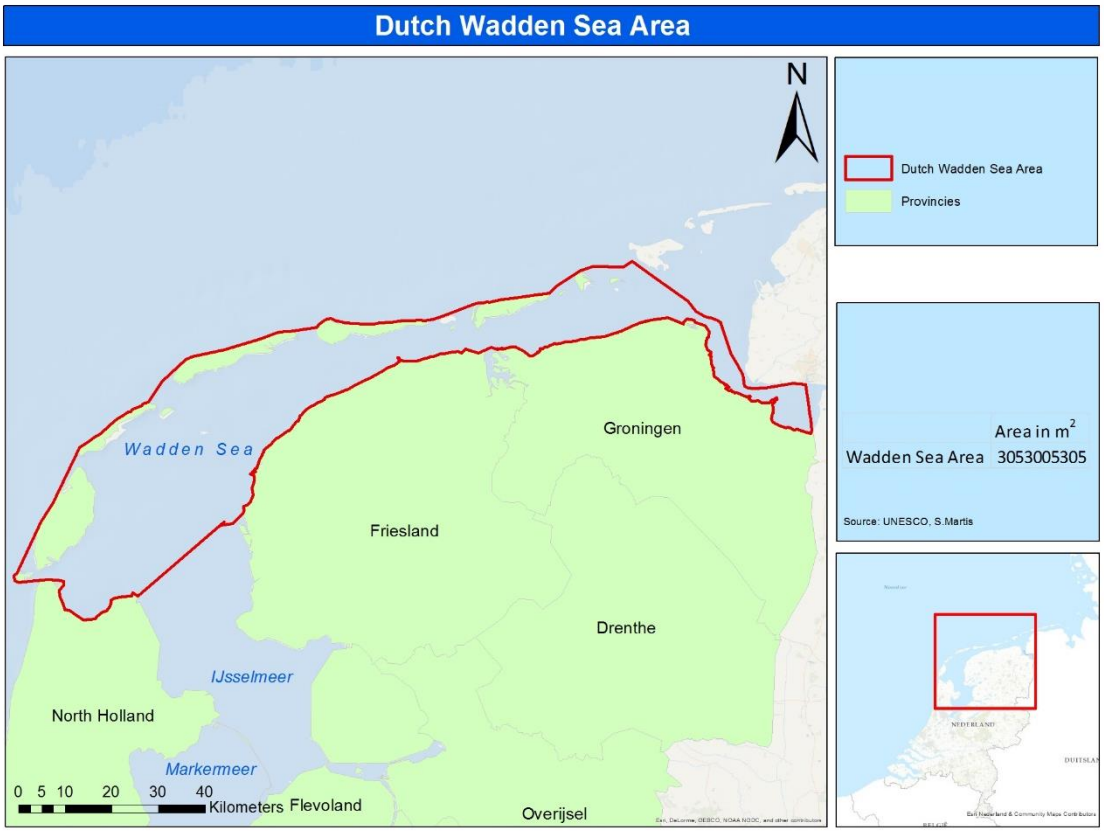

Figure 2.Map of the Dutch Wadden Sea

The Dutch Wadden Sea area extends from Den Helder to the Eems-Dollard estuary (Ecomare). The Area is displayed in figure 2. The Dutch Wadden Sea area is approximately 3.053 Km^2. This area has 11 islands of which five are inhabited. However, the six uninhabited islands are often important breeding grounds for birds and other species. The main soil type of the Wadden Sea is sand and muddy sand. Areas with the soil types mud and sandy mud and mud sediments are locally present. The soil type of the Dutch Wadden Sea area is displayed in figure 3.

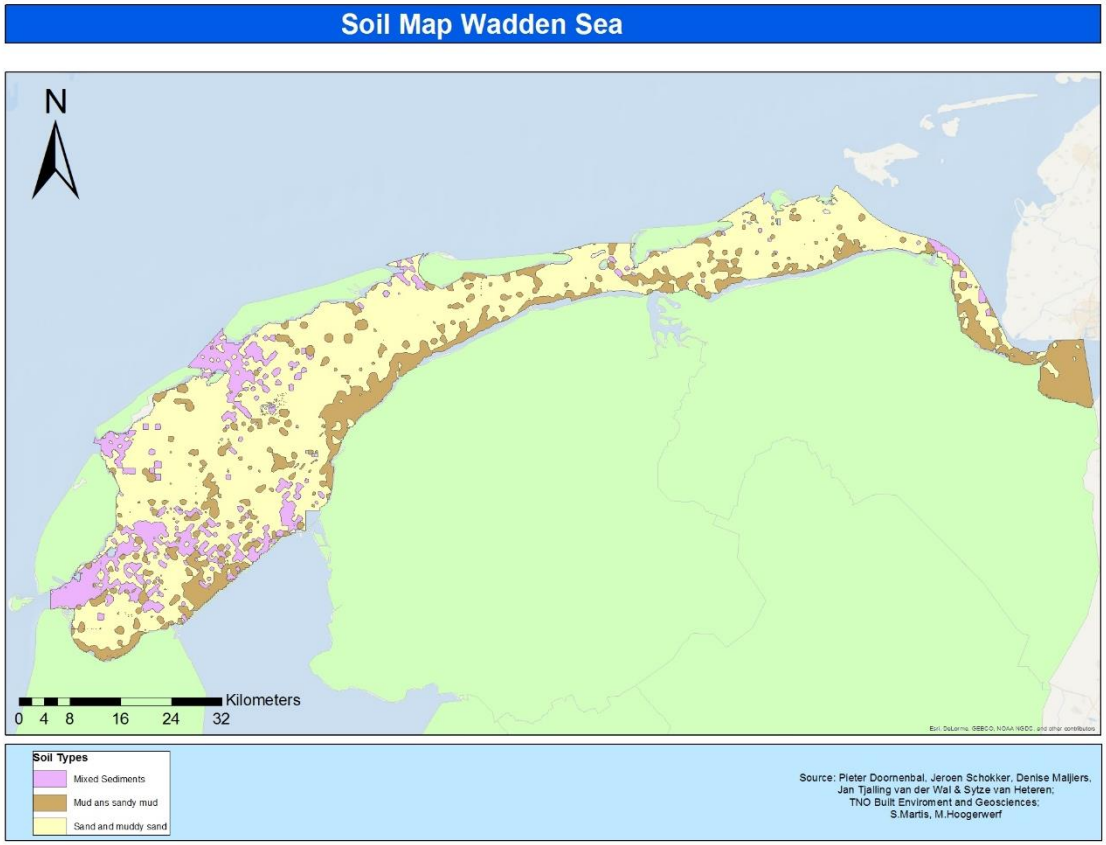

Figure 3.Soil Map of the Dutch Wadden Sea

During low tide the most of the Wadden Sea is dry. The depth of the Wadden Sea during low tide is displayed in figure 4.

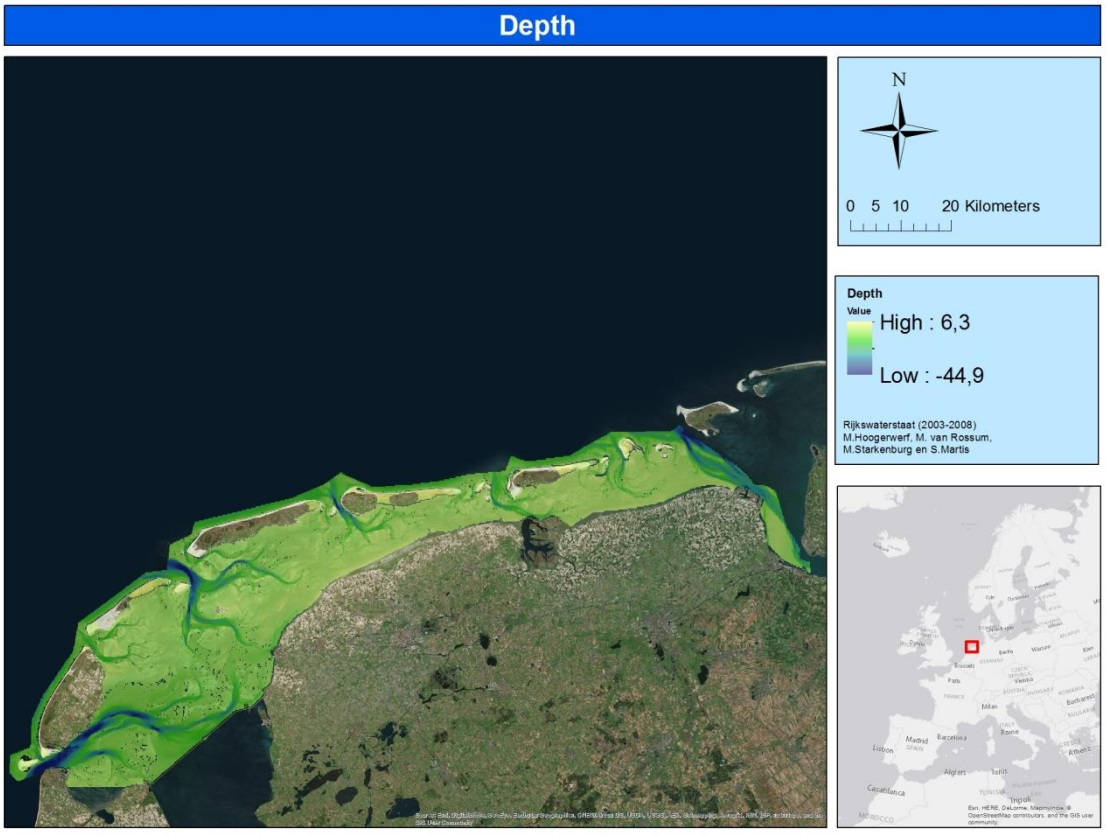

Figure 4.Depth map of the Wadden Sea

2.2 Sandwich tern *(Thalasseus sandvicensis)*

Figure 5. T. sandvicensis (Spoelmans)

The Sandwich tern (*T. sandvicensis) (figure 5)* is a common breeding and migratory bird in the Dutch Wadden Sea. *T. sandvicensis* arrives around March in the Dutch Wadden Sea and leaves around November. *T. sandvicensis* nests in colonies (Ens, Piersma, Zwarts, & Kam, 2004). *T. sandvicensis* is a bird that breeds on small secure dynamic islands with no ground predators, the only predators these birds have to deal with are the Herring gulls *(Larus argentatus).*The breeding habitat are mostly open beaches and high sand flats. But can also be in salt marshes. They hunt in areas with maximum water depth of 1.5m, and forage on for example Herring, Sandeel, Smelt and Sprat. *T. sandvicensis* is a very sensitive species, especially when it comes to human recreation on both land and water. (Alterra, 2008) In Figure 6 the breeding trends of *T. sandvicensis* in the Netherlands can be seen. This figure shows that there is an increase of breeding birds in the Netherlands. But what is the effect of sea level rise on these breeding birds in the Dutch Wadden Sea?

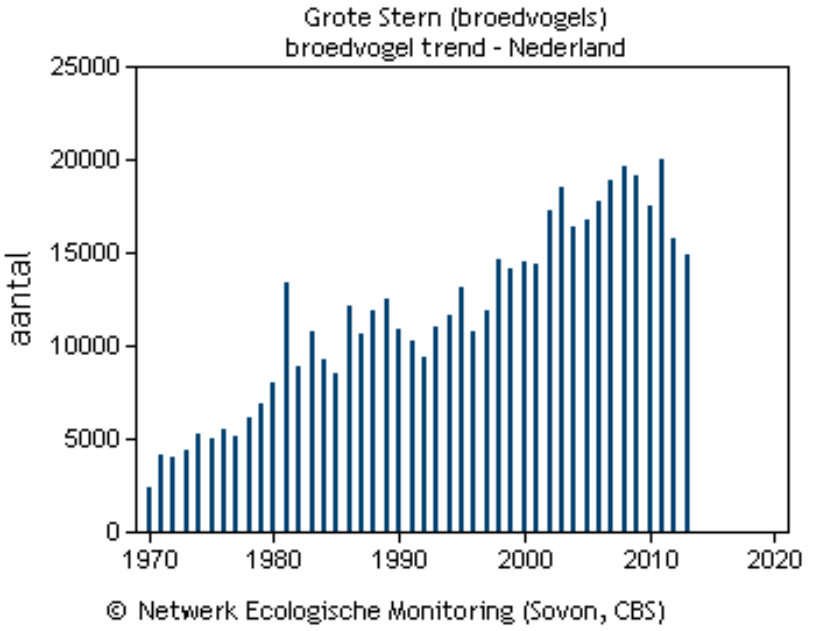

Figure 6. Trend breeding pairs of T. sandvicensis in the Netherlands between 1970 till 2014 (Sovon, 2015)

3 Materials and methods

Three subjects are studied in this case-study, the subjects are: History, Current situation and Future. The subjects are based upon the state of *T. sandvicensis* in the Wadden Sea,

3.1 History & current situation

For the results of History and Current situations existing research data has been used. Researches have studied this area and therefore enough data is available to describe the state of the *T. sandvicensis* in the Wadden Sea and around Ameland. This data has been used for the results of history and for the results of current state. More research had to be done to be able to give an inside to what the future might hold. Several data has been used for this purpose. This is described in paragraph 3.1.

3.2 Future

With the help of the data of the past and the current situation of the birds some criteria can be made. Therefore the first step of this analysis is to map the known habitat in a map for the current situation. Table 1 describes these criteria.

Criteria	**Reason**	**Indicator**
Breeding area	*T. sandvicensis* mostly breeds on high sandflats but can also be found on saltmarshes	- High mudflats, - Saltmarshes

Table 1 Criteria for breeding grounds of T. sandvicensis

Currently the IPCC possesses four scenarios of possible climate change effects. Sea level rise is one of these effects. Table 2 describes the four scenarios of sea level rise and figure 7 shows these scenarios in a graph. In this report two of the sea level rise scenarios are used to predict the possible outcomes for the birds future habitat.

	Scenario	**2046-2065**		**2081-2100**	
		mean	Likely range	Mean	Likely range
Global mean sealevel rise (m)	RCP2.6	0.24	0.17-0.32	0.40	0.26-0.55
	RCP4.5	0.26	0.19-0.33	0.47	0.32-0.63
	RCP6.0	0.25	0.18-0.32	0.48	0.33-0.63
	RCP8.5	0.30	0.22-0.38	0.63	0.45-0.82

Table 2 IPCC Scenarios for sea level rise (IPCC, 2013)

The scenarios that will be evaluated are RCP 2.6 and RCP 8.5. These two scenarios are chosen because they show the minimum and the maximum sea level rise. With the help of the 2 selected scenarios and the criteria a possible outcome for the birds future habitat can be predicted.

Both the scenarios and the criteria will be analysed in Arc GIS. With the help of this program a map with different layers will be created. Each criterion will be in a layer. These criteria and the currently known breeding grounds will be presented in one map to state the current situation. Therefore the currently known breeding grounds will also be presented in this map. Lastly both the sea level rise scenarios will be adapted in a map to describe what effect the sea level rise has on the birds breeding grounds.

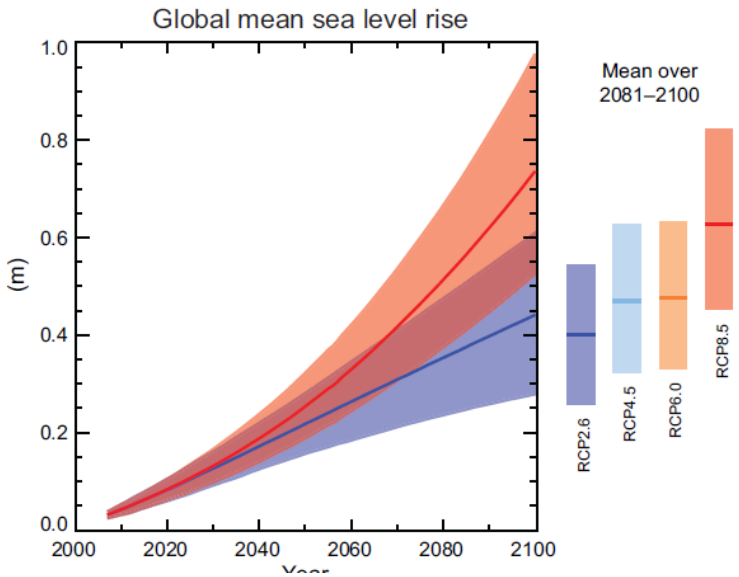

Figure 7. Global mean sea level rise scenarios as proposed by the IPCC

4 Results

4.1 History

The history of *T. sandvicensis* is very broad. In the Netherlands the population has had high and low peaks. This is due to the loss of breeding places, interactions of man and his environment and low breeding years. In the beginning of the 20th century people liked to hunt *T. sandvicensis* because of their beautiful feathers. It was used for ornaments on the hats for women (Leopold & Engels, 2014). The birds were shot down the moment they flew towards the sea. In 1908 the Sandwich Stern was legally protected by law, the population was able to grow to a steady 30,000 to 40,000. In the war these number fluctuated temporarily around 16,000 because the eggs were hunted for consumption (Leopold & Engels, 2014). Around 1960 the population dropped immensely, in 1965 only 900 breading Sandwich Stern were spotted. This drop in the population had to do with toxic waste (organochlorines) in the "Nieuwe Waterweg" (the canal that connects Rotterdam to sea) (Leopold & Engels, 2014). The big drop has been an effect because of the toxic waste, late 1950's the breeding site 'de Breed' located near Rotterdam was lost. But with all the setbacks the population of *T. sandvicensis* has been able to grow again, but not like the way it was in the 1950's (Leopold & Engels, 2014). In Figure the fluctuation breading population of *T. sandvicensis* in the Netherlands can be seen. (Rijksoverheid, 2013)

T. sandvicensis

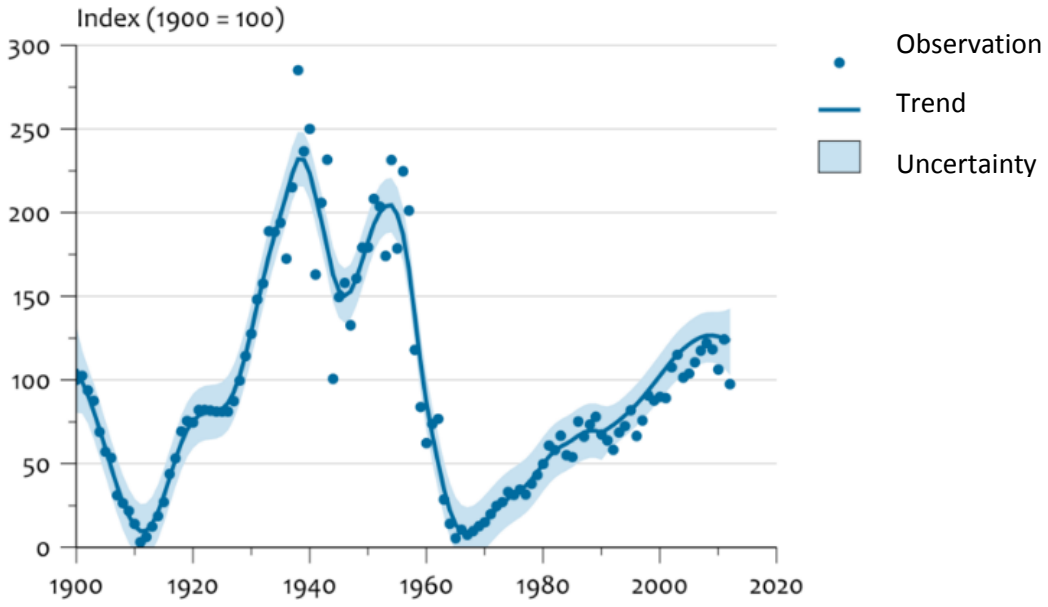

Figure 8. Count of T. sandvicenses breeding pairs in the Netherlands from 1900-2016. (Rijksoverheid, 2013)

4.1.1 Breeding history

The first breeding pairs of *T. sandvicensis* were recorded between 1973 and 1977 (Figure 9). The most common breeding places are throughout the Wadden Sea and in the south west of the Netherlands. When focusing on the Wadden Sea the breeding places are the Islands of Texel, Terschelling, Schiermonnikoog and the small uninhabited island of Griend which lies in the middle of the Wadden Sea. After the years of 1973 and 1977, there is a gap without information on the breeding colonies. It can be assumed that the birds did in fact breed during this time. Figure 10 gives an overview of the breeding colonies between the years of 2005-2008. The locations are pretty

much the same as in the map of 1973-1977 (figure 9). Except for the location on the island of Ameland.

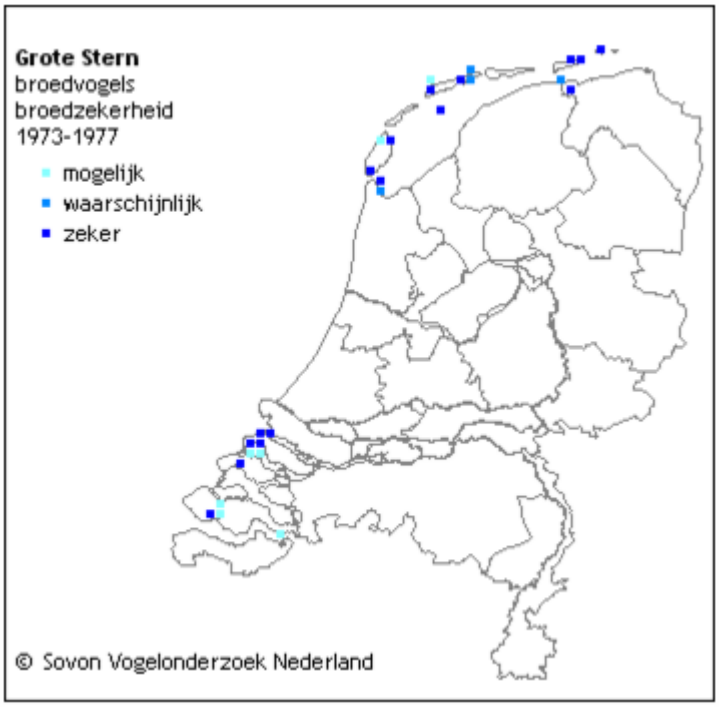

Figure 9. Breeding locations of T. sandvicensis in the Netherlands between 1973 – 1977 (Sovon, 2015)

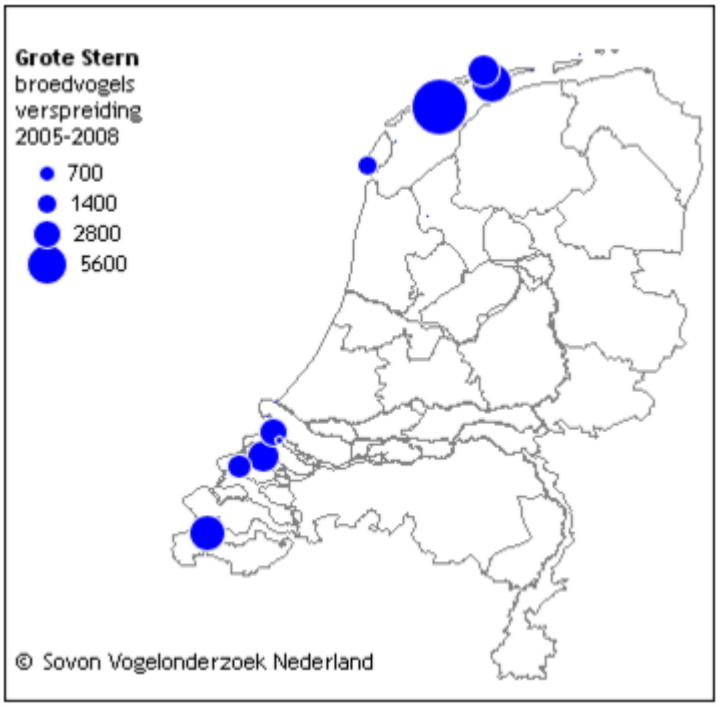

Figure 10. Breeding locations of T. sandvicensis in the Netherlands between 2005 -2008 (Sovon, 2016)

What is notable in 2010 (figure 11) is a small decline of breeding birds, compared to the map of 2005-2008. There is an increase in 2014 (figure 12), especially in the Wadden Sea. There is a decline in the province of Zeeland. And the breeding location on the island of Terschelling has disappeared. An important breeding area is the Feugelpôlle on the island of Ameland. On the north – eastern side of Ameland there is another area where *T. sandvicensis* breed. Here are the saltmarshes of Neerlands Reid. This is a large intertidal area with lots of sandflats (Birdlife international, 2000).

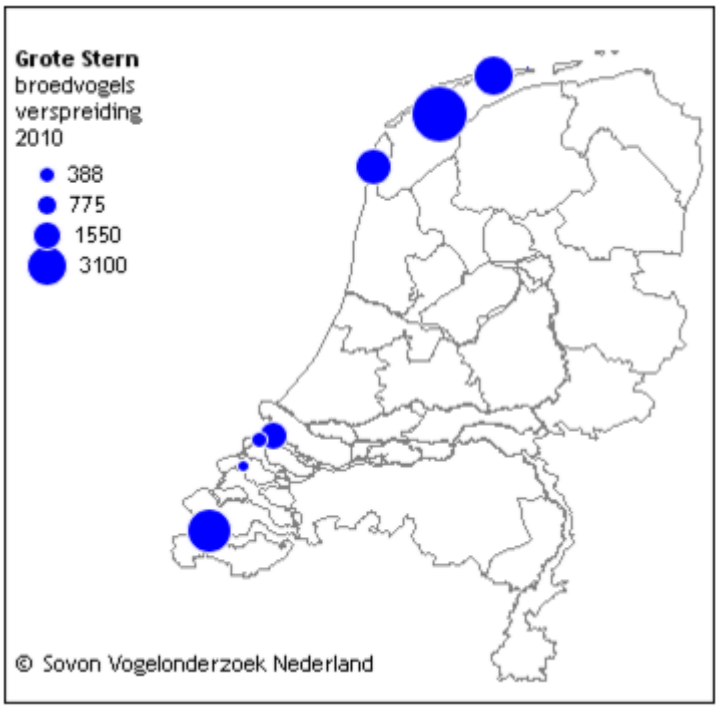

Figure 11. Breeding locations of T. sandvicensis in the Netherlands 2010 (Sovon, 2015)

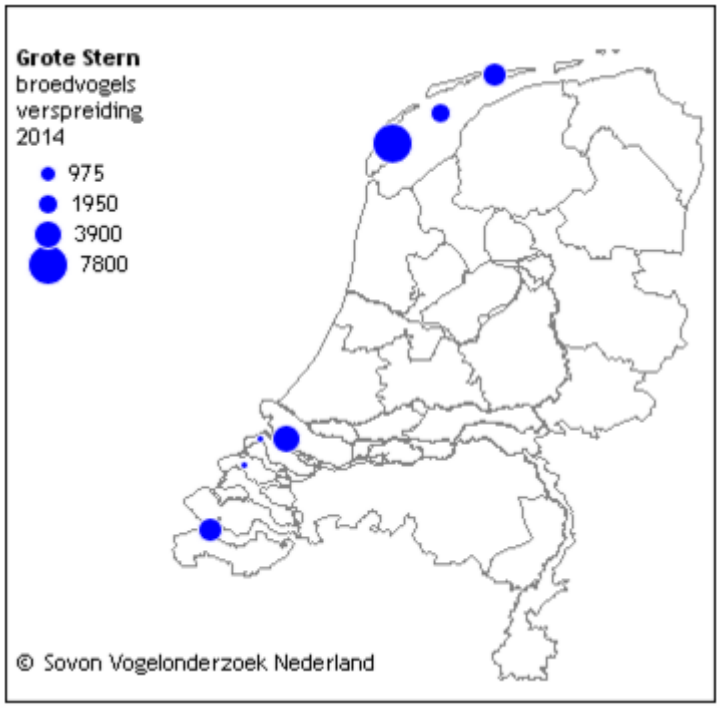

Figure 12. Breeding locations of T. sandvicensis in the Netherlands 2014 (Sovon, 2015)

4.1.2 Population history

Between 1991 and 1996 the single large colony on the Dutch island Griend supported 40-46% of the Wadden Sea population. The size of the population fluctuated between 6,600 and 900 from 1988-1995. The colony was reduced in 1996 to only 5,600 and even lower in 1997, it was recovered a year later to 7,000 pairs in the colony. The drop in the colony in 1996 was coincided with the collapse of the local Sandeel *(Hyperroplus lanceolatus* and *Ammidytes tabianus)*. Assumption could be made that the number of breeding birds is correlated with the food availability (Stienen, et al., 2000; Rasmussen, et al., 2000). Over the years the number of pairs has fluctuated, not only in the Netherlands but over the whole Wadden Sea area. The population in the Netherlands is the biggest compared to Germany and Denmark (Figure 13). (Rasmussen, et al., 2000).

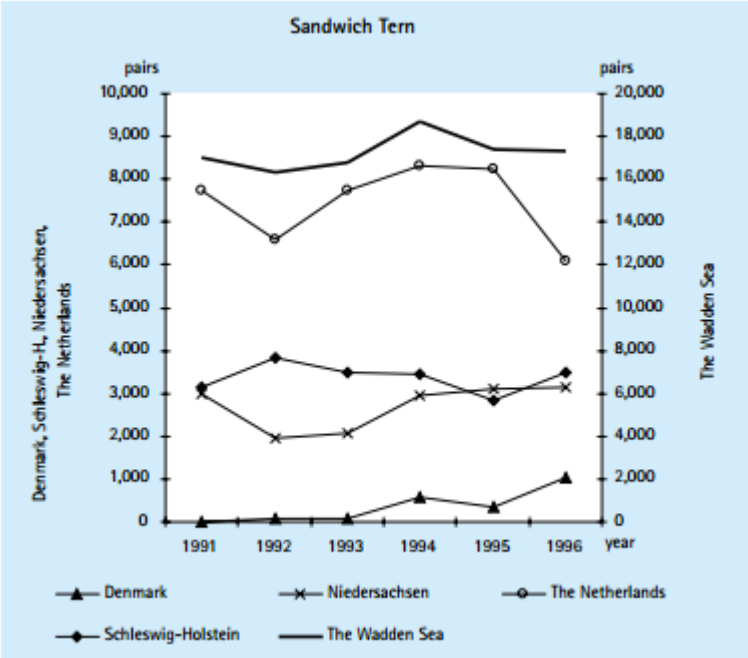

Figure 13. Number of breeding pairs of T. sandvicensis in the three countries and in the entire Wadden Sea from 1991 to 1996. (Rasmussen, et al., 2000)

In the 21th century the European breeding population was approximately 166,000-171,000, in the Netherlands this lies between 19,000 and 19,200 (Arts, 2012). Figure 5 on page 8 a small decrease in the latest trend of breeding bird in the Netherlands after 2011 is presented. To know why there is again a small decline in foraging breeding couples more research is needed from researchers. (InterWad, 2010) (Sovon, 2015)

4.2 Current Situation

The distribution of breeding pairs between 1990 till 2016 in the Wadden sea can be seen in Figure 14. The numbers of 2015 and 2016 are not the final numbers. There are three main areas where *T. sandvicensis* can be found, on the islands of Ameland, Texel and the uninhabited island Griend. What really stands out in this graph is the decline in breeding pairs on Griend. But overall the numbers of breeding pairs are increasing especially on Texel.

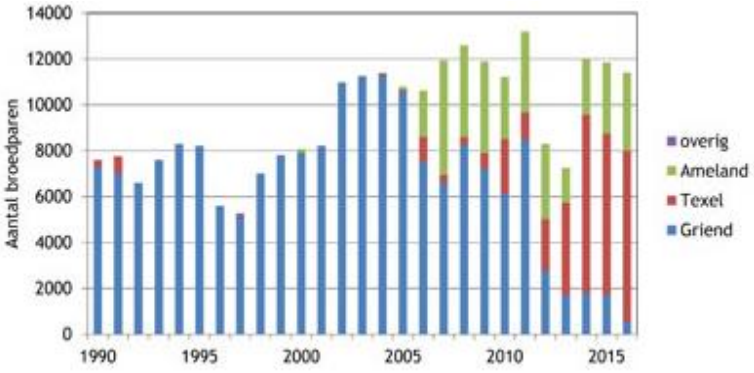

Figure 14. Numbers of breeding pairs in the Wadden Sea (Sovon, 2016)

4.2.1 Breeding population and breeding grounds in Europe

The European population has 79,900-148,000 breeding pairs, nonetheless the population size is fluctuating. In March 2015 *T. sandvicensis* has been evaluated as a European Red List species (status Least Concern). *T. sandvicensis* is breeding on several locations in Europe, for instance in Ukraine, France, the United Kingdom and the Netherlands (BirdLife International, 2015). A map of the breeding grounds and the wintering sites is placed in Figure 15.

Figure 15. Foraging and breeding areas for the Thalasseus sandvicensis

4.2.2 Breeding population and breeding grounds in the Netherlands

The breeding population of *T. sandvicensis* in the Netherlands has been estimated at 16,650-16,750 in 2014 (Sovon, 2016). In the past years *T. sandvicensis* is spotted breeding in the Wadden Sea and in the delta in the provinces of Zeeland and Zuid-Holland. Figure 14 shows the breeding sites and the number of breeding pairs found on the locations. 11,967 breeding pairs are found in the Wadden Sea, some are breeding on the islands of Ameland (1,520), Texel and on the uninhabited island Griend. In the delta *T. sandvicensis* is found on the island Markenje and Slijkplaat (Mud plate) (Sovon, 2016).

4.2.3 Breeding population in the Wadden Sea (the Dutch, Danish and German part)

The most recent count of the breeding population *T. sandvicensis* in the Wadden Sea dates from 2011, in this year the breeding population in the Wadden Sea is estimated at 26,400 (Common Wadden Sea Secretariat, 2015). Over half of the population has been breeding in the Dutch part of the Wadden Sea. The monitoring of the Dutch, Danish and German Wadden Sea is carried out by the Joint Monitoring Group for Breeding Birds (JMBB). The evaluation is carried out in the framework of the Trilateral Monitoring and Assessment Program (TMAP) of the Wadden Sea. The breeding locations of *T. sandvicensis* in the Dutch part of the Wadden Sea are: Griend, Texel and Ameland. Griend is an uninhabited island in the Wadden sea but the breeding population is declining. One of the reason for this decline is the presence of the Herring gull *(Larus argentatus)*. These gulls predate on the juvenile *T. sandvisencis* (Sovon, 2016). The location of the breeding population on Texel is Utopia, Utopia is a protected area for birds which is sheltered from the sea by dikes. The breeding location on Ameland is the Feugelpôlle, which is the second-largest breeding area for *T. sandvicensis* in West-Europe (Staatsbosbeheer, 2015). The Feugelpôlle is a salt marsh located between the villages of Hollum and Ballum on the south-western part of Ameland. Saltmarshes can usually adjust to sea level rise. But this is not the case with Feugelpôlle, because of the sea level rise a part of the Feugelpôlle has disappeared (Staatsbosbeheer, 2015).

4.3 Future

The current Habitat of *T. sandvicensis* might decrease due to sea level rise. The two scenarios which were described in paragraph 3.2 were carried out in a GIS analysis. The outcome of this analysis is illustrated in maps, as seen in Figure 16 and 17.

Figure 16 illustrates the best case scenario, which is RCP 2.6. This scenario predicts a mean sea level rise of 0.24 meters for the first 50 years and a mean sea level rise of 0.40 for the years 2081-2100. Figure 17 illustrates the worst case scenario, which is RCP 8.5. In this scenario the Sea level will rise 0.30 meters in the period of 2046-2061 and will rise approximately with 0.63 in the period of 2081-2100.

Figures 18 and 19 show the two scenarios with the locations of the breeding grounds. And what can then be seen is that Sea level rise itself will not threaten the breeding grounds of *T. sandvicensis.* But the future of the breeding grounds of *T. sandvicensis* in the Wadden Sea is not certain, there is already a decline in breeding pairs on Griend. This is perhaps not entirely due to climate change, it can also be caused by predators. But an important habitat for the breeding of *T. sandvicensis* are the mudflats, and it is uncertain what happens to the banks where they breed because the Wadden Sea is such a dynamic system. These aspects will be covered more detailed in paragraph 5.

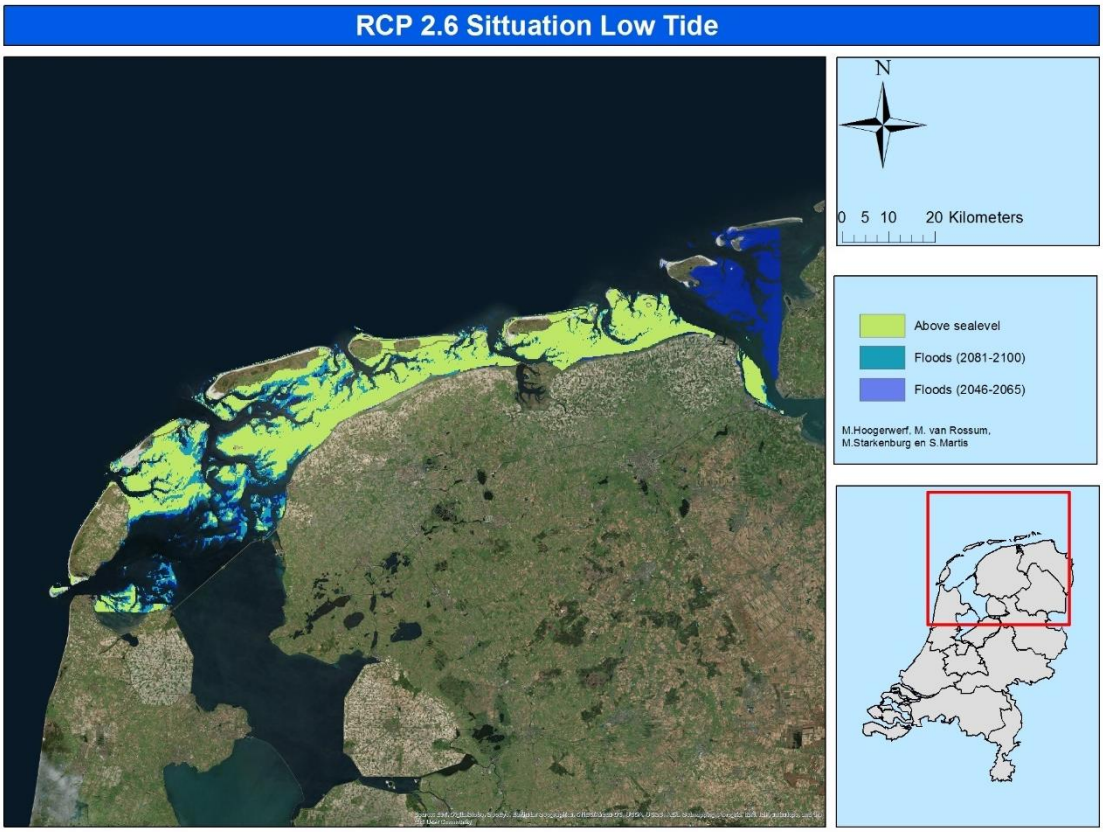

Figure 16. Sea level Rise scenario RCP2.6

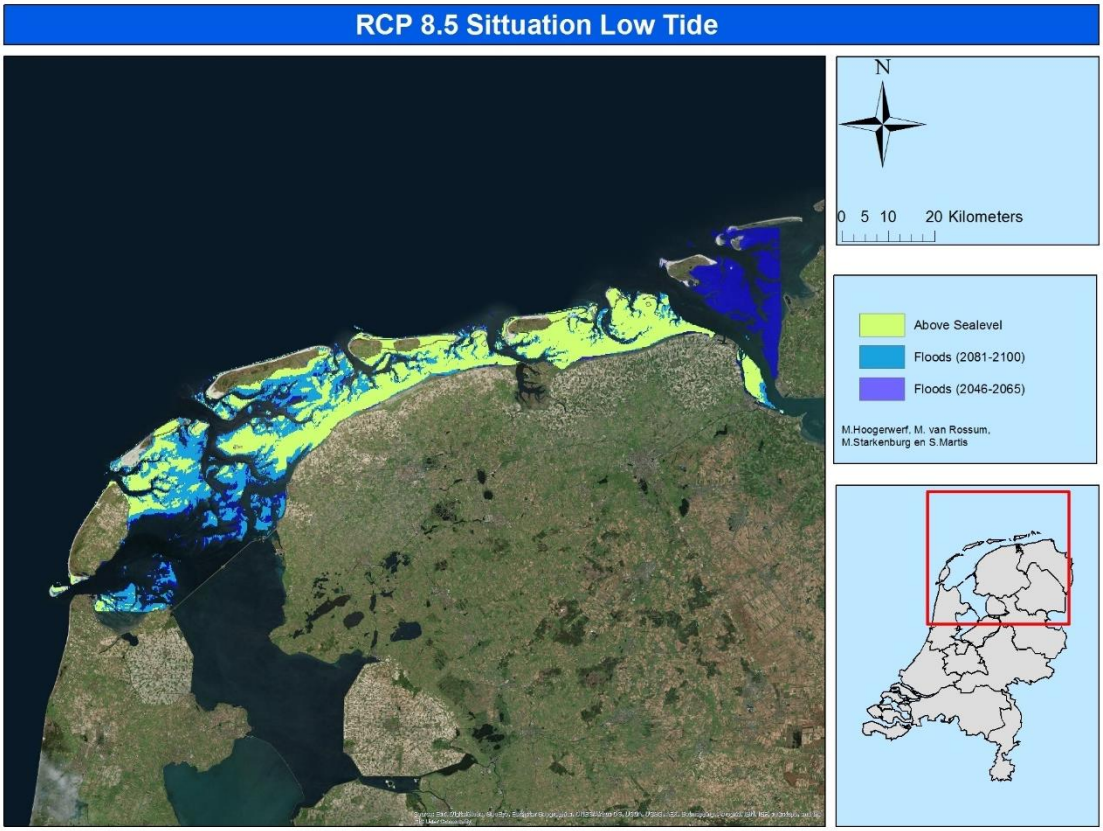

Figure 17. Sea level rise scenario RCP 8.5

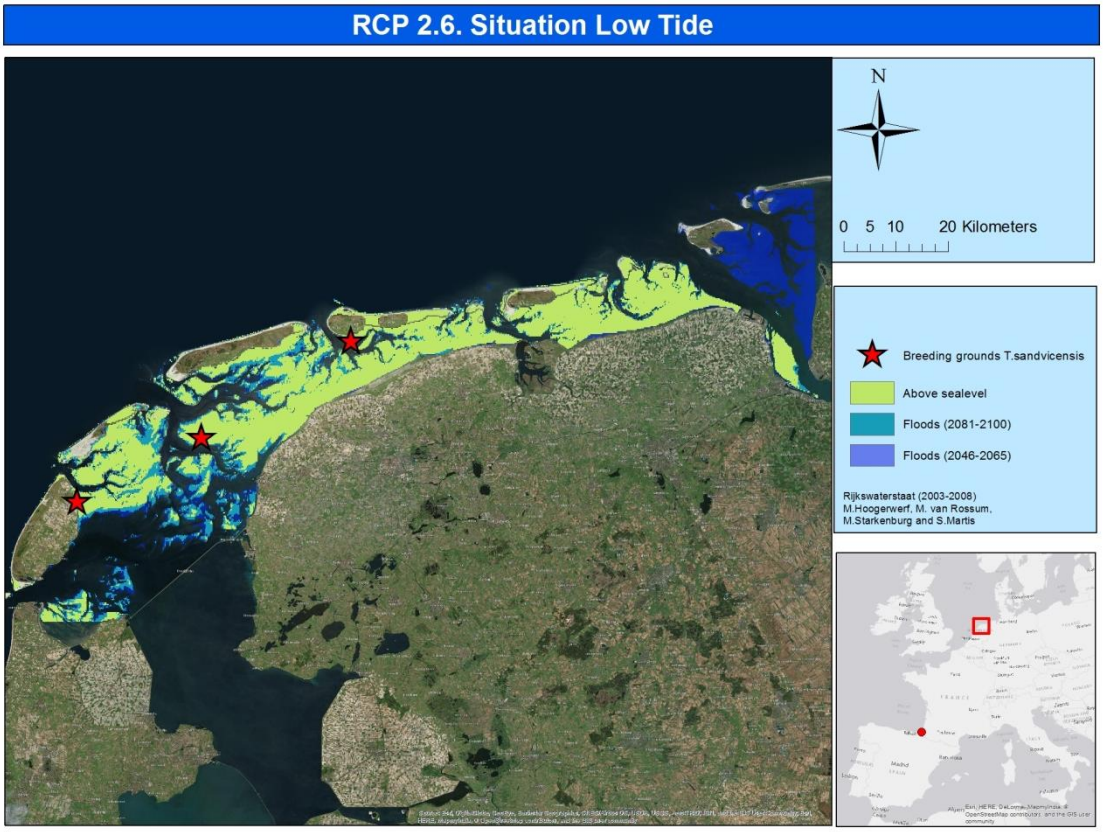

Figure 18. Sea level rise scenario RCP 2.6 with breeding ground locations

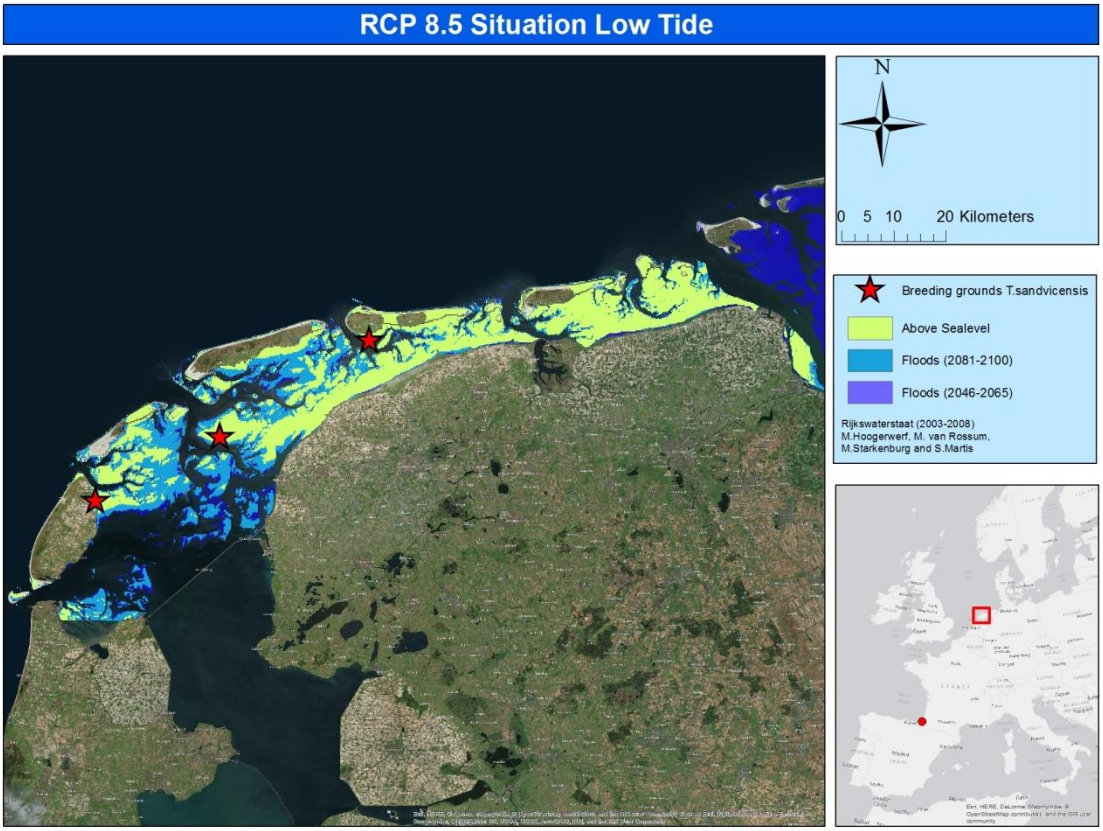

Figure 19. Sea level rise scenario RCP 8.5 with breeding ground locations

5 Discussion

The result of the research depends on the choices and assumptions that have been made during this research, an example is the assumed sea level rise. These factors are described in this chapter. This chapter also describes factors which have not been included in this research, but which possible have an effect on the population *T. sandvicensis*.

The estimated future sea level at low tide has been used to predict the effect of sea level rise on the breeding grounds of *T. sandvicensis.* The possible effects of exceptional events, which might result in for example flooding have not been evaluated. Single events might damage the breeding grounds of *T. sandvicensis* in such a way that the breeding grounds are (temporarily) no longer suitable for (a number of) individuals of the population *T. sandvicensis*. More research is needed to estimate the relation between sea level rise and the probability of such exceptional events to occur. More research into the damage to the breeding grounds of *T. sandvicensis* caused by these events is required as well.

In the Wadden Sea natural gas is extracted from gas fields. Natural gas is extracted at three locations. The extraction of gas results in the flow of the rock salt, an increase in density of the sandstone and pressure decline in the aquifers which results in subsidence (The Waddenacademie, 2015). A probable more important cause of subsidence is the salt mining in the Western part of the Dutch Wadden Sea (Waddenvereniging, 2015). The subsidence as a result of the salt mining is estimated to a total of 1 meter, or 0,03-0,05 meter a year. Subsidence might have the same effect on the Wadden Sea as the sea level rise. And perhaps that might increase the effect of sea level rise on the Wadden Sea.

That there is a correlation between food availability and the population was mentioned paragraph 4.1. However this factor was not used in the actual research. *T. sandvicensis* mostly feeds on smaller fish such as sand lance and mullet, but also eats shrimp, squid, marine worms and many insects (Kenn Kaufman, sd). Therefor a decline in the population of *T. sandvicensis* could also be caused by a decrease in marine life. Climate change is one of the main reasons for decline in marine species over the past 30 years (WWF, 2015). The commercial fishery is also a factor which might cause a decline in the food availability of *T. sandvicensis* in the future.

A number of activities take place in the surrounding area of the breeding grounds of *T. sandvicensis.* Ferries sail from multiple locations to the five inhabited islands several times a day, commercial fishery, recreational sailing and (mudflat)walking. The effect of these activities has not been evaluated, the future impact of these scenarios is therefore not included in the future scenario. This means that although sea level rise might not affect the population, the population might still be in risk because of human activities.

6 Conclusion

The aim of this research was to find out what the effect of sea level rise will be on the breeding grounds of T. sandvicensis in the Dutch Wadden Sea, and how the sea level rise will affect the population. The effects of sea level rise have been determined by evaluating the effects of the IPCC scenarios RCP 2.6 and RCP 8.5 which represent the minimum and the maximum global sea level rise. The averages of these scenarios have been used for this purpose. The scenarios have been used to predict the future sea level of the Dutch part of the Wadden Sea. Geographic Information Systems (GIS) was used to visualize the effects of the scenarios on the breeding grounds of T. sandvicensis. Several publications are used to answer the research question.

In both of the scenarios the sea level rise will not have a negative effect on the breeding grounds. This means that the sea level rise will have no effect on the population *T. sandvicensis* in both the best and the worst case scenario. However, there are some reasons to believe that other factors possible do harm the *T. sandvicensis* population in the future. Some of these factors are likely to be related with sea level rise, but most of them are not.

As described before, the estimated future sea level at low tide has been used to predict the effect of sea level rise on the breeding grounds of *T. sandvicensis.* The possible effects of exceptional events, which might result in for example flooding have not been evaluated. Single events might damage the breeding grounds of *T. sandvicensis* in such a way that the breeding grounds are (temporarily) no longer suitable for (a number of) individuals of the population *T. sandvicensis*. More research is needed to estimate the relation between sea level rise and the probability of such exceptional events to occur. More research into the damage to the breeding grounds of *T. sandvicensis* caused by these events is required as well. Global sea level rise is only one of many factors that possibly acts on the population *T. sandvicensis.* Salt mining and the extraction of natural gas in the Dutch Wadden Sea area cause subsidence of the breeding grounds. Recreational activities and commercial fishery can harm the population by causing stress or by causing injuries to individuals. Therefor there might be an effect on the breeding grounds after all. More research needs to be done to get more insight into the future of the Wadden Sea.

7 Bibliography

Alterra. (2008). *Grote stern (Sterna sandvicensis).*

Arts, F. A. (2012). *Trends en verspreiding van zeevogels en zeezoogdieren op het Nederlands Continentaal Plat 1991-2011.* Culemborg: Delta Project Managment.

Birdlife international. (2000). The Netherlands. In E. Osieck, *Important Bird areas in Europe volume 1: Northern Europe* (pp. 465 - 479). Cambridge.

Burbridge, P., Enemark, J., Maremcic, H., Oost, A., Reise, K., Schroor, M., & Wolff, W. (2012). *Waddenzee Werelderfgoed.* Utrecht: Matrijs.

Burbridge, P., Enemark, J., Marencic, H., Oost, A., Reise, K., Schoor, M., & Wolf, W. (2012). Waddenzee, Werelderfgoed. Utrecht: Matrijss.

Ecomare. (sd). *Nederlandse Waddengebied*. Opgehaald van ecomare.nl : http://www.ecomare.nl/ecomare-encyclopedie/gebieden/waddengebied/nederlands-waddengebied/

Ens, B., Piersma, T., Zwarts, L., & Kam, J. (2004). *Shorebirds ans illustrated behavioural ecology.* Utrecht: KNNV publishers.

InterWad. (2010, December 2). *Vogels*. Opgehaald van waddenzee.nl: http://www.waddenzee.nl/Vogels.1219.0.html

IPCC. (2013). *Climate Change The Physical science Basis.* New York: Cambridge University.

Kenn Kaufman. (sd). *Sandwich Tern*. Opgehaald van audubon.org: http://www.audubon.org/field-guide/bird/sandwich-tern

Leopold, M., & Engels, B. (2014). *De grote stern : een 'zeestern' gaat binnendijks .*

Lotze, H. K. (2007, 11). Rise and fall of fishing and marine resource use in the Wadden Sea, southern North Sea. *Fisheries Research*, 208-218.

National Geograpic. (2008). *Sealevel rise.* Opgehaald van ocean.nationalgeograpic: http://ocean.nationalgeographic.com/ocean/critical-issues-sea-level-rise/

Rasmussen, L. M., Fleet, D. M., Hälterlein, B., Koks, B. J., Potel, P., & Südbeck, P. (2000). *Breeding birds in the Wadden Sea in 1996 - Results of a total survey in 1996 and of numbers of colony breeding species between 1991 and 1996.* Wilhelmshaven: Common Wadden Sea Secretaria, Trilateral Monitoring and Assesment Group, Joint Monitoring Group of Breeding Birds in the Wadden Sea.

Reise, K. (2013). *A Natural History of the Wadden Sea.* Leeuwarden, the Netherlands: Wadden Academie.

Rijksoverheid. (2013, 12 30). *Compendium voor de Leefomgeving Milieukwaliteit en Natuur*. Retrieved from Rijksoverheid : http://www.clo.nl/indicatoren/nl1103-grote-stern-en-organochloorverbindingen?i=17-94&pdf=new

Sovon. (2015). *Grote stern*. Opgehaald van Sovon: https://www.sovon.nl/nl/soort/6110

Sovon. (2016, 06 02). *Texel in trek bij broedende Grote Sterns in Waddenzee*. Opgehaald van Sovon: https://www.sovon.nl/nl/actueel/nieuws/texel-trek-bij-broedende-grote-sterns-waddenzee

Spoelmans. *Grote Stern - T. sandvisensis.* Texel.

Staatsbosbeheer. (2015). *Feugelpôlle: natuurlijke klimaatbuffer*. Opgehaald van Staatsbosbeheer: http://www.staatsbosbeheer.nl/natuurgebieden/ameland/feugelpolle

Stienen, E. W., Van Beers, P. W., Brenninkmeijer, A., Habraken, J. M., Raaijmakers, M. H., & Van Tienen, P. G. (2000). Reflections of a specialist: Patterns in food provisioning and foraging conditions in Sandwich Terns Sterna Sanvicensis. *Ardea*, 33-49.

UNESCO. (n.d.). *wadden Sea*. Retrieved from werelderfgoed.nl: http://www.werelderfgoed.nl/en/world-heritage/wadden-sea

van de Kam, J., Ens, B., Piersma, T., & Zwarts, L. (2006). *Shorebirds An illustrated behavioural ecology.* Utrecht: KNNV Publishers.

Vink, A., Steffen, H., Reinhardt, L., & Kaufmann, G. (2007). Holocene relative sea-level change, isostatic and the radial viscosity structure of the mantle of northwest Europe (Belgium, the Netherlands, Germany, southern North Sea). *Quanternay Science Reviews*, 3249-3275.

World heritage. (n.d.). *Dutch-Wadden Sea*. Retrieved from http://www.waddensea-worldheritage.org/wadden-sea-world-heritage/dutch-wadden-sea

WWF. (2015). *Climate change and fish*. Opgehaald van https://www.msc.org/healthy-oceans/the-oceans-today/climate-change