Case Study Sandwich Terns – a probabilistic analysis of the ecological effects of dredging

Yvonne van Kruchten (DHV)
Tessa van der Hammen (IMARES)
Report number C055/11

IMARES Wageningen UR

(IMARES - Institute for Marine Resources & Ecosystem Studies)

Client:	ECOSHAPE- BUILDING WITH NATURE Burgemeester de Raadtsingel 69 3311 JG Dordrecht
Publicatiedatum:	Mei 2011

IMARES is:

- an independent, objective and authoritative institute that provides knowledge necessary for an integrated sustainable protection, exploitation and spatial use of the sea and coastal zones;
- an institute that provides knowledge necessary for an integrated sustainable protection, exploitation and spatial use of the sea and coastal zones;
- a key, proactive player in national and international marine networks (including ICES and EFARO).

P.O. Box 68 1970 AB IJmuiden Phone: +31 (0)317 48 09 00 Fax: +31 (0)317 48 73 26 E-Mail: imares@wur.nl www.imares.wur.nl	P.O. Box 77 4400 AB Yerseke Phone: +31 (0)317 48 09 00 Fax: +31 (0)317 48 73 59 E-Mail: imares@wur.nl www.imares.wur.nl	P.O. Box 57 1780 AB Den Helder Phone: +31 (0)317 48 09 00 Fax: +31 (0)223 63 06 87 E-Mail: imares@wur.nl www.imares.wur.nl	P.O. Box 167 1790 AD Den Burg Texel Phone: +31 (0)317 48 09 00 Fax: +31 (0)317 48 73 62 E-Mail: imares@wur.nl www.imares.wur.nl

Building with Nature

EcoShape

Adaptive Monitoring Strategies in dredging;

Case Study Sandwich Terns – a probabilistic analysis of the ecological effects of dredging

EcoShape – Building with Nature

Project:	Adaptive monitoring strategies 1
Report number	C055/11
Report title:	Case Study Sandwich Terns – a probabilistic analysis of the ecological effects of dredging
Authors:	Yvonne van Kruchten (DHV) Tessa van der Hammen (IMARES)
Project manager:	Martin Baptist
Date:	May, 2011

Contents

1 Introduction

1.1 Background

Every year, large amounts of sand are extracted from the North Sea to meet the demands for construction activities. Potential ecological effects of these sand mining activities have to be examined and reported in so called Environmental Impact Assessments (EIA's). In the Netherlands, the potential impacts of sand mining activities on tern populations often form an important topic in these EIA's. Sand mining causes an increase in silt concentrations. This increase will influence the turbidity of the water, which may affect populations of visual hunting birds, such as terns.

The quantification of ecological effects in Environmental Impact Assessments is mostly done by deterministic modeling of cause-effect chains. However, within these cause-effect chains, usually a large number of uncertainties play a role. Part of these uncertainties are inherent to natural variation, other uncertainties are caused by a lack of knowledge on the relevant processes in the cause-effect chain. Worst-case assumptions are necessary in the deterministic approach to account for these uncertainties. As a result, the predicted impact is based on an accumulation of worst-case assumptions making it a highly conservative approach with an unknown uncertainty margin. However, also a probabilistic approach can be applied for the quantification of the possible ecological effects. In a probabilistic approach the relevant uncertainties are incorporated in the modeling of the ecological effects. The result of the probabilistic modeling is a probability distribution of the possible effects, which includes information on the probability of occurrence of certain impacts. Besides, the results show the influence of natural dynamics on the uncertainty margin of the predicted impact.

1.2 Objective

The objective of this case study is to explore how a probabilistic approach can be applied for the quantitative modeling of the potential effects of sand mining on tern populations. As an example, the probabilistic methodology is worked out for the effects of a fictitious dredging project on a population of Sandwich Terns (*Sterna sandvicensis*). First, a literature search was performed to explore how tern populations may be affected by dredging activities. From the results of this literature research a cause-effect chain was formed. The relations within the cause-effect chain were quantified, making it possible to model the impact of dredging on the tern population.

1.3 Report structure

Chapter 2 describes the ecology of Sandwich Terns. A qualitative description of the cause-effect chain from dredging activities to Sandwich Terns is given in Chapter 3. The quantitative modeling of the impact on tern populations is worked out in Chapter 4. The findings of this case study are discussed in Chapter 5.

2 Ecology of the Sandwich Tern (*Sterna sandvicensis*)

Sandwich terns are visual hunters and forage primarily in shallow coastal waters. Their diet consists almost entirely of fish. In the Netherlands this is mainly *Clupeidae* (herring *Clupea harengus* and sprat *Sprattus sprattus*) and *Ammodytidae* (sandeel, *Ammodytes tobianus* and greater sandeel, *Hyperoplus lanceolatus*) (Veen, 1977; Stienen & Brenninkmeijer, 1998; Stienen *et al*., 2000). This restricted choice is expected to make them vulnerable to variation in the availability of these fish species.
Terns use aerial plunge diving as foraging technique (Taylor, 1983). While plunging from the air, they must continuously adjust their position and rate of descent to match the location of visually-located prey (Ainley, 1977). They therefore depend on the availability of fish in the top layer of the water column, as well as on the transparency of the water to locate their prey.

Figure 1 Sandwich Tern (Sterna sandvicensis), picture: Martin Baptist

Most European terns winter along the west coast of Africa. In the Netherlands, Sandwich terns are present during their breeding period (Figure 2). They breed in colonies which are usually large and dense, around 2-10 nests per m^2. They lay 1 or 2 (occasionally 3) eggs between the end of April and half of May. The breeding period is around 25 days and both parents feed and take care of the chicks. The distance between the colony and the foraging ground is variable and may exceed 25 km (Stienen, 2006). The Dutch population suffered from a major kill in the 1960 due to pesticides, when the population decreased from around 35.000 to less than 900 breeding pairs. In the last decennia, the population increased strongly (Figure 3). The population is not fully recovered to the level from before the crash, causing the Sandwich tern to be on the IUCN red list of protected species. However, Sandwich terns are not believed to approach the thresholds for the population decline criterion, therefore the species is evaluated as ‘Least Concern’.

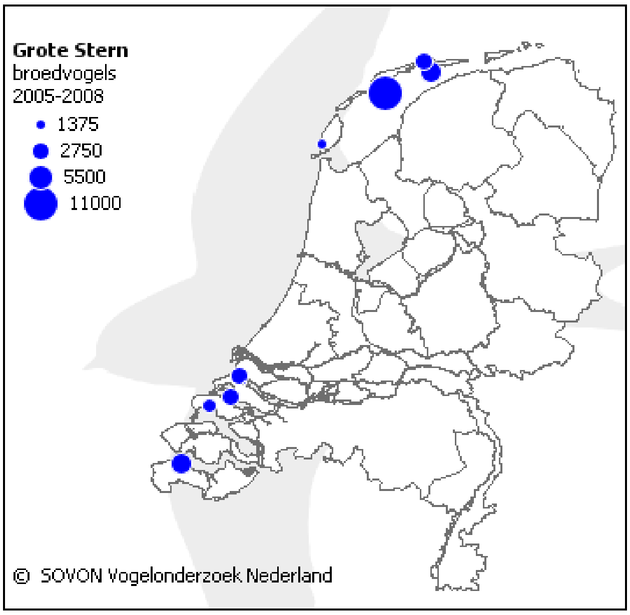


Figure 2 Breeding colonies of Sandwich Terns in the Netherlands, source: www.sovon.nl

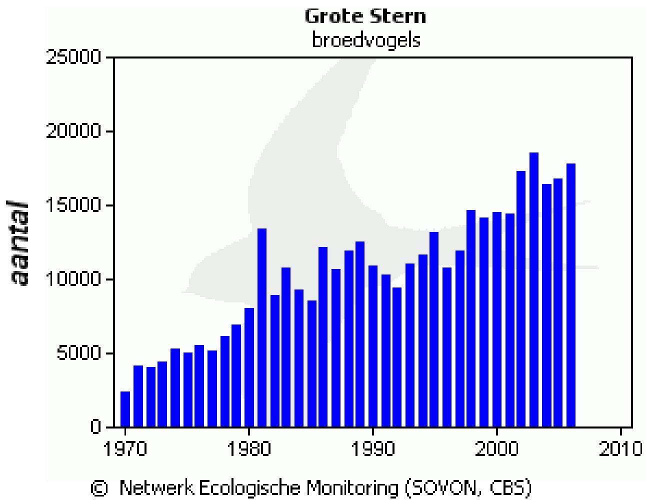


Figure 3 Number of breeding pairs in the Netherlands, source: www.sovon.nl

3 Cause-Effect Chain

In order to model the impact of dredging activities on Sandwich Tern populations, literature search was carried out to find out how dredging could affect these populations. This literature search led to the cause-effect chain that is shown in *figure 4*[1]*.* In this chain the relations that are expected to influence the population size are visualized.

In short, the cause effect chain is based on that an increase of silt concentrations caused by dredging leads to an effect on the population size through a decrease in breeding success. The main steps involved leading to this reduction are (orange boxes in figure 4):

(1) sand extraction by dredging activities causes an increase of the silt concentration in the water column
(2) the increase of the silt concentration causes an increase in turbidity of the water
(3) the increase in turbidity reduces the catchability of fish by terns
(4) the reduced catchability leads to an increase in time needed to catch enough food
(5) if the available time is limiting, the amount of food brought to the chicks is reduced
(6) if food intake of the chicks is reduced, the breeding success of the terns decreases

In the following sections the steps in the cause-effect chain will be explained in more detail.

[1] In the cause-effect chain of Figure 4 no link has been added between water transparency or silt concentration and prey density. In this study is assumed that prey density and prey size are not affected by an increase of silt concentrations or turbidity. This assumption is expected to be valid for prey fish in the Dutch coastal zone and for the range of silt concentrations that is considered in this study. However, this assumption is not founded on literature research.

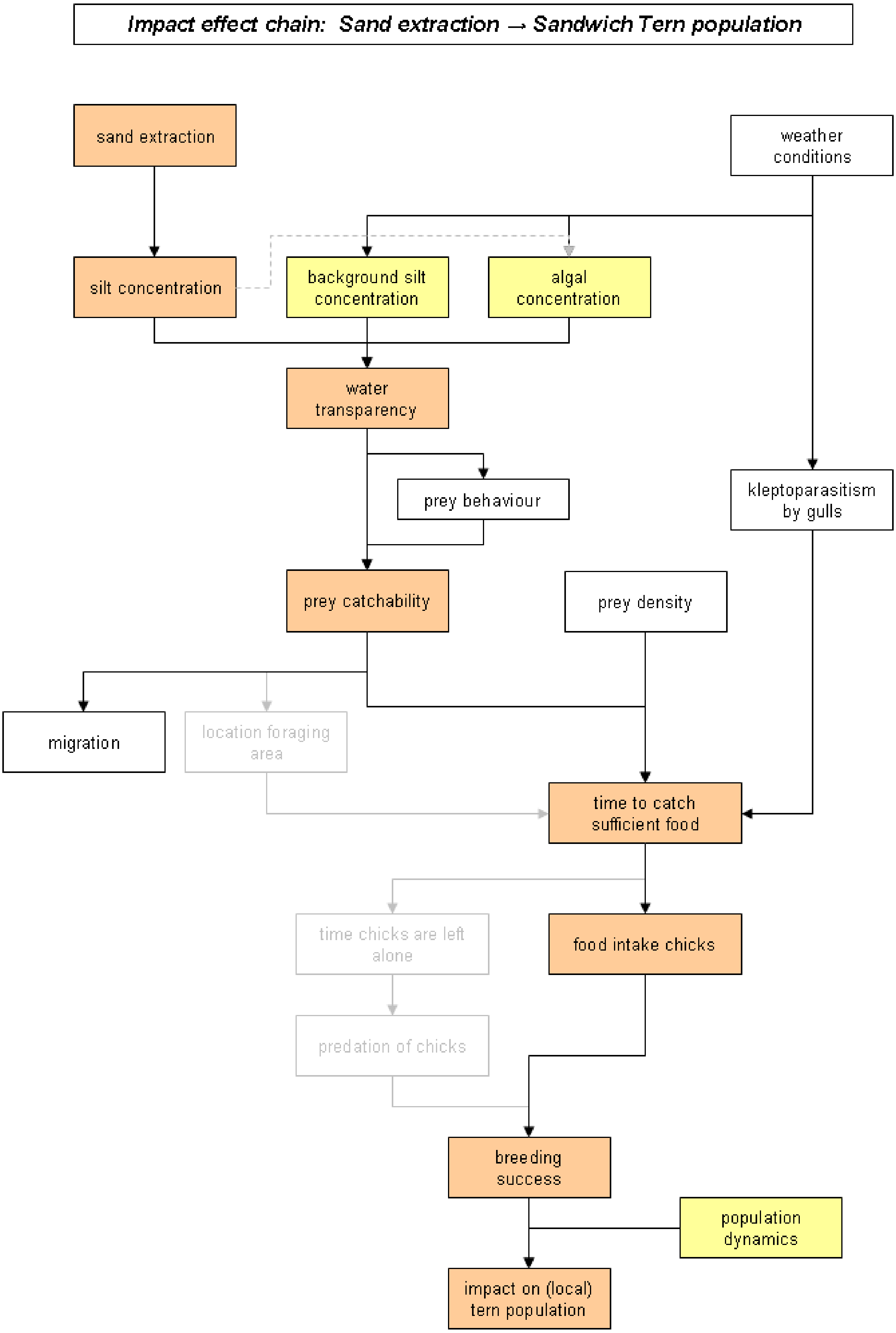


Figure 4 Cause-effect chain dredging – Sandwich Tern population

3.1 Sand extraction – water transparency

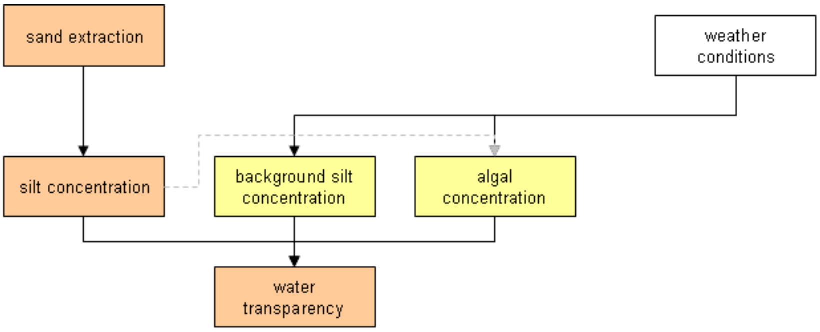


Figure 5 Part of the impact-effect chain: sand extraction - water transparency

Sand extraction activities will cause a release of fine sand and silt particles in the water column. During the dredging process a sand-water mixture is pumped up from the seabed into the hold of the dredging vessel. While the sandy part of this mixture settles in the hold, the excess transport water will flow back into the sea. This overflowing water contains fine particles, up to 150 μm. The sand particles (>63 μm) will settle relatively quickly at the seabed, but the silt particles (<63 μm) will stay suspended in the water column for a longer time. These suspended silt particles cause a 'dredging plume' near the dredging vessel. As a result of tidal currents and wave action, this dredging plume will be spread out over a larger area. After settling at the seabed, the silt particles can be stirred up again during stormy periods by wave motions. Due to these mechanisms the sand extraction causes an increase of the silt concentration over an area much larger than the visible dredging plume. The impact also lasts longer than the period during which the dredging plume is visible.

Apart from the suspended particulate matter (SPM) that is released during the dredging process, seawater always contains a certain background concentration of SPM. This background concentration is not constant, but fluctuates due to wave action, current velocities, tide and river discharges. Next to the SPM-concentration, phytoplankton concentrations also influence the transparency of seawater. The concentration of phytoplankton depends on the intensity of sunlight, the availability of nutrients and on the water transparency itself. The phytoplankton concentration (primary production) is limited by the light intensity of the water column. Therefore, there is a back-feeding mechanism between phytoplankton concentrations and the water transparency.

The relative contribution of the dredging activities to the turbidity of the water at a specific location will depend strongly on the background turbidity (SPM and phytoplankton), the distance to the sand extraction site and the time elapsed since finishing the dredging activities.

3.2 Water transparency – prey catchability

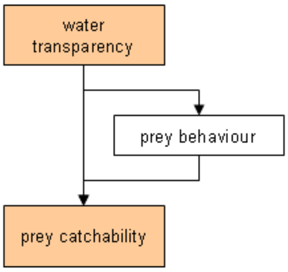


Figure 6 Part of the impact-effect chain: water transparency-prey catchability

An increase of the turbidity of the water may have a negative impact on the 'catchability' of fish for visual hunters like terns. In turbid waters it may be more difficult for terns to locate their prey. If so, this may lead to an increased searching time for prey and the probability of a successful catch-attempt to decrease.

There are two studies that show that the catchability of fish by Sandwich terns may indeed depend on the water transparency. First, Brenninkmeijer et al (2002) show that the capture rate of fish by Sandwich Terns in Guinea-Bissau decreased at higher levels of turbidity. Second, Baptist and Leopold (submitted) also found a decreasing capture rate for decreasing transparency in the North Sea near the Dutch island Texel, but only at levels of Secchi disk transparency lower than 1.74 meter (figure 13). At higher levels of transparency, they observed that the catch probability decreased with increasing transparency (figure 13).

On the other hand, prey may adjust their vertical position depending on light conditions and tidal movements, resulting in fluctuations in prey availability for the terns during the day (Thorpe, 1978). More importantly, prey availability on the surface of the water also depends on the turbidity of the water. If the water is clearer, fish move deeper in the water to avoid predation and if the water is more turbid the fish move nearer to the water surface.

3.3 Prey catchability – time to catch sufficient food

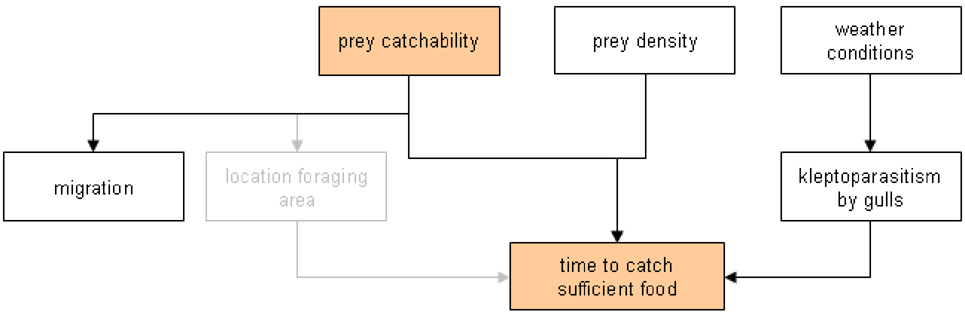


Figure 7 Part of the impact-effect chain: prey catchability – time to catch sufficient food

A reduction in the catchability of prey may lead to a shortage of food intake. However, the impact of catchability on the food intake of the birds and their chicks will depend strongly on the time available for foraging. If time is not limiting to make the amount of plunges needed to provide the chicks with sufficient food, there is no reason to assume that a reduction in catchability will lead to a reduction in the fitness of the birds. However, it is likely that turbidity not only decreases the catchability of prey, but also the searching time to locate the prey. Unfortunately, no information was found on this relationship. In

chapter 4 is described in more detail how this step is quantified despite of the poor data availability. Other factors that may influence the effort (time) needed to catch enough food for the terns to raise their chicks are prey density and kleptoparasitism.
Below the different factors that influence this step in the effect chain are described.

3.3.1 Time available

Terns at Griend have been observed foraging between 4.00 in the morning till 22.00 at night (figure 8, Stienen et al, 2000). This results in approximately 18 available hours for foraging per parent (4.00h-22.00h). However, it is unknown how much time the terns need resting per day, thus how many hours are available per tern. Other sources have suggested that the time available is around 10 hours (In Guinee Bissau, Stienen thesis page147) or 15 hours (Baptist & Leopold, 2007).

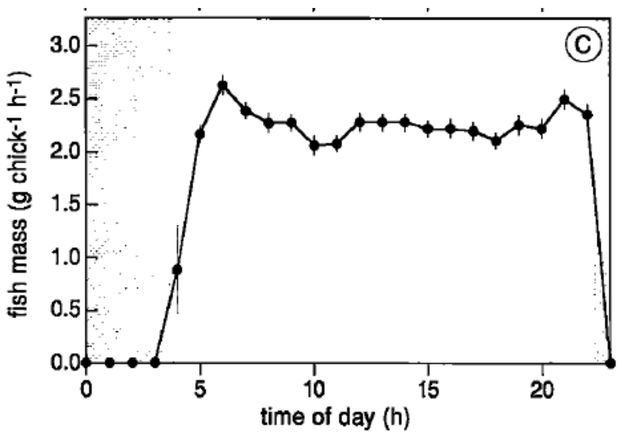


Figure 8 Diurnal patterns in mass provisioning rate of Sandwich Tern chicks on Griend (1992-1998). Means ±SE are plotted. It was assumed that no feeding occurred during the night. (Stienen et al., 2000).

3.3.2 Prey density

The availability (density) of prey may influence the number of fish caught by terns. In the Netherlands, terns feed predominantly on *Clupeidae* (herring *Clupea harengus* and sprat *Sprattus sprattus*) and *Ammodytidae* (sandeel *Ammodytes tobianus* and greater sandeel *Hyperoplus lanceolatus*, Veen 1977, Stienen & Brenninkmeijer 1998). On Griend, in the Dutch Wadden Sea, 99.3% of the diet consists of these species (Stienen & Brenninkmeijer 1998). Although highly specialized piscivorous seabirds such as Sandwich Terns, are often particularly vulnerable to temporal and spatial variations in their prey, Stienen and Brenninkmeijer (1998) showed that differences in prey fish abundance did not reflect the food supply of the tern's chicks by their parents. However, Stienen (thesis, p161, referring to Cardinale et al 2003) mention that it is difficult to measure food availability for sandwich terns because their prey occur in shallow water, are patchily distributed and perform species - specific diel vertical migration, schooling and feeding behaviour. However, they did find that the proportion of herring in the food brought to the colony reflected the herring availability quite well (Stienen and Brenninkmeijer 1998), suggesting that the availability of herring is important in the chick's diet.

3.3.3 Foraging location

When the catchability of prey decreases in the usual foraging area of the terns due to an increase in turbidity levels, the birds may change their foraging location to another area further away, where turbidity levels are lower. Terns are capable of enduring flight distances from the breeding ground to the foraging area of more than 25 km (Stienen 2006, and references therein). Therefore, if other foraging grounds are in the vicinity of the original breading ground, they may be able to switch. Unfortunately no research has been done on this topic.

In this case study the possibility that the terns change their foraging location in case of an increased turbidity, is not taken into account (worst-case assumption). Probably the terns only change their foraging area if this minimizes the total time it takes to catch and to bring a fish to their nest (the longer flight distance should be compensated by the better catchability at the new foraging location). Ignoring the time minimization to catch a fish, is a conservative approach for modeling the possible impacts of dredging.

3.3.4 Migration

Most Sandwich terns return to the same colony to breed as the year before. However, of the Griend population, 25 % of the birds are migrants from other colonies. In addition, in a Danish Sandwich tern colony only 18.4% of the birds was found nesting in the colony of birth (Stienen & Brenninkmeijer 1998). It is likely that if food conditions are poor due to the sand mining, birds may migrate to other colonies and return if the conditions are better. Unfortunately, there is no knowledge of an effect of sand mining on the migration of birds. Due to the lack of quantitative information, in this case study it is assumed that birds do not migrate to and from colonies near to the sand mining activities.

3.3.5 Kleptoparasitism

Sandwich terns benefit from the proximity of Black Headed gulls, because they actively chase away avian predators and act as a buffer against ground predators (Veen 1977). However, black headed gulls also rob fish caught by terns (kleptoparasitism). Veen 1977 report parasitism rates between 18-38% of the fish brought back by Sandwich terns. The gulls prefer large prey, therefore Sandeel is stolen more frequently than *Clupeidae* (herring and sprat). They also report that the amount of kleptoparasitised fish depends strongly on weather conditions. At high wind speeds, 50-100% of the Sandeel may be kleptoparasitised. This is supported by results from Stienen et al. (2000), who showed that heavy wind lowers the food intake of the chicks. However, the proportion of *Clupeidae* taken by the gulls did not change with wind-speed in any relevant way. The differences between both groups of fish seemed related to the preference of the gulls for relatively large fish. In all weather conditions the sandeels supplied were roughly of the same size. The size of the *Clupeidae*, however, decreased with increase of wind-speed. In stormy weather all *Clupeidae* were very small, which made them less attractive for the gulls (Veen 1977). Due to lack of quantitative information on the relation between the number of gulls, weather and the rate of kleptoparasitism, it was decided to not take kleptoparasitism into account in the modeling study. Instead it was assumed that 30% of the caught prey gets lost (see below).

3.4 Time to catch sufficient food - breeding success

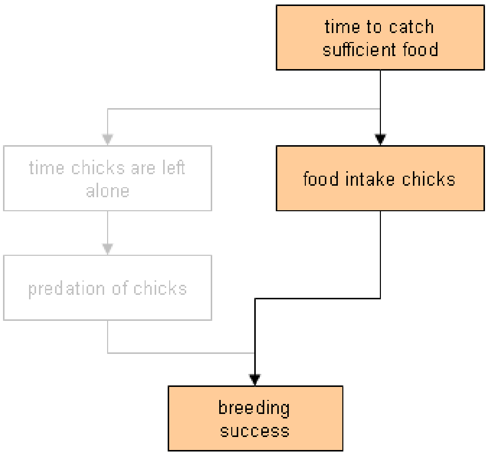


Figure 9 Part of the impact-effect chain: time to catch sufficient food – breeding success

3.4.1 Number of fish needed

During the breeding season, the total amount of fish needed per day is the sum of the prey fish needed for the young and the fish needed for the adult. Although food conditions are often suggested as a limiting factor for breeding success, a clear relation between the amount of provided food and breeding success has not been found yet. The best relationship was found by Stienen & Brenninkmeijer (1998) , who measured the breeding success and the amount of provided food during 5 breeding periods. These data from Stienen & Brenninkmeijer are shown in (Table 4, Figure 16 & 17).
In addition, information on the amount of prey needed for each adult tern is limited. However, some information is available on Basal Metabolic Rates, energy expenditure while flying and energy expenditure while resting. Combining this information with data on prey sizes, energy contents and digestibility makes it possible to estimate the amount of prey needed by using energy balances.

3.5 Breeding success – impact on (local) tern population

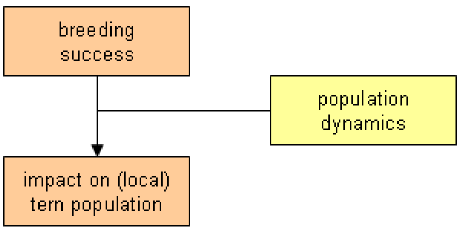


Figure 10 Part of the impact-effect chain: breeding success – impact on tern population

The last step involves the impact of the reduction in breeding success on the tern population. Breeding success was estimated as the number of fledging chicks. This last step assumes that if there are lower numbers of fledging chicks, fewer birds would return the next year to the breeding ground.

4 Modeling the cause-effect chain

This chapter shows an example of how possible effects of dredging activities on a fictitious Dutch tern population can be modeled and how this model can be complemented with a probabilistic shell.

4.1 Monte Carlo analysis

The cause-effect chain for the impact of dredging activities on tern populations contains several uncertain and variable factors. As these uncertainties may have a significant influence on the impact on tern populations, a probabilistic model is set-up.

First, the relationships between the different elements in the cause-effect chain are made quantitative. The resulting chain of equations was used in a Monte Carlo analysis. In the Monte Carlo analysis, the impact of dredging on the tern populations is simulated a large number of times (e.g. 1000 times).

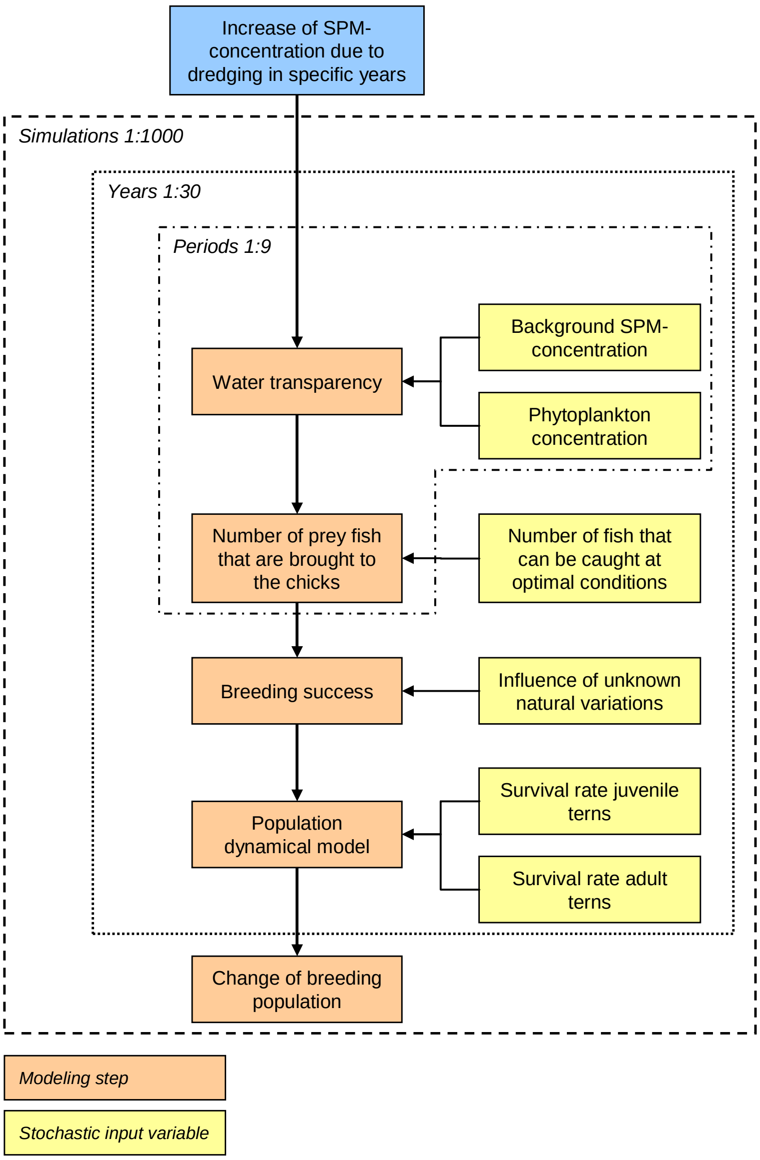


Figure 11 Visualization of the probabilistic modeling

For each simulation a different set of input variables is used. Probability density functions (pdf's) are estimated for all relevant stochastic input variables and uncertain parameters (yellow boxes in Figure 11). From these pdf's 1000x30[(2)] sets of input variables are generated randomly. For each set of input variables the development of the tern population is modeled twice: one time for the dredging scenario, including an increase of SPM-concentrations, and a second time for the reference scenario. Comparing the modeled population sizes for the dredging and reference scenario leads to the relative change of the population size, caused by the dredging activities. Finally, the Monte Carlo analysis results in a probability distribution of the change of the population size that is caused by the dredging activities.

4.2 Sand extraction – water transparency

In section 3.1 was explained that water transparency is mainly influenced by the silt that is released by the dredging activities, the background SPM-concentration and the concentration of phytoplankton. To model the impact on tern populations, the increase of the SPM-concentration during the feeding period of tern chicks, within the foraging area of the tern population is relevant. In this study, for two fictitious dredging scenarios the increase of SPM-concentrations are defined (see Table 7), which are used as input variables for the model.

Background SPM-concentrations and phytoplankton concentrations show large fluctuations, caused mainly by changing weather conditions. Because of these fluctuations, the SPM and phytoplankton concentrations are incorporated as stochastic input variables in the model, which is described in the following paragraphs.

Relation between total suspended matter and water transparency

Advanced numerical models can be used for modeling the reduction of the water transparency by sand mining activities and phytoplankton concentrations.. However, for this conceptual case the following simple empirical relation is used (Suijlen & Duin, 2001):

$$K_d = 0.05 \cdot c_{SPM} + 0.03 \cdot c_{Chl-a} + 0.04$$

with K_d = light attenuation coefficient [m^{-1}]
c_{SPM} = concentration of suspended particulate matter [g/m^3]
c_{Chl-a} = concentration of Chlorophyll-a [$\mu g/m^3$]

The following empirical relation for the southern North Sea, determined by Visser in 1970, is used to convert the light attenuation coefficient K_d to the Secchi disk transparency S (Baptist & Leopold, 2009):

$$S = \frac{1.25}{K_d}$$

with S = Secchi disk transparency [m]

Stochastic variables: background SPM- and phytoplankton concentrations

SPM- as well as phytoplankton concentrations strongly depend on weather conditions. Therefore, these concentrations show large fluctuations and often influence the water

---

[2] 100x30='Number of simulations' x 'number of years for which the population development will be modeled'. For some variables 1000x30x9 times a random value will be chosen (see section 4.2)
For which probability of occurrence a reliable estimate of the impact is required determines the required number of simulations within the Monte Carlo analysis.

transparency more than dredging activities. As the change in weather conditions during the feeding period of tern chicks cannot be predicted in advance, neither can the fluctuations of SPM and phytoplankton concentrations. The uncertainty on the development of weather conditions can be incorporated in the model in two ways:

- modeling the SPM- and phytoplankton concentrations a large number of times by a numerical model, using different changing weather conditions (as a stochastic input variable) each time;
- using SPM- and phytoplankton concentrations as a stochastic input variable, deriving the probability density functions from measurements.

The eventual influence of the increased SPM-concentration on primary production can only be taken into account by using the first method (numerical modeling). For this case study, it is assumed that this influence is not relevant during the feeding period of terns[3] and therefore the second method is used.

If sufficient measurement data are available on the SPM- and phytoplankton concentrations within the foraging area of the terns, probability density functions (pdf's) can be derived by fitting pdf's to these data. Otherwise, pdf's have to be estimated by expert judgment and/or a limited number of data.

For the fictitious case, data from measurement stations at the North Sea is used to estimate pdf's for background SPM- and phytoplankton concentrations[4]. Pdf's are estimated by fitting different types of probability density functions. On the basis of 'goodness-of-fit' tests it is determined which type of pdf has the most likely fit. For practical reasons, Weibull pdf's are used for all measurement stations in this case study. The Weibull distribution was one of the best-fitting pdf's.

Table 1 Estimated pdf's for the background SPM-concentration, based on measurements of SPM-concentrations during May, June and July, data from Suijlen & Duin (2001)

Location	**Average SPM-concentration**	**pdf SPM-concentration**	**Number of measurements**
Callantsoog, 1 km from coast (C1)	23.0 mg/l	Weibull(1.47;25.92)	47
Callantsoog, 2 km from coast (C2)	16.3 mg/l	Weibull(1.22;18.00)	48
Callantsoog, 4 km from coast (C4)	9.3 mg/l	Weibull(1.16;9.65)	50
Terschelling, 4 km from coast (TS4)	9.1 mg/l	Weibull(0.98;9.39)	49

[3] A sensitivity analysis using a numerical model (in which the influence of water transparency on phytoplankton concentrations is incorporated, for example Delft3D-ECO) is recommended to check the validity of this assumption.
[4] Random sampling from original measurement data might be an option if the number of measurements is very large. This is not possible in case of a relatively small dataset, as extreme values may fail.

Table 2 Estimated pdf's for the chlorophyll-a -concentration, based on measurements of chlorophyll-a concentrations during May, June and July, data from www.waterbase.nl

Location	Average chlorophyll-a concentration	pdf chlorophyll-a concentration	Number of measurements
Callantsoog, 1 km from coast (C1)	14.0 μg/l	Weibull(1.28;15.73)	47
Callantsoog, 2 km from coast (C2)	12.4 μg/l	Weibull(1.13;13.45)	46
Callantsoog, 4 km from coast (C4)	9.3 μg/l	Weibull(1.03;9.92)	49
Terschelling, 4 km from coast (TS4)	8.5 μg/l	Weibull(1.22;9.66)	134

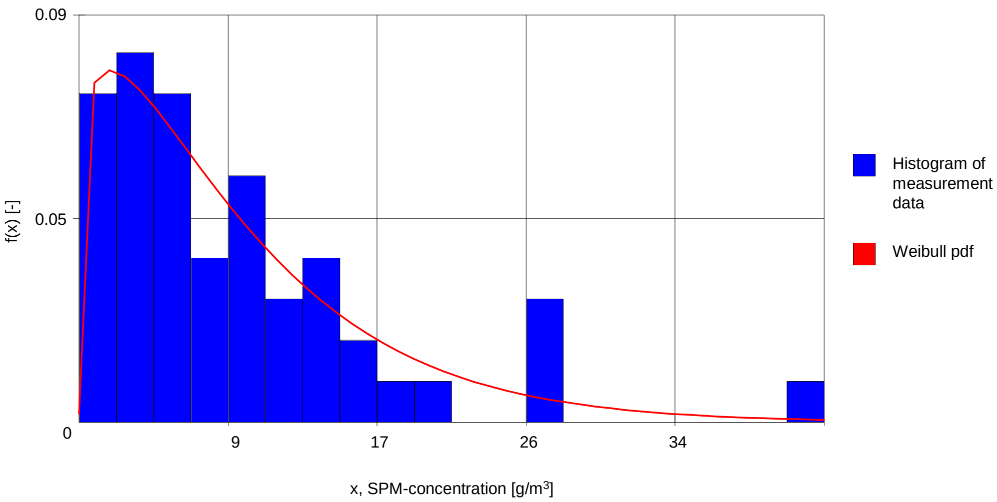


Figure 12 Comparison of input distribution (data SPM-concentrations Callantsoog, 4 km from coast) and Weibull(1.16;9.65)-pdf (f=probability density)

The data that are used to estimate the pdf's of the background turbidity are measurements at a given moment in time. Because of this, the variation of the measured SPM- and chlorophyll-a concentrations is expected to be larger than the fluctuations of weekly or monthly averaged concentrations. To prevent assuming too much variation, the concentrations that follow from the pdf's are assumed to be representative for a period of three days. Assuming that the feeding period of terns lasts 27 days, for 9 periods of 3 days SPM- and chlorophyll-a concentrations are chosen randomly from the pdf's. Subsequently for each period the amount of food provided to the chicks will be modeled. The average amount of food caught during the breeding period will be used to estimate the breeding success (see sections 4.3 and 4.4).

Remarks on relevant assumptions

Spatial differences within the foraging area

In this study is assumed that there are no relevant spatial differences in water transparency within the foraging area of the tern population. Before applying this model for a specific tern population it is recommended to check whether the water transparency shows large spatial differences within the foraging area. If such differences exist, it may be necessary to build the model for several 'sub foraging areas'. In this case, information on the importance of the different sub foraging areas for the tern population will be necessary to determine a weighted average for the amount of fish that can be caught per day.

4.3 Water transparency – number of prey that can be caught

On the basis of literature (see section 3.2) turbidity is expected to reduce the number of prey fish that can be caught per day by terns. In this section a quantitative relation is derived step by step.

4.3.1 Catch probability

Baptist & Leopold (2009) studied prey capture probability as a function of water transparency for foraging Sandwich Terns. Prey capture probability is defined as the probability that an attempt to catch a fish succeeds. A logistic optimum curve shows the relationship between transparency and prey capture probability:

Equation 1:

$$P_{capture}(S) = \frac{e^{\beta_0 + \beta_1 \cdot S - \beta_2 \cdot S^2}}{1 + e^{\beta_0 + \beta_1 \cdot S - \beta_2 \cdot S^2}}$$

With: $P_{capture}$ = catch probability [-]

The logistic regression analysis that was done by Baptist & Leopold (2009) led to the following values for parameters β_0, β_1 and β_2:

	Value	Std. dev.	P_r (> | z|)
β_0	-1.48	0.72	0.0408
β_1	2.33	0.99	0.0188
β_2	-0.67	0.31	0.0306

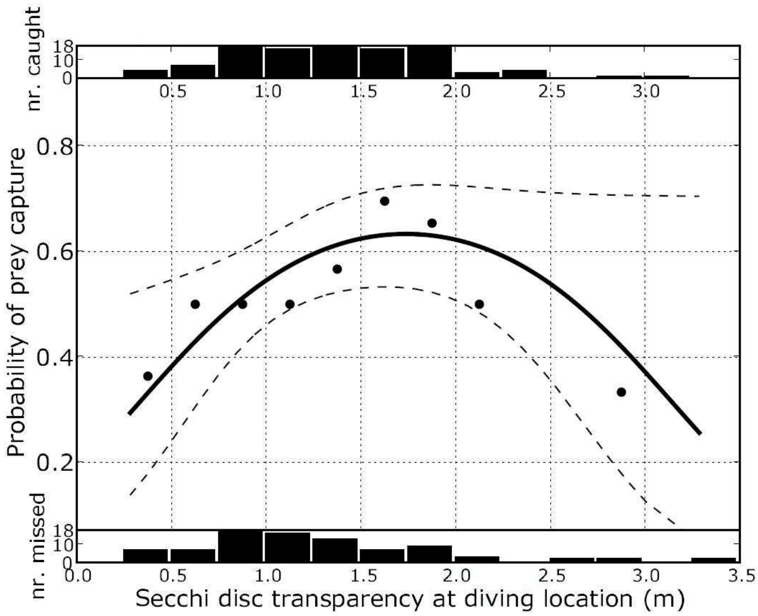


Figure 13 Relationship between transparency and prey capture probability. The solid line presents the results of the logistic regression, the dotted line gives the 95% confidence interval. The histograms on the top and bottom respectively give the number of caught prey and missed prey and the dots give the average probability for each histogram class [Baptist & Leopold, 2009]

According to the relation that was found by Baptist & Leopold (2009), prey capture probability decreases with an increasing water transparency at Secchi disk transparencies higher than 1.7 m. This decreasing trend at high transparency values is only based on a few measurements. In accordance with the precautionary principle it could be best to neglect the positive influence of increasing turbidity in case of very clear water. However, research results of Brenninkmeijer *et al*. (2002b) confirm that an increase of turbidity has a positive influence on the number of fish that can be caught by Sandwich Terns, in case of clear water (see Figure 14). Therefore, Equation 1 will be used for modeling the impact of dredging on Sandwich Tern populations. If prey capture probability can increase by an increasing turbidity, dredging activities may have a positive influence on tern populations in some cases.

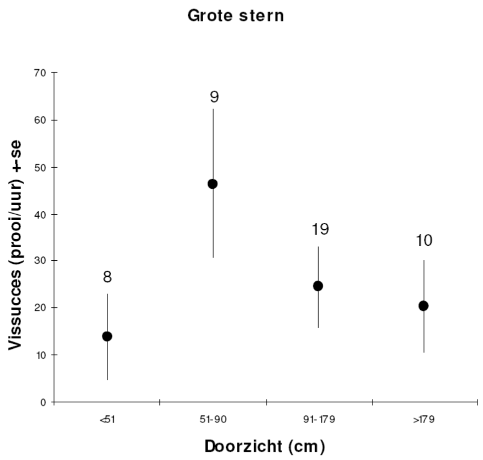


Figure 14 Number of caught fish per hour of Sandwich Terns in the Western Scheldt for different levels of turbidity (Brenninkmeijer et al., 2002b)

NB: During the observations that were used to construct the graph of Figure 14, only 27% of all dives were successful (Brenninkmeijer *et al*., 2002b). This percentage is remarkably lower than the prey capture probabilities in Figure 13. The highest capture rate is found at lower transparencies than the maximal value of the prey capture probability in Figure 13. These differences lead to question marks over the general applicability of Equation 1.
The difference in optimal transparency between Figure 13 and Figure 14 might also indicate that prey fish are easier to find in more turbid water. If the ‘searching time’ for prey is shorter at more turbid water, this might compensate for the lower prey capture probability. However, in accordance with the precautionary principle this will not be taken into account in the next subsection.

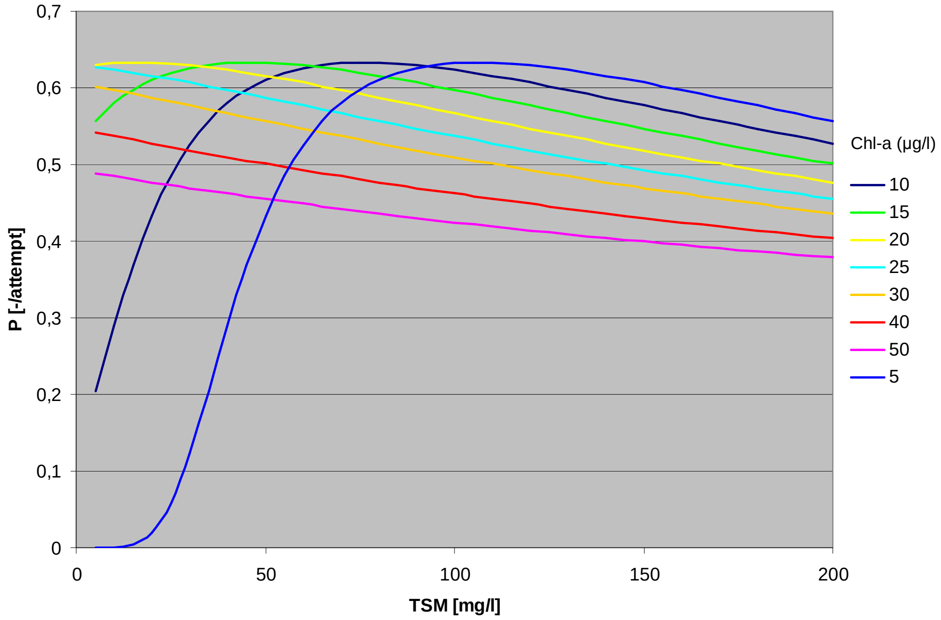


Figure 15 Relation between SPM-concentration and the prey capture probability, given a chlorophyll-a concentration, based on the equations of Suijlen & Duin (2000), Visser (1970) and Baptist & Leopold (2009)

4.3.2 'Findability' of prey

The number of attempts that is necessary to catch a fish by plunge-diving is probably not the only factor that will change in case of increased water turbidity. It is likely that terns also have to search longer for their food. On the other hand, an effect of reduced visibility might be compensated by the behavior of the prey fish. In case of clearer water, fish may swim deeper to avoid predation and in case of more turbid water fish may swim closer to the water surface. Unfortunately no information is available on the relation between turbidity and 'searching-time'.

In accordance with the precautionary principle is assumed that searching-time increases with increasing turbidity.

The increase of the number of attempts that is necessary to catch one prey can be determined on the basis of the decrease of the prey capture probability (section 4.3.1). To be able to make the increase of the searching time quantitative is assumed that the relative increase of the searching time is equal to the relative increase of the number of attempts. To determine the relative increase of attempts, the number of attempts for a specific water transparency is compared to the number of attempts at an optimal transparency.

From Equation 1 follows that prey capture probability is optimal at the following water transparency:

$$S_{optimum} = -\beta_1 / (2*\beta_2)$$

Using the values of β_1 and β_2 that were found by Baptist & Leopold (2009), the maximal prey capture probability can be found at a Secchi disk transparency of 1.74 m[5].

[5] Also this value has an uncertainty margin. This uncertainty margin has not been taken into account in the Monte Carlo analysis, as its influence on the final results is expected to be negligible compared to the influence of other uncertainties. However, it is recommended to carry out a sensitivity analysis to check whether this assumption is correct.

The number of attempt necessary to catch one fish is:

$$NA(S) = \frac{1}{P_{capture}(S)}$$

The relative increase of the number of attempts is:
Relative increase of NA = NA(S)/NA($S_{optimum}$*)*

The relative increase of the searching-time is assumed to equal the relative increase of the number of attempts.

4.3.3 Number of prey that can be caught per day

The relative increase of the number of attempts and the searching time is necessary for estimating the number of fish that can be fed to the chicks. For estimating this number the following additional information is necessary:
- how many fishes can be caught at optimal transparency conditions;
- how many fishes do adult terns need for food per day;
- how much time per day is available for foraging.

Capture rate at optimal conditions

Unfortunately only limited information is available on the number of fish that can be caught per day by terns in the Netherlands. Brenninkmeijer *et al*. (2002b) found a mean prey capture rate of 20.8 fish per hour for Sandwich Terns in the Western Scheldt. The highest capture rate was found at Secchi disk transparencies of 51 to 90 cm: on average 46.5 fish per hour. These capture rates are quite high compared to the amount of food that is necessary per day for adult terns and chicks (43, see following part of this subsection). Even in very turbid water (S<50 m), the average capture rate found by Brenninkmeijer *et al*. (2002b) was 13.9 fish per hour. This might indicate that terns can easily find sufficient food (assuming that almost 8 hours are available for foraging, see 'Time available'). In this case it is unlikely that an increase of turbidity affects the breeding success of terns. Taylor (1983) also measured high capture rates at a foraging location of Sandwich Terns in Scotland: up to 90 fish per hour.
However, as the total amount of observations of capture rates is limited , the eventual negative influence of the increased turbidity on breeding success can not be excluded for all tern populations in the Netherlands. Possibly large local and temporal differences exist in the capture rate at optimal water transparencies (which might be caused by local and temporal differences in for example prey fish density).

To model the impact of the decreased water transparency on the breeding success of terns, three options are available:
1. worst case: assuming that the amount of fish that can be caught per day at optimal conditions is exactly the number of fish that is necessary for the adult terns, plus the number that is necessary for feeding the chicks, leading to an optimal breeding success;
2. conservative approach: assuming such a capture rate at optimal conditions, that any decrease of the capture rate leads to a lower breeding success;
3. based on measurements: estimating the capture rate at optimal conditions from measurements. (If measurements are available, a probability density function of the capture rate at optimal conditions can be estimated. In this case, implicitly also the natural variation of prey availability can be taken into account.)

These different approaches will be illustrated in section 4.6.

From the capture rate at optimal conditions, the searching time per caught prey can be estimated:

$$t_{search\_optimal} = \frac{60 \cdot P_{capture\_optimal}}{C_{optimal}}$$

Note: up till now it is assumed that all fishes that are caught by terns are suitable as food for adults as well as for feeding chicks. However, Stienen *et al*. (2000) mention that parents seem to adjust prey size to the age of their first chick. During the breeding season, parents bring in longer fishes to keep pace with the growing energy demands of their growing chicks, instead of bringing in more fish. This might indicate that only a specific range of fish sizes is suitable as food for chicks (or this selective food provisioning is a way to minimize the number of times the terns have to fly forth and back to the nests). If indeed only a specific range of fish sizes is suitable for chicks, taking into account the capture rates of food for chicks and food for adults separately is a possibility for improving the model in the future.

Amount of fish necessary for adult terns

The number of fish needed per adult per day depends on the total time spent on "the wing", because energy expenditure when flying is higher than energy expenditure during resting. Based on energy budgets, Brenninckmeijer *et al*. (2002a) calculated the number of fish needed per day per adult in Guinee Bissau.

Brenninkmeijer *et al*. (2002a) estimated daily energy expenditure for tern species in Guinea-Bissau as a function of the Basal Metabolic Rate (BMR):

$$\text{Energy Expenditure} = t_{flying} * 4.77\text{BMR} + (24 - t_{flying}) * 1.62\text{BMR}$$

In 1984 Flint and Nagy estimated the rate of energy expenditure during flight for the tropical Sooty Tern (*Sterna fuscata*) at 4.77*BMR and at 1.62*BMR during the remainder of the time (Brenninkmeijer *et al*. 2002a). The values 4.77 and 1.62 were adopted by Brenninkmeijer et al. (2002a) for the tern species in Guinea-Bissau. As no other data are available, these values will also be used in this study for Sandwich Terns in the Netherlands.

Energy income should equal energy expenditure. From this energy balance can be calculated how many prey fish an adult tern has to eat per day (NF_{food_adult}):

$$D_{fish} * E_{Content\_fish} * m_{fish} * NF_{food\_adult} = t_{flying} * 4.77\text{BMR} + (24 - t_{flying}) * 1.62\text{BMR}$$

Apart from the time terns spend flying per day (t_{flying}), the values of parameters D_{fish} (digestability of fish), $E_{Content\_fish}$ (energy content of fish), m_{fish} (average fish mass) and BMR are necessary in order to complete the energy balance. Unfortunately, hardly any information is available on these parameters. As a best guess, the values presented in Table 3 will be used in this case study.

Table 3 Parameters for energy balance

Parameter	Value	Reference
Basal Metabolic Rate (BMR)	202 kJ/d	Value for Sandwich Terns, measured on the Isle of Griend (the Netherlands) by Klaassen in 1994. Unpubl. data from Klaassen and Brenninkmeijer in Brenninkmeijer *et al.* (2002a)
Energy content of fish ($E_{Content\_fish}$)	6.37 kJ/g	Energy content of small (sub)tropical roundfish (Brenninkmeijer *et al.*, 2002a)
Digestibility (D_{fish})	76.8 %	Digestibility of small (sub)tropical roundfish (Brenninkmeijer *et al.*, 2002a)
Average mass of fish (m_{fish})	4 g	Stienen (2006) found an average mass of 3.5 g (sandeel) and 4.5 g (herring) of the prey fed to the chicks. Possibly the adults themselves feed on larger prey. However, an average mass of 4 g is used as a conservative assumption.

Time available
To estimate the amount of fish brought to the nest per day, the available time for foraging as well as the capture rate of prey needs to be known.

During the breeding season, the daylight period in the Netherlands lasts about 18 hours (Figure 8). It is unknown whether the terns can spend all this time 'on the wing'. In this case study is assumed that only 2/3rd of the available daylight time can be spend flying, resulting in 12 hours available "on the wing". These hours will be spent for foraging as well as for flying from the nest to the foraging area and back again.

For a population that breeds at a distance of, for example, 7.5 km from the foraging area, it would mean that less than 8 hours can be spend for foraging. This is based on the following assumptions:

Number of times flying forth and back	10* (7 fishes per adult necessary for optimal breeding success, about 30% gets lost, see the following)
Flying speed of Sandwich Terns	10 m/s
Distance between foraging area and colony	7500 m
Total amount of time that can be spend flying	12 h
Total amount of time necessary for flying forth and back	*4:10 h (=2*10*7500/(10*3600))*
Total amount of time available for foraging	*7:50 h*

* This would enquire an iterative process (the number of fish provided to the chicks depends on the amount of time for foraging). However, compared to the rough assumption on the total amount of time that can be spend on the wing, the assumption on the number of times flying forth and back is of minor importance.

In accordance with observations done by Stienen (Baptist & Leopold, 2009), it is assumed that a fraction of 0.3 of the prey brought to the nest gets lost (fc_{lost}). On the basis of the energy balance of Sandwich terns is estimated that adult terns need 33 small fishes (4 g) per day, if they are flying for 12 hours. Figure 16 shows that the breeding success does not increase further when more than 14 fishes are fed to the chicks per day (7 per adult). Taking into account that 30% gets lost, each adult has to catch 33+10 fishes per day.

Amount of food brought to the nest
The amount of food provided to the nest per adult tern is modeled in the following way:

$$t_{search}(S) = t_{search\_optimal} \cdot \left(\frac{1/P_{capture}(S)}{1/P_{capture\_optimal}} \right)$$

$$NF_{caught}(S) = \frac{60 \cdot t_{foraging}}{NA(S) \cdot t_{search}(S)}$$

$$NF_{provided}(S) = 2 \cdot (1 - fc_{lost}) \cdot (NF_{caught}(S) - NF_{food\_adult})$$

4.4 Amount of food brought to the nest – Breeding success

Although food conditions are often suggested as a limiting factor for breeding success, a clear relation between the amount of provided food and breeding success has not been found yet. Stienen & Brenninkmeijer (1998) measured the breeding success and the amount of provided food during 5 subsequent breeding periods (Figure 16).

Table 4 Breeding success and amount of provided food as observed by Stienen & Brenninkmeijer (1998)

	Data from Stienen & Brenninkmeijer (1998)				
Year	**Breeding success**	**Provided herring n/chick/day**	**Provided sandeel n/chick/day**	**Clutch size n**	**Total amount of fish provided n/nest/day**
1993	0.67	4.66	3.56	1.64	12.9
1994	0.80	7.17	1.19	1.70	14.4
1995	0.82	6.19	2.80	1.75	15.9
1996	0.67	2.29	4.75	1.29	9.1
1997	0.51	7.03	1.86	1.70	14.7
				Average:	13.4

As a relation between the amount of provided food and the breeding success is expected to exist, different possible relations are fitted to the data from Stienen & Brenninkmeijer (1998).

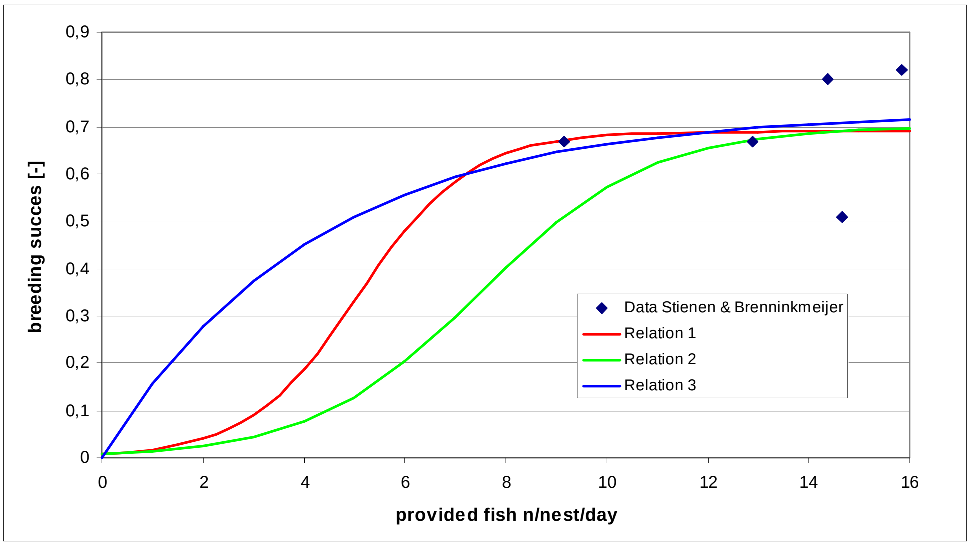


Figure 16 Possible relations between the amount of fish provided to the chicks and the breeding success

Relation 1: $$B = \frac{0.69}{1 + e^{-0.9 \cdot (NF_{provided\_av} - 5.1)}}$$

Relation 2: $$B = \frac{0.7}{1 + e^{-0.6 \cdot (NF_{provided\_av} - 7.5)}}$$

Relation 3: $$B = 0.73 \cdot \left(1 - e^{-0.24 NF_{provided\_av}}\right)$$

Two different types of relations, which are expected to be reasonable on the basis of physical arguments, are fitted to the data. The parameters of relations 1 and 3 are estimated by using the least-squares-method. Also relation 2 is derived by using the method of least squares; however, one data point has been ignored. This relation has been added because it might lead to a more conservative estimate of the probability of occurrence of negative impacts (in some specific cases). In accordance to the precautionary principle, the relation that leads to the most conservative results has to be used.

The data from Stienen & Brenninkmeijer (1998) show a large scatter around the estimated relations. This scatter might be caused by other, variable factors that influence breeding success (for example predation). This influence on the breeding success from unknown factors will be incorporated in the probabilistic modeling by adjusting the breeding success that follows from relations 1, 2 or 3, by a random factor α. The probability density function of α is estimated on the basis of the scatter from the data of Stienen & Brenninkmeijer (1998) around the fitted functions.

Table 5 Probability density function of α for each relation between fish provided and breeding success

	pdf of α
Relation 1	Weibull(8.06;1.08)
Relation 2	Weibull(7.77;1.09)
Relation 3	Weibull(8.89;1.06)

Figure 17 shows the variation of the breeding success, given the amount of fish provided, that will be included in the model.

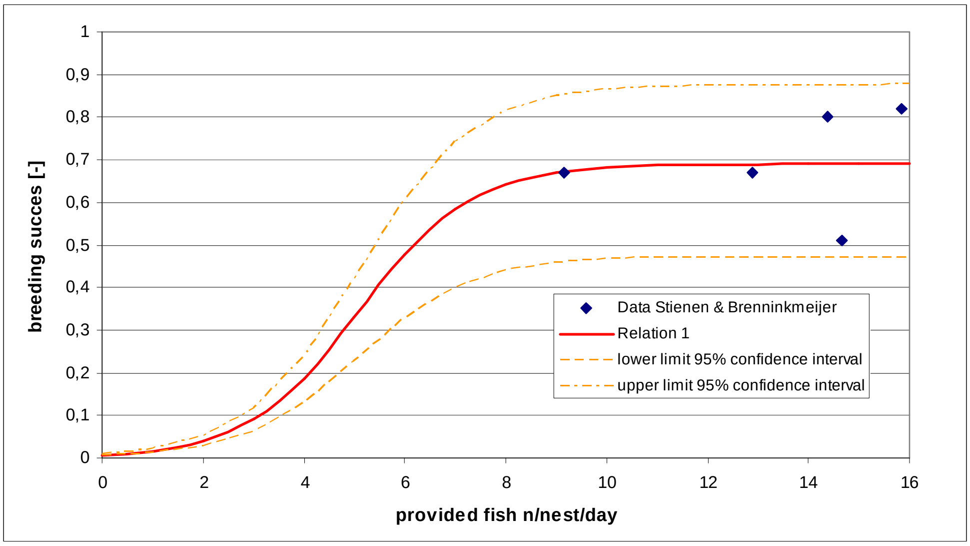


Figure 17 Relation 1 between provided fish and breeding success and the uncertainty margin that is incorporated in the probabilistic model by the variation of α (the 95% confidence interval is given)

Temporal differences during the feeding period in the amount of provided food
The measured amounts of food provided from Stienen & Brenninkmeijer (1998) are estimates of the average amounts of food during the whole breeding period. This may lead to a misrepresentation of the relation between breeding success and the amount of food provided to the chicks. When the average amount of provided food is high, the feeding period may still include a period of time in which hardly any food has been provided. Such a period with a food shortage, may lead to a low breeding success, whereas on the basis of the average amount of provided food during the breeding season, a high breeding success

would be expected. It is recommended to do further research on the effect on the breeding success of short periods during which hardly any food is provided to the chicks.

4.5 Population dynamical model

A decrease of the breeding success of terns is expected to result in a decrease of the population size. A method for modeling this change of the population size is the Leslie-matrix, which is a discrete, age-structured model for population ecology. For an explanation of this method is referred to Van Boven & Schobben (1993).

Van Boven & Schobben (1993) developed a population-dynamical model for the Sandwich Tern in the Netherlands. They used the following values for the input variables of the Leslie-matrix:

Table 6 Values as used by Van Boven & Schobben (1993) within the Leslie-matrix for Sandwich Tern populations

Parameter / variable	**Value**
Breeding success per pair	Uniform probability density function (0.20-1.20)
Survival rate of juveniles	50%
Survival rate of 1-year old and older terns	Uniform probability density function (0.80-0.90)
First year of breeding	5th year of life
Maximal age	23 years
Percentage of adults that is breeding	100%

The model as developed by Van Boven & Schobben (1993) resulted in the prediction of an autonomous decrease of the population size. This does not correspond with the development of the population size in the Netherlands (see Figure 3). Therefore the values of the survival rates are adjusted in this case study in such a way that on average a constant population size is modeled by the Leslie-matrix. The breeding success will follow from one of the relations in section 4.4.

No clear indications exist that the survival or reproduction rates of terns in the Netherlands are influenced by the population density (Van Boven & Schobben, 1993). Because of this, no density-dependent effects are incorporated in the Leslie-Matrix.

4.6 Results

Using the probabilistic model, the impact of two different dredging scenario's on the number of breeding terns is modeled.

Table 7 Defined dredging scenarios

Scenario		**Year**							
		1	2	3	4	5	6	7	8
1) Far field effects of large dredging project, which takes several years	Relative increase of SPM-concentration [%]	20	50	50	20	20	10	10	10
2) Far field effects of (relatively) small dredging project	Absolute increase of SPM-concentration [mg/l]	8	1	0	0	0	0	0	0

The three different options given in subsection 4.3.3 are worked out in this section. The worst-case approach (option 1) turns out to be impossible. If the amount of fish that is necessary for an optimal breeding success can only be caught at optimal transparency conditions, it would not be possible to have a tern population which is more or less in equilibrium. As transparency conditions are mostly suboptimal, using this worst-case assumption would lead to low breeding successes. These breeding successes would cause a decrease of the population size, unless survival rates are much higher than estimated by Van Boven & Schobben (1993) (see Table 6).

The results show probability distributions of the maximal, relative change of the number of breeding pairs that occurs during a period of 35 years after the start of the dredging activities. Within the Monte Carlo simulation the population development was modeled for the dredging as well as for the reference scenario (see also appendices A and B). The modeled number of breeding pairs in the reference scenario was compared with the modeled number for the dredging scenario, for each year within the period of 35 years. This comparison leads to the relative decrease of the number of breeding pairs. The maximal (most negative) value in these 35 years is the maximal relative change.

4.6.1 Conservative approach

In this subsection the conservative approach (option 2 in subsection 4.3.3) is worked out. Relation 1 (section 4.4) between the food provided and the breeding success is used. Relation 1 is chosen as it leads to the most conservative estimate of the probability distribution of the impact of dredging.
First, the capture rate at optimal conditions is determined iteratively. Combining relation 1 and the conservative approach this capture rate should lead to an average number of 8 fishes per day that is provided to the chicks. Any decrease of this number would directly lead to a decrease of the breeding success (see Figure 17).
Subsequently, the input variables of the population dynamical model are adjusted in such a way that the tern population in the reference situation is constant (on average).

Influence of background turbidity
For dredging scenario 1, the impact on the number of breeding pairs was modeled for a range of background turbidities at the fictitious foraging area. The different probability density functions of SPM- and chlorophyll-a concentrations are based on observations for measurement stations C1, C2 and C4 (see Table 1 and Table 2).

The set of input variables for the different model runs is given in Table 8.

Table 8 Conservative approach, input variables as used for runs 1a, 2a and 3a

Input variable	**Run1a**	**Run2a**	**Run3a**
	Background turbidity as measured at C1	Background turbidity as measured at C2	Background turbidity as measured at C4
pdf of background SPM-concentration [mg/l]	Weibull(1.47;25.92)	Weibull(1.22;18.00)	Weibull(1.16;9.65)
pdf of Chlorophyll-a concentration [µg/l]	Weibull(1.28;15.73)	Weibull(1.13;13.45)	Weibull(1.03;9.92)
Capture rate at optimal conditions [fishes/h^{-1}]	7	6.45	6.15
pdf of yearly survival rate of adult terns [-]	Uniform(0.845;0.945)	Uniform(0.842;0.942)	Uniform(0.840;0.940)
pdf of yearly survival rate of juvenile terns [-]	Uniform(0.65;0.75)	Uniform(0.65;0.75)	Uniform(0.64;0.74)
Relation food provided ($NF_{provided\_av}$) - breeding success (B)	$B = \alpha \cdot \frac{0.69}{1+e^{-0.9 \cdot (NF-5.1)}}$	$B = \alpha \cdot \frac{0.69}{1+e^{-0.9 \cdot (NF-5.1)}}$	$B = \alpha \cdot \frac{0.69}{1+e^{-0.9 \cdot (NF-5.1)}}$
pdf of α [-]	Weibull(8.06;1.08)	Weibull(8.06;1.08)	Weibull(8.06;1.08)
Dredging scenario	1	1	1

Figure 18 shows the results of model runs 1a, 2a and 3a; the probability distribution of the impact on the number of breeding pairs (the total number of 4 year-old and older terns). These probability distributions show the probability (y-axis) that the impact that will occur in reality is smaller (more positive value) than the possible impact X at the x-axis. A negative value at the x-axis means a decrease of the population size.
In appendix C is explained in more detail how to read these graphs.

As expected, the impact of dredging is larger at a foraging area with higher background turbidity. While the average Secchi disk transparency is 1.0 m at area C1, the average Secchi disk transparency at C4 is 1.9 m. At a transparency of 1 m, any increase of turbidity leads to a stronger decrease of capture probabilities than at a transparency of 1.9 m (see Figure 13).

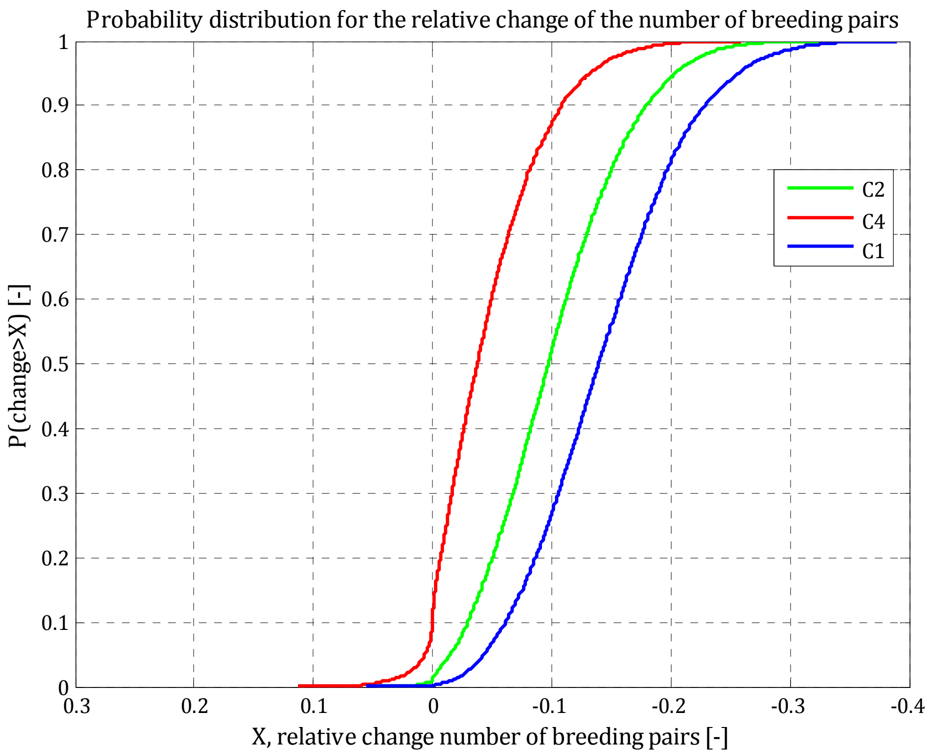


Figure 18 Results Run1a, 2a and 3a, impact of dredging scenario 1 for different background turbidity conditions

Dredging scenario 2

In addition, the impact of dredging scenario 2 on the number of breeding terns has been modeled by using the conservative approach (see Figure 19 and Figure 20).

Table 9 Conservative approach, input variables as used for runs 1b and 3b

Input variable	**Run1b**	**Run3b**
	Background turbidity as measured at C1	Background turbidity as measured at C4
pdf of background SPM-concentration [mg/l]	Weibull(1.47;25.92)	Weibull(1.16;9.65)
pdf of Chlorophyll-a concentration [µg/l]	Weibull(1.28;15.73)	Weibull(1.03;9.92)
Capture rate at optimal conditions [fishes/h^{-1}]	7	6.15
pdf of yearly survival rate of adult terns [-]	Uniform(0.845;0.945)	Uniform(0.840;0.940)
pdf of yearly survival rate of juvenile terns [-]	Uniform(0.65;0.75)	Uniform(0.64;0.74)
Relation food provided ($NF_{provided\_av}$) - breeding success (B)	$B = \alpha \cdot \dfrac{0.69}{1+e^{-0.9\cdot(NF-5.1)}}$	$B = \alpha \cdot \dfrac{0.69}{1+e^{-0.9\cdot(NF-5.1)}}$
pdf of α [-]	Weibull(8.06;1.08)	Weibull(8.06;1.08)
Dredging scenario	2	2

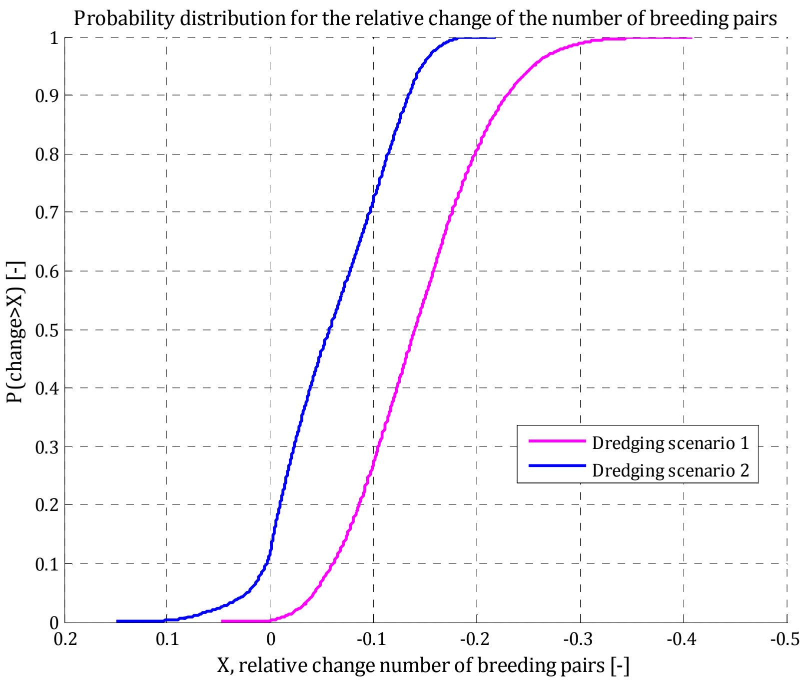


Figure 19 Results Run1a(pink line) and Run1b (blue line); probability distribution for the relative change of the number of breeding pairs (background turbidity like C1)

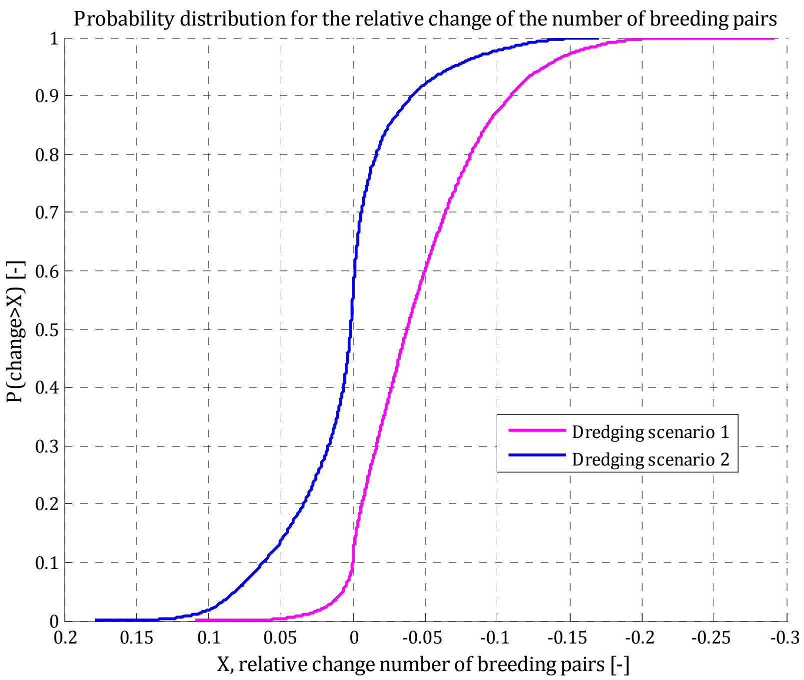


Figure 20 Results Run3a (pink line) and Run3b (blue line); probability distribution for the relative change of the number of breeding pairs (background turbidity like C4)

The results of run 3b show a relatively large probability on positive effects. This can be explained by the low background turbidity and the short period over which turbidity is increased by the dredging activities. On average the background turbidity (location C4) is lower than the optimal turbidity; the water is mostly too clear for optimal foraging conditions. Due to this, an increase of silt concentration mostly has a positive effect on the catchability of prey (see Figure 15, for TSM-concentrations < 20 mg/l and Chl-a concentrations < 20 µg). Only during years in which silt- and chlorophyll-a concentrations are substantially higher than the average concentrations, an increase of turbidity due to dredging activities can affect prey catchability negatively. The probability that such background turbidity conditions (extreme for C4) occur simultaneously with the impact of the dredging, which is only noticeable during two years in scenario 2, is quite low. This explains why the probability of occurrence of positive effects is relatively large for this specific case.

4.6.2 Capture rates based on measurements

As long as no observations on capture rates or the amount of provided food are available for the possibly affected tern population, using the conservative approach of previous subsection might be necessary (precautionary principle). In this subsection the impact on tern populations has been modeled for two fictitious cases in which measurements of capture rates are available.

Case A: average capture rates of 40 fishes per hour
Brenninkmeijer *et al*. (2002b) and Taylor (1983) measured (optimal) capture rates of 46.5 and 90 fishes per hour respectively. If Sandwich Terns can forage for almost 8 hours per day, an impact of an increased turbidity on the population is very unlikely. Probably the amount of food that can be caught per day is not limiting for the breeding success. Only if capture rates decrease dramatically compared to these observed rates, the amount of caught prey might get less than the amount that is necessary per day for an optimal breeding success.

The following modeling result illustrates that dredging will not have an impact on the tern populations, if capture rates are about 40 fishes per hour. In this model run, the capture rate has been modeled as a stochastic variable (normal probability density function with mean value of 40 and a standard deviation of 10). Figure 21 shows that an impact of dredging on tern populations is very unlikely.

Table 10 Approach: $C_{optimal}$ based on measurements – case A, input variables as used for runs 1b and 3b

Input variable	Run4a
	Background turbidity as measured at C1
pdf of background SPM-concentration [mg/l]	Weibull(1.47;25.92)
pdf of Chlorophyll-a concentration [µg/l]	Weibull(1.28;15.73)
pdf of Capture rate at optimal conditions [fishes/h^{-1}]	Normal(40;10)
pdf of yearly survival rate of adult terns [-]	Uniform(0.83;0.93)
pdf of yearly survival rate of juvenile terns [-]	Uniform(0.57;0.67)
Relation food provided ($NF_{provided\_av}$) - breeding success (B)	$B = \alpha \cdot \frac{0.69}{1+e^{-0.9\cdot(NF-5.1)}}$
pdf of α [-]	Weibull(8.06;1.08)
Dredging scenario	1

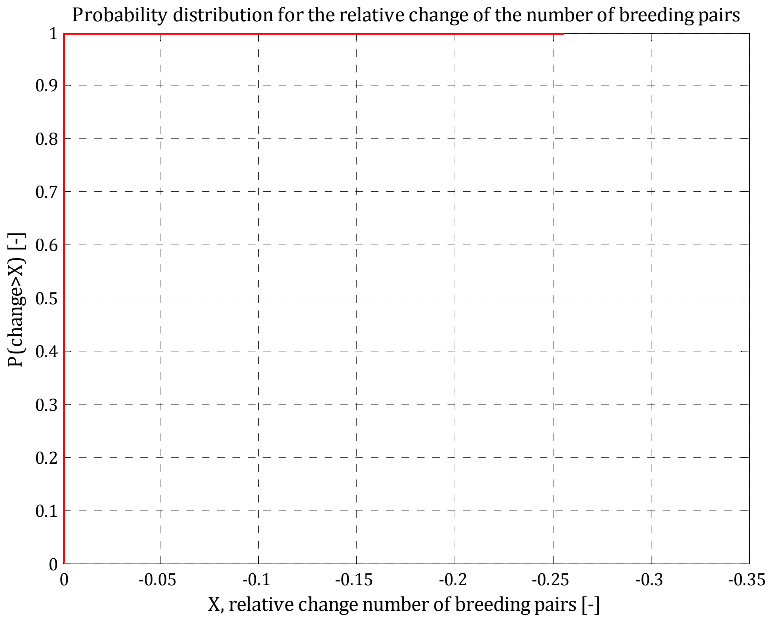


Figure 21 Result Run4a; probability distribution for the relative change of the number of breeding pairs (dredging scenario 1, background turbidity like C4)

Case B: on average 13 fishes per day provided to the nest

Stienen & Brenninkmeijer (1998) observed that on average 13.4 fishes were provided to the nest per day (see Table 4). For model runs 5a and 6a the optimal capture rate was adjusted to such a value that the average number of fish provided (modeled for the reference situation) is 13.4 per day.

The difference between Run5a and Run6a shows the influence of the uncertain parameter values of the relation between food provided and breeding success.

Table 11 Approach: $C_{optimal}$ based on measurements – case B, input variables as used for runs 5a and 6a

Input variable	**Run5a**	**Run6a**
	Background turbidity as measured at C2	Background turbidity as measured at C2
pdf of background SPM-concentration [mg/l]	Weibull(1.22;18.00)	Weibull(1.22;18.00)
pdf of Chlorophyll-a concentration [µg/l]	Weibull(1.13;13.45)	Weibull(1.13;13.45)
Capture rate at optimal conditions [fishes/h^{-1}]	7.45	7.45
pdf of yearly survival rate of adult terns [-]	Uniform(0.825;0.925)	Uniform(0.825;0.925)
pdf of yearly survival rate of juvenile terns [-]	Uniform(0.64;0.74)	Uniform(0.64;0.74)
Relation food provided ($NF_{provided\_av}$) - breeding success (B)	$B=\alpha\cdot\frac{0.69}{1+e^{-0.9\cdot(NF-5.1)}}$ (relation 1)	$B=\alpha\cdot\frac{0.7}{1+e^{-0.6\cdot(NF-7.5)}}$ (relation 2)
pdf of α [-]	Weibull(8.06;1.08)	Weibull(7.77;1.09)
Dredging scenario	1	1

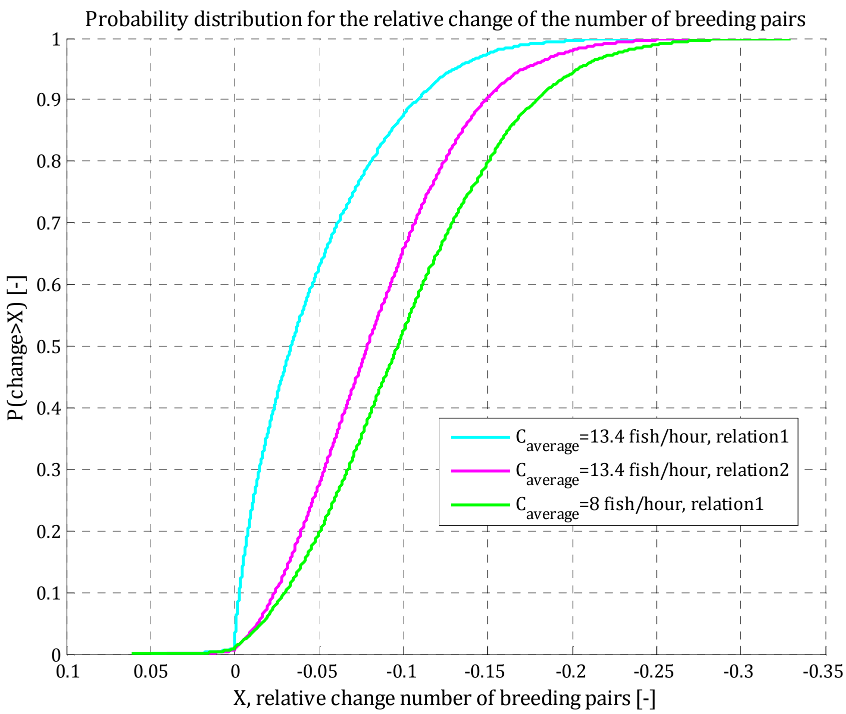


Figure 22 Results Run2a, Run5a and Run6a; probability distributions for the relative change of the number of breeding pairs (dredging scenario 1, background turbidity like C2)

4.6.3 Alternative presentation of the impact of dredging

In previous subsections the impact of dredging on tern populations was defined as the relative decrease of the number of breeding pairs, compared to the number of breeding pairs in the reference situation (without dredging).

Also in the reference scenario a decrease of the number of breeding terns is possible. By using the data that are given in Table 12, a Monte Carlo analysis was carried out for the population development over a period of 35 years:

$$R_{population\_development} = \frac{NT^{breeding}[year = 35]}{NT^{breeding}[year = 1]}$$

The results for the reference situation show that the probability is about 50% that the population size will decrease autonomously. As a consequence of a dredging project (increasing turbidity) the probability distribution for the population development will change.

To illustrate the sensitivity of the tern population on a change of Secchi disk transparencies, the population development was modeled for different, theoretical dredging scenarios. In these theoretical scenarios, the Secchi disk transparency during two successive feeding periods will decrease to a certain, constant value[6]. Figure 23 shows the results.

Table 12 Input variables as used for the reference situation of Figure 23

Input variable	**Reference**
	Background turbidity as measured at C2
pdf of background SPM-concentration [mg/l]	Weibull(1.22;18.00)
pdf of Chlorophyll-a concentration [µg/l]	Weibull(1.13;13.45)
Capture rate at optimal conditions [fishes/h^{-1}]	7.45
pdf of yearly survival rate of adult terns [-]	Uniform(0.825;0.925)
pdf of yearly survival rate of juvenile terns [-]	Uniform(0.64;0.74)
Relation food provided ($NF_{provided\_av}$) - breeding success (B)	$B = \alpha \cdot \frac{0.69}{1+e^{-0.9\cdot(NF-5.1)}}$
pdf of α [-]	Weibull(8.06;1.08)

[6] In practice transparency will never be constant during a whole feeding period

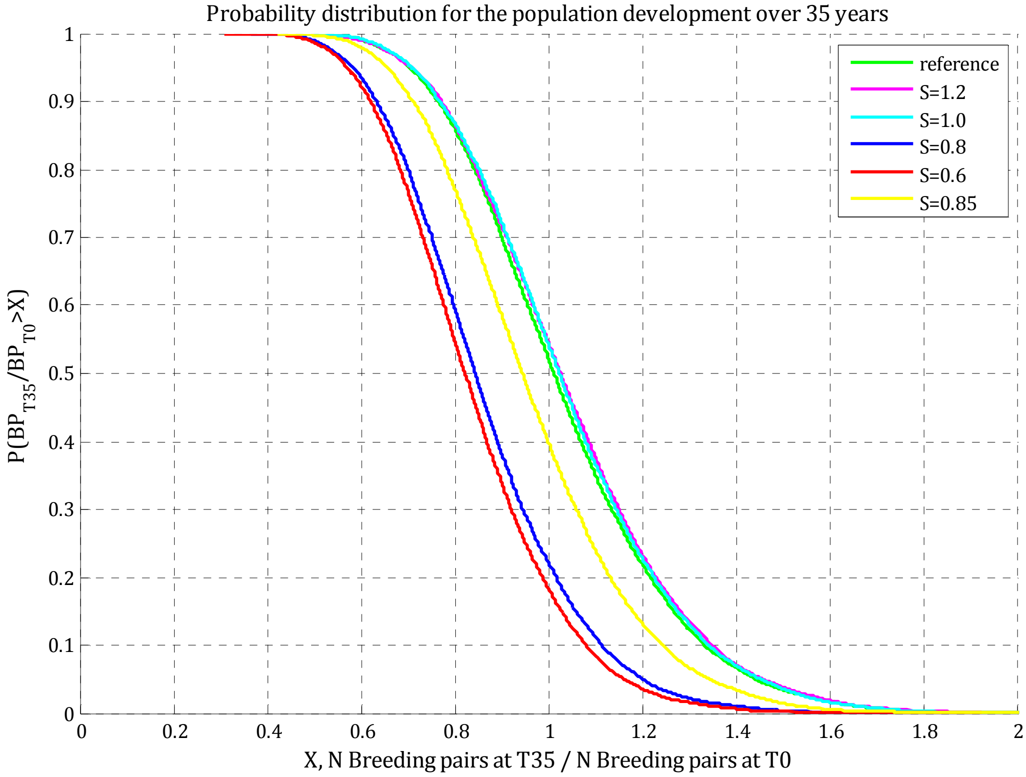


Figure 23 Probability distributions for $R_{population\ development}$ for a reference situation and different dredging scenario's.

The Secchi disk transparency in the reference situation was 1.34 m on average. If the transparency decreases for two successive feeding periods (year 1 and 2) to (constantly) 1 m, this hardly changes the probability distribution for the population development over 35 years. In case of a Secchi disk transparency of 0.8 m, the probability on a decrease of the population increases significantly, compared to the probability in the reference situation.

5 Discussion and recommendations

5.1 Discussion

To assess the impact of an activity on the environment, investigators often deal with limited knowledge about possible effects. Consequently assumptions have to be made. In general, the foundation of the methods that were used in the past to estimate impacts on tern populations quantitatively is very limited.

For a more realistic approach, extensive literature research and the formation of a cause-effect chain may give a good insight in which aspects may be important to prevent negative effects of a certain activity on a given species.
By using a probabilistic approach, insight is given in the probability of occurrence of certain impacts. This will prevent that the accumulating of worst case assumptions creates an unrealistic negative impact estimation of an activity. The probabilistic approach will allow estimating a more realistic view of the occurrence of the impact and also quantifies the uncertainty of this impact.

However, safe assumptions of possible effects of human activities are often made because of lack of knowledge and research on possible effects. The case study on Sandwich terns, as described in this report, shows that it can be difficult to make a reliable assessment of possible impacts of dredging activities on a tern population. The literature research showed that there is much knowledge about Sandwich and other related tern species. However, most of this research was descriptive and did not quantify the connections in the impact effect chain directly. Research that did quantify aspects was mostly correlative, as causal relations are difficult to establish for birds. This resulted in uncertain quantifications for many connections in the impact effect chain. In addition, to make some of the relations in the chain probabilistic, some uncertainty margins had to be estimated, as they could not be based on measured data. Furthermore, some pragmatic (and conservative) assumptions had to be made, because of lack of knowledge. For example many aspects (migration, change in foraging area, effects of dredging activities on prey behaviour/availability, effects other than turbidity on the tern population, combined effects of kleptoparasitism and weather) are acknowledged to possibly have significant effects on the population, but are not taken into account in the analysis. Consequently, the uncertainty margin of the expected impact on the tern population might be even larger than the model results suggest.

Furthermore, estimates had to be made on very limited data and knowledge for the connection between “prey availability” and “time to catch enough food”. There is good research on the relationship between catchability and turbidity. However, to connect turbidity level with breeding success proved to be difficult. It was decided to assume that a reduction in catchability would result in an increase in searching time (“findability”). Because of this, time would be a limiting factor. However, these estimates do not have a reliable basis on existing research and are therefore highly uncertain. The relationship between food intake of the chicks and breeding success is based on real data, but only on 5 data points that were highly variable. As a consequence, the estimated relationship (figure 11) is highly uncertain. Therefore, it is recommended to collect more data on these connections in the cause-effect chain, in order to better model the impact of dredging on tern populations.

5.2 Recommendations

Monitoring

For the prediction of effects of specific dredging projects on tern populations, monitoring the following parameters in advance is recommended:

- *The number of fish that can be caught by terns per day*. If terns are able to catch a large number of fish easily, the amount of available time for foraging is not limiting. On the basis of observations of prey capture rates, it would be possible to estimate a probability density function for the prey capture rate at optimal conditions. If this information is available, using conservative assumptions on this variable is not necessary anymore. Using measurements, instead of these conservative assumptions, leads to a more realistic and probably less pessimistic estimate of the impact on terns (see chapter 4, results Run2a and 5a).
- *The background turbidity at the foraging location (SPM- and chlorophyll-a concentrations).* The background turbidity has a large influence on the expected impact from dredging activities (see Figure 18). In addition, it is relevant to know whether large spatial differences exist in turbidity levels within the foraging area (see section 4.2).

If the probability of occurrence of significant effects, predicted in advance, is not negligible, monitoring *capture rates* and *turbidity* during the dredging process is recommended. By substituting the uncertain input variables in the model with the measured values, the prediction of the ecological impact can be adjusted. If the probability on significant effects increases to an undesirable value, adaptation of the dredging process will be desirable. Preferably the additional SPM-concentration, caused by the dredging process, is hind casted during the dredging process. This makes it possible to distinguish the effects of changes in the background turbidity (reference situation) from the effects that are caused by the dredging activity.
Regarding the adaptation of the dredging process, attention should be paid to the effectiveness of the possible measures. As tern populations are expected to be more affected by long term, far field effects of the dredging activities than by short term effects close to the dredging site, a certain time lag will exist between the moment of taking measures and the effect of these measures in the foraging area. It is recommended to do research on this time lag, as information on this time lag is highly relevant for the development of an effective, adaptive monitoring strategy. In case of the tern population: measures that are taken on the basis of today’s monitoring results should have a positive effect in the foraging area before the breeding period ends.

Information on the development of the tern population is also valuable. If information on the population size and composition is available, it can be used to validate the population dynamical model. In addition, in the assessment of the predicted impact, it may be relevant to know whether the population shows an autonomous increase or decrease.

Improving the modeling of impacts on tern populations

Further research on the following topics is recommended to improve the model of the effects of dredging on Sandwich Tern populations:

- How does an increase of turbidity affect the ‘findability’ of food by terns? A point of attention is the possible influence of wave amplitude (Taylor, 1983), as high turbidity levels often occur simultaneously with high wave amplitudes.
- More measurement data on the relation between breeding success and the amount of provided food are desirable. This makes a better founded estimate of the relation between these factors possible.
- Do temporal differences in the amount of food that is provided to tern chicks have a significant influence on the breeding success?

- Is the relation between water transparency and prey capture probability as found by Baptist & Leopold (2009), generally applicable?
- The impact of kleptoparasitism on the amount of food provided to tern chicks. If more quantitative information is available, this effect can be incorporated in the model. A point of attention is the correlation between kleptoparasitism and turbidity, because both factors depend on weather conditions.
- Do terns migrate to other colonies if food conditions are limiting at their regular breeding colony? If so, do they return to their former breeding grounds when the disturbance has disappeared?
- The values of several parameters (see for example Table 14) are estimated or founded on research about other tern species. More research on the values of these parameters for Sandwich terns is desirable. This would result in better estimates of the values and their probability density functions. When insight into these pdf's is gained, it is recommended to consider whether or not these uncertainty margins can have a relevant influence on the final results of the probabilistic modeling. In that case these uncertainty margins have to be taken into account in the probabilistic model.
- Within the foraging area, possibly relevant spatial differences exist in turbidity and the presence of prey fish. A relation might exist between spatial differences in turbidity and the distribution of patches of fish over the foraging area. Research into this subject is recommended, as it may be relevant to incorporate the effects of the local differences in the modeling of the impact of dredging activities on tern populations.

References

Ainley, D.G. (1977) Feeding methods in seabirds: a comparison of polar and tropical nesting communities in the eastern Pacific Ocean. *In: Llano, G. A. (ed.) Adaptations within Antarctic ecosystems. Smithsonian Inst., Washington, D.C., p. 669-685*

Baptist, H. (2007) Lesliematrix bij kolonievogels, Toegepast voor Visdiefjes in de Westerschelde, *Ecologisch Adviesbureau Henk Baptist, oktober 2007*

Baptist & Leopold (2009) The relationship between water transparency and prey capture probability of sandwich tern, *Sterna sandvicensis*, on Texel, *submitted*

Baptist & Leopold 2007. De relatie tussen zichtdiepte en vangstsucces van de grote sterns van de petten, Texel. Imares rapport.

Brenninkmeijer, A., Stienen, E.W.M., Klaassen, M. and Kersten, M. (2002a) Feeding ecology of wintering terns in Guinea-Bissau, *Ibis (2002), 144, p 602-613*

Brenninkmeijer, A., Doeglas, G. & De Fouw, J. (2002b) Foerageergedrag van sterns in de westelijke Westerschelde in 2002, *Altenburg en Wymenga ecologisch onderzoek, A&W-rapport 346*

Dunn, E.K. (1972a). Effect of age on the fishing ability of Sandwich Terns *Sterna sandvicensis*. Ibis 114: 360-366.

Fasola, M. & G. Bogliani 1990. Foraging ranges of an assemblage of Mediterranean seabirds. Colonial Waterbirds 13: 72-74.

Haney, J.C. & A.E. Stone (1988). Seabird foraging tactics and water clarity: are plunge divers really in the clear? Mar. Eco. Prog. Ser. 49: 1-9.

Raaijmakers, M.H.J.E., P.W.M. van Beers & J.M.P.M. Habraken 1993. Telemetrische bepaling van de foerageerplaatsen en foerageerroutes van de op Griend broedende Grote Sterns Sterna sandvicensis. Intern rapport. Instituut voor Bos- en Natuuronderzoek, Arnhem.

Stienen & Brenninkmeijer (1998) Effects of changing food availability on population dynamics of the Sandwich Tern

Stienen, E.W.M., A. Brenninkmeijer & C.E. Geschiere (1993). De relatie tussen de foerageermogelijkheden van de grote stern Sterna sandvicensis en het doorzicht van het water, alsmede de invloed van kleptoparasitisme door de kokmeeuw *Larus ridibundus* op de visaanvoer en het broedsucces van de grote stern: voorlopige resultaten. IBN-DLO, DG-512.

Stienen, E.W.M. & A. Brenninkmeijer (1994). Voedselecologie van de grote sterns (*Sterna sandvicensis*): onderzoek ter ondersteuning van een populatie-dynamisch model. IBN-DLO, IBN-rapport 120. 94 pp.

Stienen, E.W.M. & A. Brenninkmeijer (1997). Fluctuaties in de lokale voedselbeschikbaarheid in relatie tot de populatiedynamiek van de Grote Stern *Sterna sandvicensis*: resultaten 1995-1996. BEON project IBN 95 H 24. BEON rapport nr 97-1, 40 pp.

Stienen, E.W.M., Van Beers, P.W.M, Brenninkmeijer, A., Habraken, J.M.P.M., Raaijmakers, M.H.J.E. & Van Tienen, P.G.M (2000) Reflections of a specialist: patterns in food provisioning and foraging conditions in Sandwich Terns *Sterna sandvicensis*, *Ardea 88: 33-49*

Stienen E.W.M. (2006). Living with gulls : trading off food and predation in the Sandwich Tern *Sterna sandvicensis*. Alterra scientific contributions 15, Proefschrift Rijksuniversiteit Groningen, ISBN 90-367-2480-5.

Stienen, E.W.M., W. Courtens & M. van de Walle (2007). Population dynamics of gulls and terns. In: Vincx, M., E. Kuijken & F. Volckaert (Eds.). Higher trophic levels in the southern North Sea (TROPHOS). Belgian Science Policy.

Suijlen, J.M. & R.N.M. Duin (2001). Variability of near-surface total suspended matter concentrations in the Dutch coastal zone of the North Sea; Climatological study on the suspended matter concentrations in the North Sea. Rijkswaterstaat Report RIKZ/OS/2001.150X

Taylor, I.R. (1983). Effect of wind on the foraging behaviour of Common and Sandwich Terns. Omis scandinavica 14: 90-96. doi:10.2307/3676011.

Thorpe, J.E. 1978. Rhythmic activity of fishes. Academic Press, London.

Van Boven, R.M. & Schobben, J.H.M. (1993) Risico-analyse voor een indicator-soort van het zeemilieu: De populatiedynamica van de grote stern in Nederland, *Rijkswaterstaat – Dienst Getijdewateren, Rapport DGW-93.006, maart 1993*

Veen (1977) Functional and Causal Aspects of Nest Distribution in Colonies of the Sandwich Tern (*Sterna Sandvicencis*): Behaviour, *p 83*

Appendix A Model schematization and input parameters

List of symbols

B	breeding success [-]
BMR	basal metabolic rate [kJ/d]
$C_{optimal}$	prey capture rate at optimal water transparency conditions [h^{-1}]
c_{Chl-a}	concentration of chlorophyll-a [mg/m^3]
$c_{silt\_background}$	background concentration of Suspended Particulate Matter (SPM) [g/m^3]
$c_{silt\_dredging}$	additional concentration of SPM, caused by dredging [g/m^3]
c_{SPM}	total SPM-concentration [g/m^3]
D_{fish}	digestibility of fish by terns [-]
$E_{content\_fish}$	energy content of fish [kJ/g]
$E_{\exp enditure}$	energy expenditure of terns per day [kJ/d]
E_{income_fish}	energy income for terns per eaten fish [kJ/eaten fish]
f	probability density [-]
fc_{lost}	fraction of food that gets lost before it is eaten by the tern chicks [-]
K_d	light attenuation coefficient [-]
L_{flight}	distance between foraging area and colony of terns [m]
m_{fish}	average mass of prey fish [g]
NA	number of attempts necessary to catch one prey [-]
$NA_{optimal}$	number of attempts necessary to catch one prey at optimal water tranparency conditions [-]
$N_{flights}$	number of times per day that terns fly forth and back from foraging area to colony [-]
NF_{caught}	number of fish that is caught per day by a tern [-]
NF_{food_adult}	number of fish that has to be eaten by adult terns per day [-]
$NF_{provided}$	number of fish that is provided to the nest by two parent terns per day [-]
$NF_{provided\_av}$	average number of fish that is provided to the nest per day over the feeding period [-]
NT	number of terns [-]
$NT^{breeding}$	total number of terns of 4-year old and older [-]
$P_{capture}$	prey capture probability per attempt [-]
$P_{capture\_optimal}$	maximum prey capture probability per attempt (at optimal transparency conditions) [-]
S	Secchi disk transparency [m]
$S_{\max}$	maximum value of Secchi disk transparency [-]
s_{adults}	yearly survival rate of adult terns [-]
$s_{juveniles}$	yearly survival rate of juvenile (0-year old) terns [-]

t_{search}	average amount of time necessary to find a prey fish [min]
$t_{search\_optimal}$	average amount of time necessary to find a prey fish at optimal conditions [min]
t_{flying}	amount of time that can be spent flying by terns per day [h]
$t_{foraging}$	amount of time that is spent foraging by terns per day [h]
u_{flying}	flying speed of terns [m/s]
α	uncertainty factor on relation between provided food and breeding success [-]
β	
Δ_{silt}	relative increase of SPM-concentration [-]
$\Delta_{breedingTerns}$	relative change of the number of breeding terns, comparison between reference and dredging scenario [-]
$\Delta^{Max}_{breedingTerns}$	maximal relative change of number of breeding terns over a period of 35 years after the start of dredging [-] (= definition of impact of dredging on tern populations in this case study)

Input – impact of dredging on SPM-concentrations

Table 13 Defined dredging scenario's – impact on turbidity

Scenario		Year							
		1	2	3	4	5	6	7	8
1) Far field effects of large dredging project, which takes several years	Relative increase of SPM-concentration Δ_{silt} [-]	0.2	0.5	0.5	0.2	0.2	0.1	0.1	0.1
2) Near field effects of dredging project	Absolute increase of SPM-concentration $c_{silt\_dredging}$ [mg/l]	8	1	0	0	0	0	0	0

Dredging scenario 1: $c_{silt\_dredging} = \Delta_{silt} \cdot c_{silt\_background}$

Parameters, equal for each model run

Table 14 Assumed values of parameters (see chapter 4 for foundations)

Parameter	Value	Comments
BMR	202 kJ/d	
D_{fish}	0.768	
$E_{content\_fish}$	6.37 kJ/g	
fc_{lost}	0.3	
L_{flight}	7500 m	
m_{fish}	4 g	
$N_{flights}$	10	
$P_{capture\_optimal}$	0.63	
$S_{\max}$	3m	To prevent unrealistically high values of transparency (and subsequent, extremely low prey capture probabilities)
t_{flying}	12 h	
u_{flying}	10 m/s	

$$t_{foraging} = t_{flying} - 2 \cdot N_{flights} \cdot \frac{L_{flight}}{3600 \cdot u_{flying}} = 12 - 2 \cdot 10 \cdot \frac{7500}{3600 \cdot 10} = 7.8\ \mathrm{h}$$

$$NF_{food\_adult} = \frac{E_{\exp enditure}}{E_{income\_fish}} = \frac{\frac{t_{flying}}{24} \cdot 4.77 \cdot BMR + \frac{(24 - t_{flying})}{24} \cdot 1.62 \cdot BMR}{m_{fish} \cdot E_{content\_fish} \cdot D_{fish}} = 33.0$$

$$NA_{optimal} = \frac{1}{P_{capture\_optimal}} = 1.6$$

$$t_{search\_optimal} = \frac{60 \cdot P_{capture\_optimal}}{C_{optimal}}$$

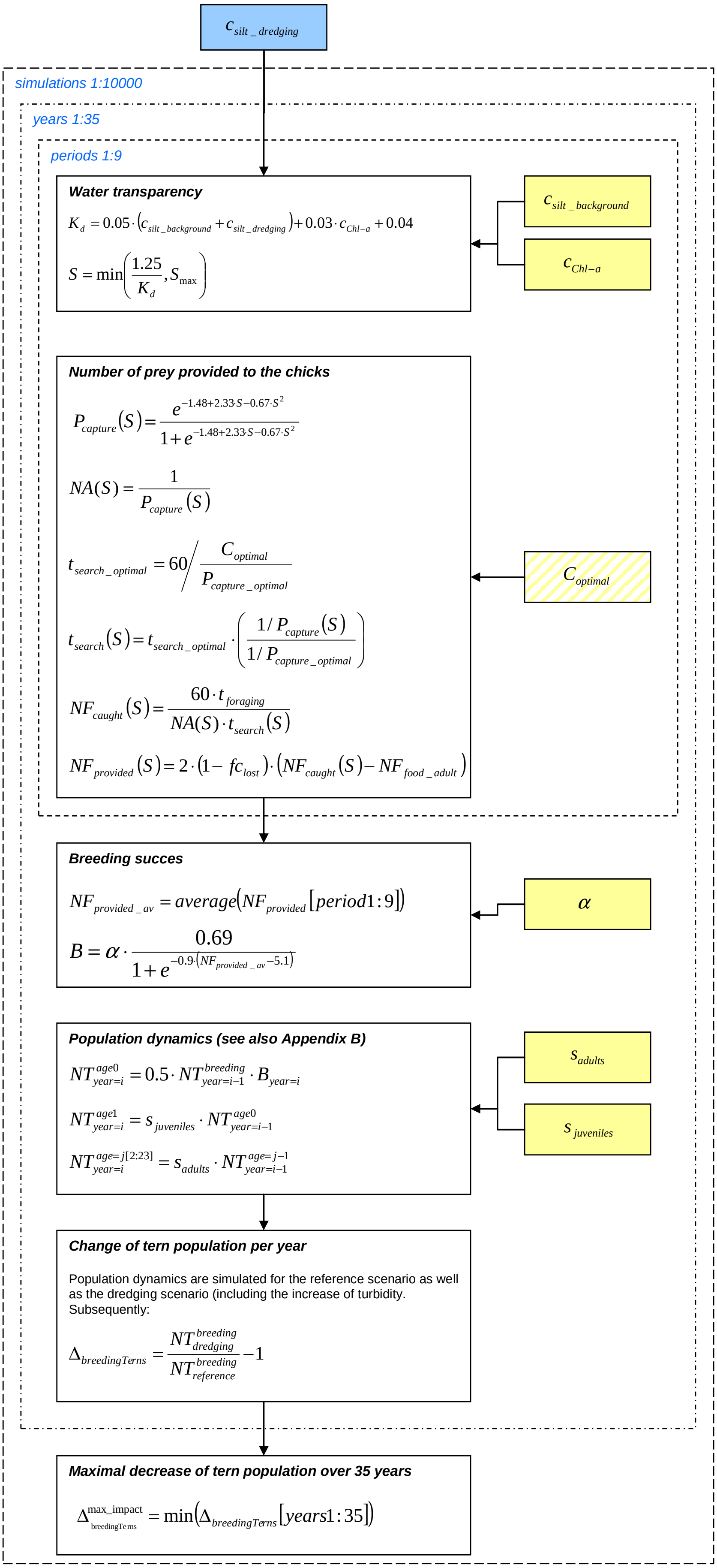
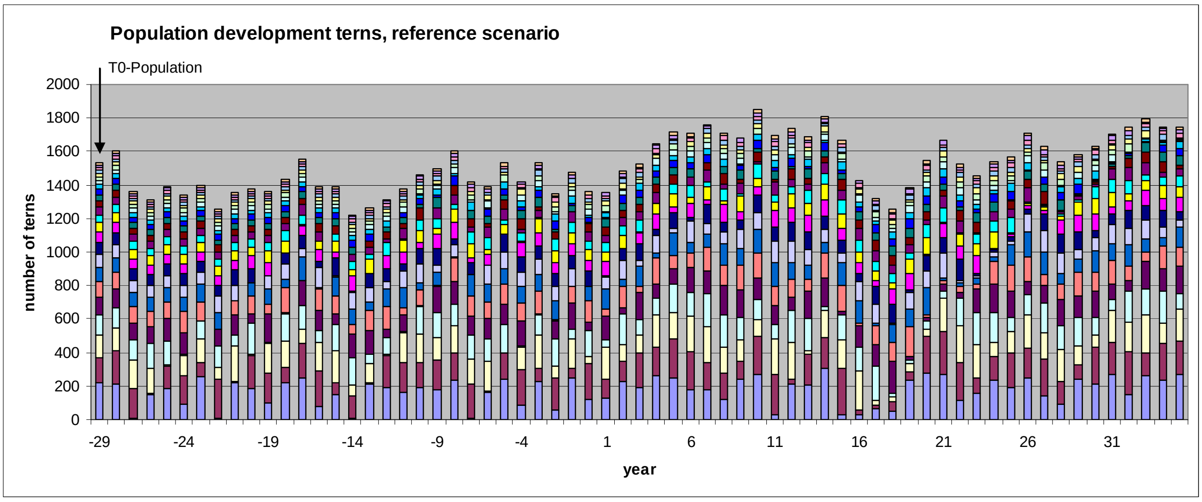
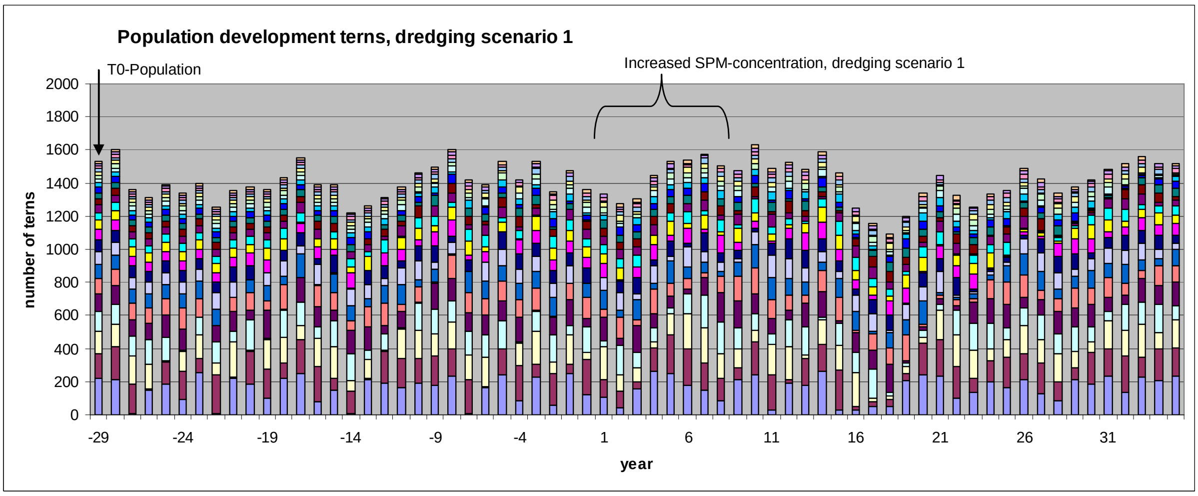


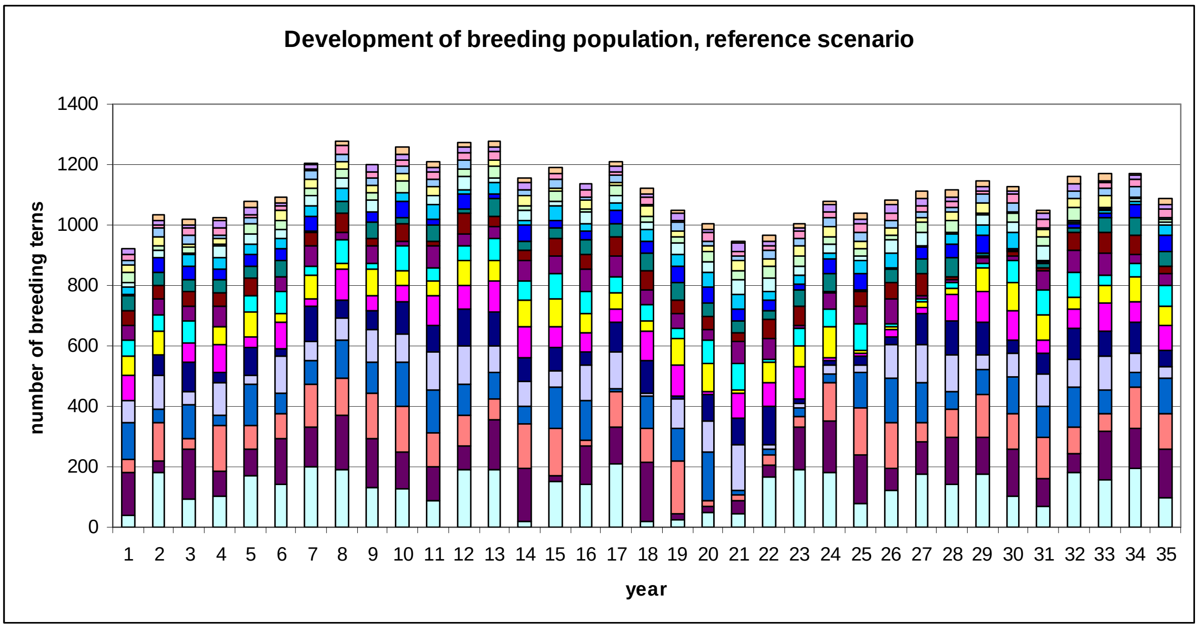
Figure 24 Schematization of the Monte Carlo simulation

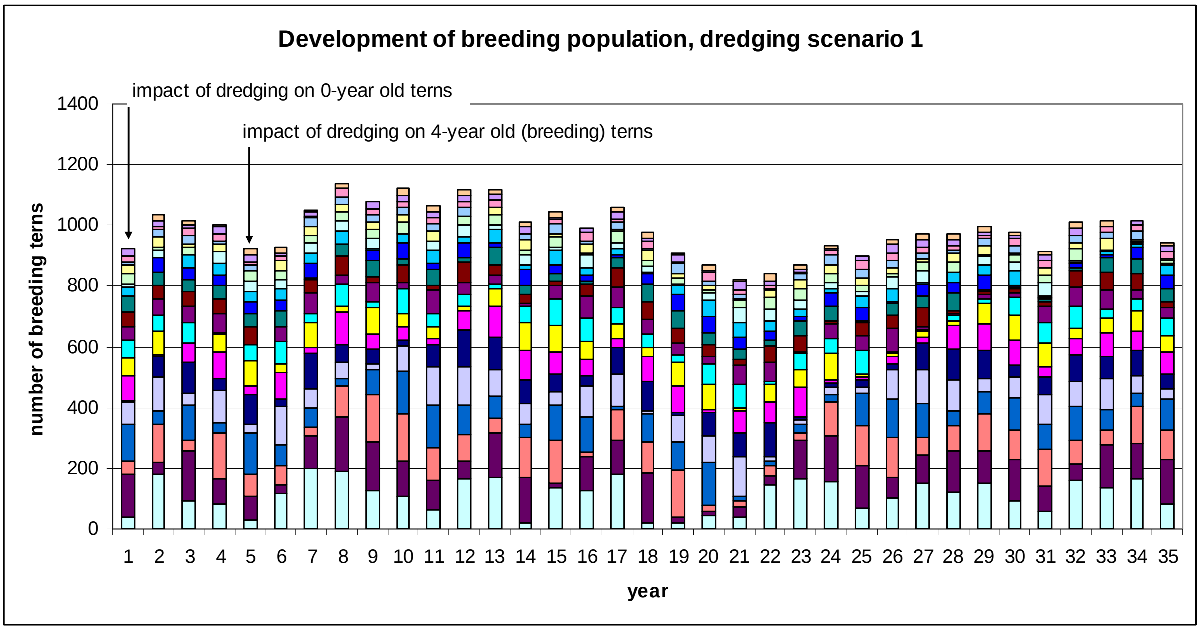
Appendix B Population dynamics

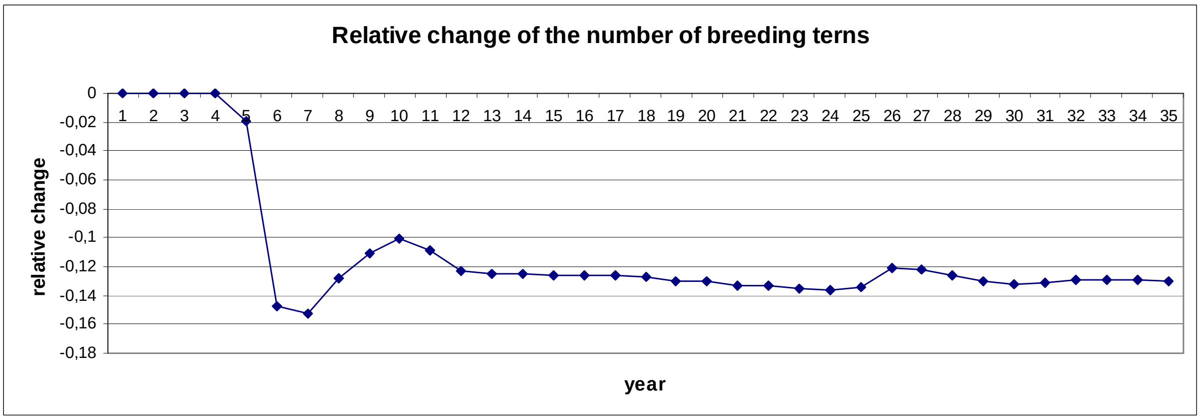
The population dynamics of Sandwich Terns was modeled by varying survival rates and breeding successes (as a function of a variable water transparency) randomly. On the basis of average survival rates, a population composition was chosen to start the simulation (T0-population). To prevent that this choice influences the modeled impact of dredging, the T0-population was as the population at ‘year -29’. The increase of turbidity due to the dredging project starts at year 1.











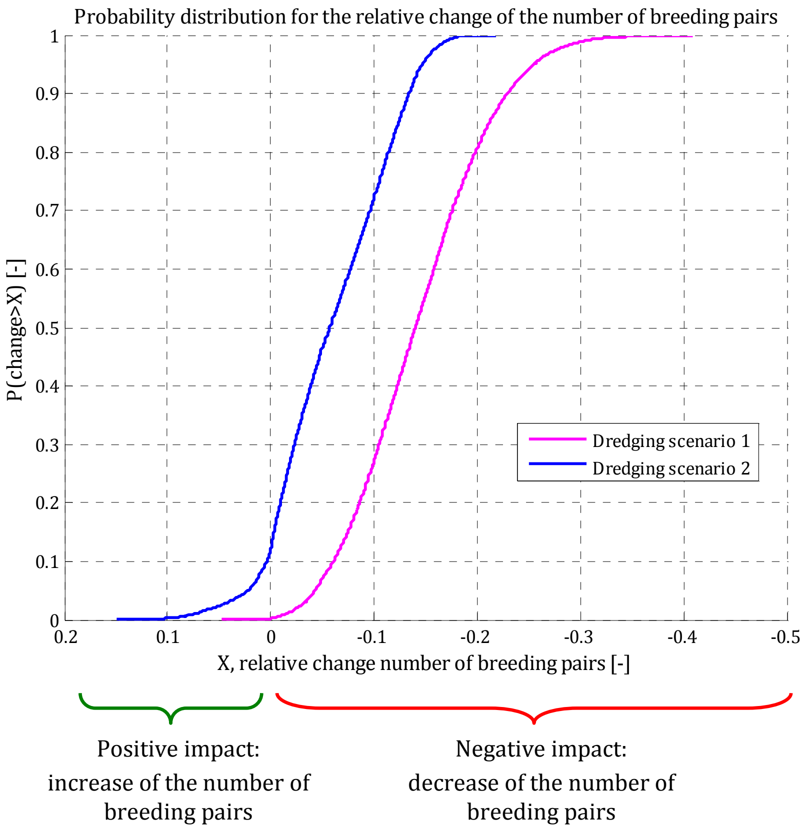
Maximal change: -15.3% (year 7)
(background turbidity based on location C1)

Appendix C Probability distributions

In this appendix is explained how to read the graphs of the probability distributions in section 4.6.

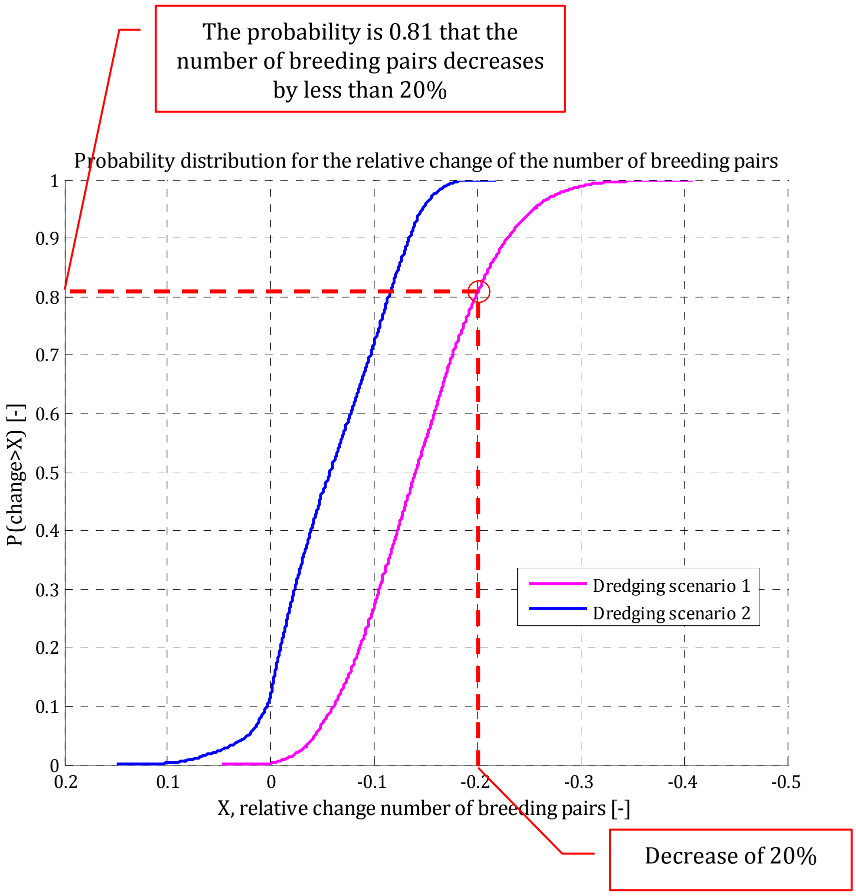
The horizontal axis of the graphs with the probability distributions shows the possible impact of the dredging activities on the tern populations. A negative value means that the population size decreases. A positive value means a positive impact; the number of breeding pairs will increase.

For example: a value of -0,2 on the horizontal axis means a decrease of the number of breeding pairs by 20%, compared to the scenario without dredging. This 20% is the maximal relative decrease that occurs during a period of 35 years after the start of the dredging activities.



The vertical axis shows the probability of exceedance of the value at the horizontal axis. In this specific case this value is the probability that the impact on the tern population is less negative than the value at the x-axis.

For example: the results for ‘dredging scenario 1’ show that the probability is 0.81 that the decrease of the number of breeding pairs will be less than 20%. The probability of occurrence of a decrease of 20% or larger is 1-0.81=0.19.



The probability is 0.81 that the number of breeding pairs decreases by less than 20%
Probability distribution for the relative change of the number of breeding pairs
P(change>X) [-]
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
X, relative change number of breeding pairs [-]
Dredging scenario 1
Dredging scenario 2
Decrease of 20%

Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

Justification

Rapport number C055/11
Project Number: 4306111061

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Pepijn de Vries
Scientist

Signature:

Date: April 2011

Approved: Jakob Asjes
Head of Department

Signature:

Date: May 2011

EcoShape is een consortium bestaande uit