Above: Artist's rendering of the Maasvlakte 2, the extension plan for the port of Rotterdam, which borders on the so-called Voordelta (Fore-Delta), a designated Natura 2000 area.

Y.J.G. VAN KRUCHTEN, T. VELLINGA AND F. HEINIS

A PROBABILISTIC ANALYSIS OF THE ECOLOGICAL EFFECTS OF SAND MINING FOR MAASVLAKTE 2

ABSTRACT

For the construction of the new port area Maasvlakte 2 in the Netherlands, which is an extension of the existing port, a large amount of sand has to be extracted from the North Sea. The potential ecological effects of the sand mining activities have been investigated in an Environmental Impact Assessment (EIA). One of the identified potential effects in this EIA was a temporary decrease in the number of eider ducks in the Natura 2000 area "Voordelta". Within the impact-effect chain from dredging to eider ducks, a large number of uncertainties play a role. Keeping in mind the precautionary principle, worst-case assumptions were used in the EIA in case of uncertainties.

Owing to this, the final predicted impact is a result of the accumulation of several safe assumptions. Therefore, the probability of occurrence of this predicted impact might be small. Information on this probability of occurrence will be useful in the discussion about the necessity of implementing mitigating or compensating measures.

The main objective of this study was to give insight into the probability of occurrence of the possible effects of sand mining on eider ducks in the Voordelta. A probabilistic approach was used to analyse the uncertainties in the impact-effect chain and to find a method to take these uncertainties into account in the modelling of the ecological effect. The final result was a probability density function of the impact of the sand mining on eider ducks. This result led to the conclusion that the probability that the sand mining activities for Maasvlakte have a significant effect on eider ducks in the Voordelta is very small and can be considered negligible. The methodology that is used in this study is expected to be applicable as well to the assessment of ecological effects of other human activities.

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INTRODUCTION

Maasvlakte 2 is a land reclamation project in the Netherlands for the extension of the port of Rotterdam. For its construction about $250*10^6$ m^3 sand has to be extracted from the North Sea. The mining areas are located relatively close to the Natura 2000 area known as the "Voordelta". In this area certain bird species and habitat types are protected by law. If the ecological effects on these species or habitat types are significant, it is obligatory to mitigate or compensate these effects.

The consequences of the land reclamation and sand extraction have been described in an Environmental Impact Assessment (EIA) (Berkenbosch *et al.* 2007; Vertegaal *et al.* 2007). For this EIA, the processes by which the release of silt particles by dredging activities could affect protected habitats and species have been investigated thoroughly. While most of the effects turned out to be insignificant, the question of whether the predicted temporary impact on the common eider (*Somateria mollissima*) was significant or not has been a subject of discussion. It was known, however, that the predicted impact on eiders had to be considered as an upper limit, as the prediction was based on an accumulation of worst-case assumptions.

Within the impact-effect chain from dredging process to eider ducks, a large number of uncertainties play a role. Some of these uncertainties are caused by unpredictable natural variations and some uncertainties are a consequence of lack of knowledge. In the deterministic approach followed by the EIA, mostly worst-case assumptions were made to deal with these uncertainties. As a large number of safe assumptions were used to estimate the impact on eiders, the probability of occurrence of this effect was expected to be small.

In order to evaluate an ecological effect in its context, not only the predicted effect, but also the probability of its occurrence is important. Information on the probability of occurrence of the ecological effects is essential for a thorough discussion about the necessity of taking mitigating and/or compensating measures.

The main objective of this study was to investigate the probability of occurrence of the possible effect on eiders by the sand mining activities for Maasvlakte 2, resulting in a probability distribution of the decrease in the numbers of eider ducks.

The methodology that was used to derive the probability distribution is described in this article. A secondary objective was to investigate whether or not probabilistic analyses are applicable to EIAs.

IMPACT-EFFECT CHAIN

Sand extraction by trailing suction hopper dredgers will cause a release of fine sand and small silt particles that are present in the seabed. Silt particles (< 63 μm) can be transported over large distances by tidal currents because of their small settling velocity. After the deposition of silt particles on the seabed, part of these particles can get entrained into the seabed. Gradually the amount of silt that is buffered in the seabed will be released again (during stormy conditions) and dispersed over a larger area. This effect will go on for several years after finishing the sand extraction activities.
In this way the sand mining causes a temporary increase in the concentration of Suspended Particulate Matter (SPM) in a particular area along the Dutch coastline. An increase of the SPM concentration leads to a reduction in the transparency of the water and subsequently to a stronger attenuation of the light intensity in the water column.

Phytoplankton, which form the base of the marine food chain, need a minimal light intensity for net primary production (production of organic compounds from inorganic matter). In the case of net primary production, the total biomass of the phytoplankton concentration increases. Phytoplankton concentrations are low during winter and increase quite rapidly during spring. This rapid increase is called the algal bloom. As a result of the reduction of the light intensity in the water column by the increased silt concentration, the timing of the algal bloom will be delayed.

Phytoplankton form the main food for bivalves and their larvae. The larvae of bivalves hatch at a certain moment in the spring. If the hatching takes place before the algal bloom, the concentration of phytoplankton will be too low for the bivalve larvae to grow optimally. In this case a so-called mismatch occurs. As described by Philippart *et al.* (2003) and Bos *et al.* (2006 and 2007), a mismatch between the availability of sufficient food and the hatching of the bivalve *Macoma Balthica* (Baltic tellin) can lead to a growth lag of these larvae. In this way the mismatch can have a negative impact on the total biomass of the bivalve population in the Voordelta.

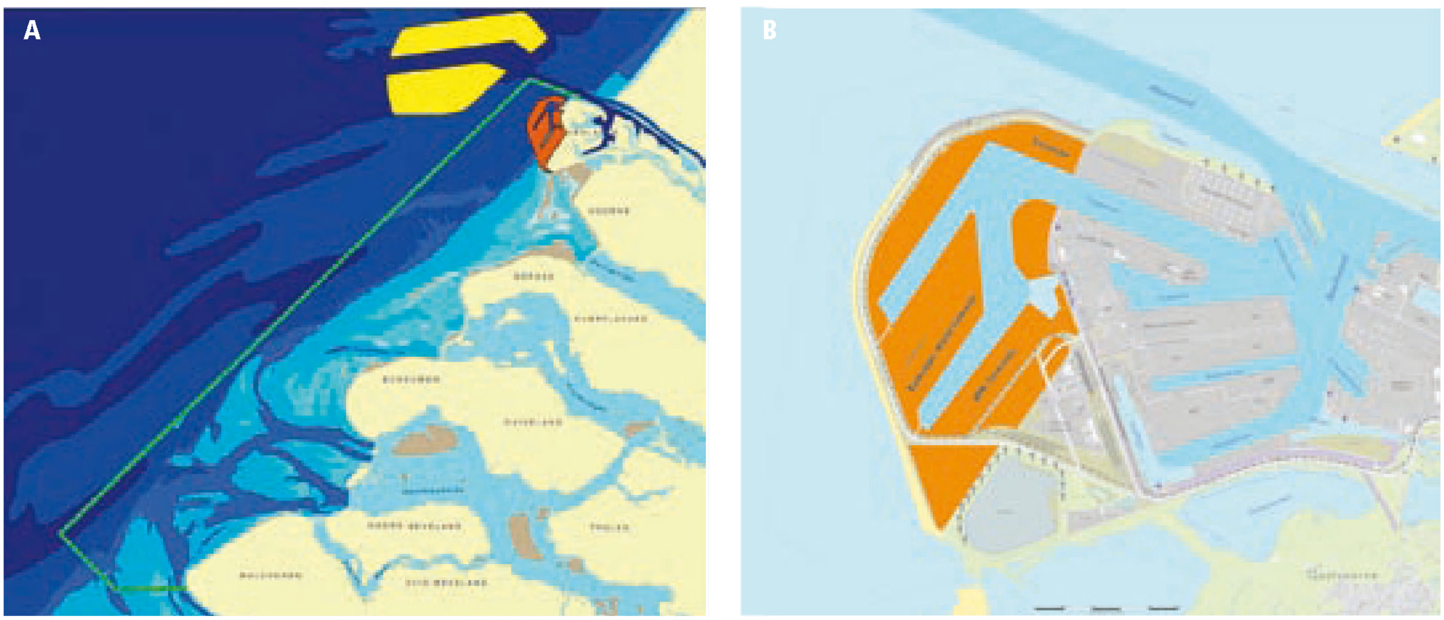

Figure 1. A) Location of Maasvlakte 2 (orange), boundary of the Natura 2000 area "Voordelta" (green line) and the potential sand mining areas (yellow). (Data from Rijkswaterstaat). B) Enlargement of the orange area in A – a schematic drawing of the Maasvlakte 2 port area.

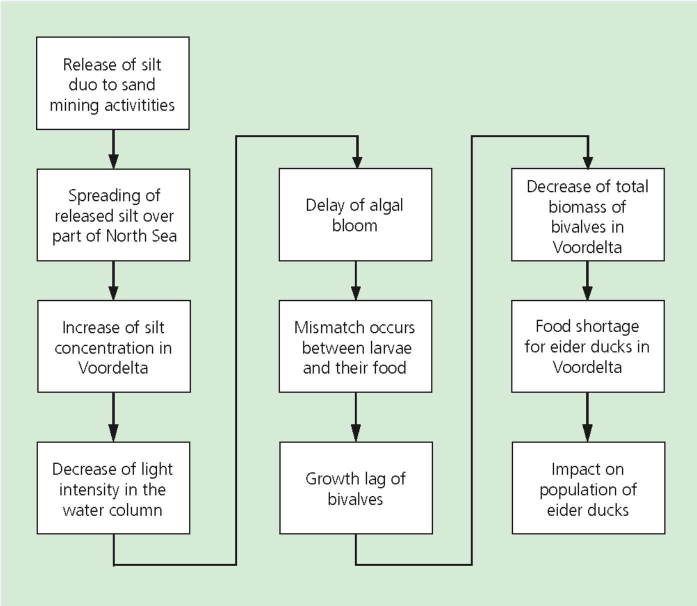

Figure 2. Impact-effect chain.

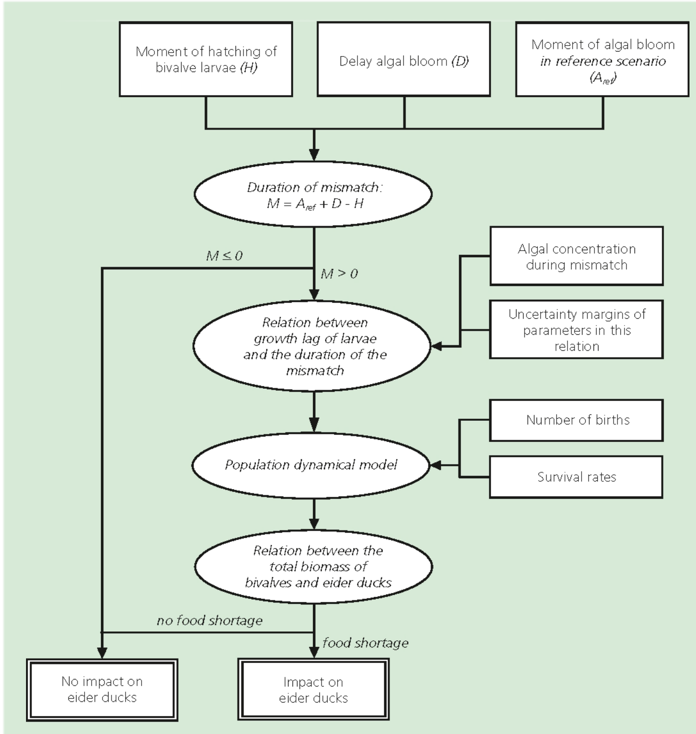

Figure 3. Schematised ecological model used in the Monte Carlo analysis.

In the Voordelta, eider ducks mainly feed on the bivalves *Cerastoderma edule* (cockles) and *Ensis directus* (American razor shell). A decrease of the total biomass of bivalves in the Voordelta can lead to a food shortage for these sea ducks. In this way sand mining activities can affect the number of eider ducks in the Voordelta.

METHOD ANALYSIS

First the deterministic approach of the EIA was analysed to investigate the uncertainties involved in modelling of the ecological effects of the sand mining. The uncertainties, which have a large influence on the final result and accompanying uncertainty margin, have been investigated more thoroughly to find a method to incorporate these uncertainties in a probabilistic calculation. To account for these uncertainties in the ecological effect modelling, probability density functions have been estimated for the relevant variables. These probability density functions are used in a Monte Carlo analysis, where they are used to generate randomly (a large number of) sets of input variables. For each set of input variables the impact on eiders has been calculated, using the model as shown in Figure 3, resulting in a probability distribution for the impact of sand mining on eiders.

DELAY OF THE ALGAL BLOOM

The relation between the increase of the silt concentration and the delay of the algal bloom that was used in the probabilistic analysis is based on the Delft3D-ECO model (Deltares). The ECO module of the numerical model Delft3D is used to simulate the bio(chemical) and biological processes related to growth of algae and nutrient dynamics. Within the probabilistic analysis, the formulas underlying this model were analysed to gain insight in the relation between the increased silt concentration and the delay of the bloom, as well as in the influence of other input variables on

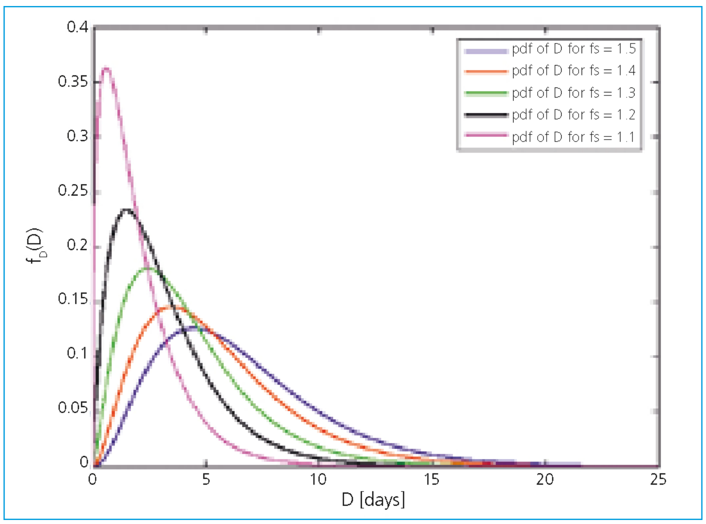

Figure 4. Probability density function of the delay of the algal bloom *D* for different values of *fs*.

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this relation. The analysis showed that not only the relative increase of the silt concentration determines the delay of the bloom, but that also short-term fluctuations of solar irradianc e (amongst other things dependent on cloudiness) and silt concentrations (owing to a changing wave climate) have a large influence on this delay.

Probability density functions of the delay of the algal bloom *D* have been derived by Van Kruchten (2008) on the basis of solar irradiance measurements and modelled silt concentrations (model results Deltares), by using the formulas of the Delft3D-ECO model. Figure 4 shows the probability density function of *D* for different values of *fs*. The definition of *fs* is the average relative increase of the silt concentration in the Voordelta during spring, caused by the sand mining activities.

For the EIA, numerical models were used to simulate the spreading of the released silt in the southern part of the North Sea (Van Prooijen *et al.* 2006; Desmit *et al.* 2007). Based on the modelling results, an increase of the silt concentration for a period of 8 years after the start of the sand mining activities was predicted (Van Ledden *et al.* 2007). The modelled, relative increase of the silt concentration *fs*, which is more or less constant during the relatively short spring period, is used in the probabilistic analysis. The values of *fs* for different sand mining scenarios are shown in Figure 5.

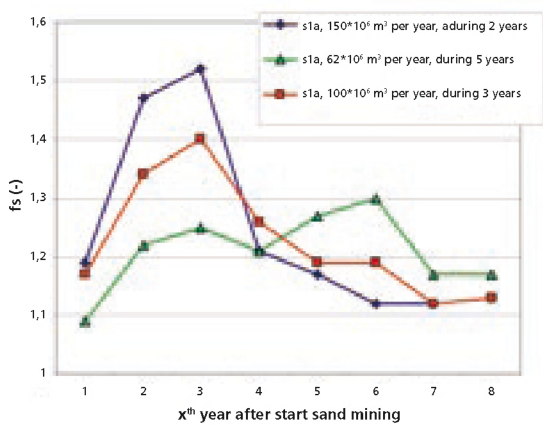
Within the Monte Carlo analysis the ecological impact of the sand mining is modelled for a period of 13 successive years. As bivalves can get about 5 years old, a mismatch resulting from the increased silt concentration in the 8th year after the sand mining can still have an impact on the bivalve population in the 13th year. For the delay of the algal bloom *D*, the probability density functions for the values of *fs* as shown in Figure 5 have been used for each specific year (for the 1st till 8th year after the start of the sand mining).

PROBABILITY OF OCCURRENCE OF A MISMATCH

The EIA assumed that a delay of the algal bloom would always lead to a mismatch between the presence of bivalve larvae and a sufficiently high algal concentration. This assumption only holds if, in a reference scenario without sand mining, the hatching of larvae would always takes place at the same moment as the algal bloom.

However, as the hatching of larvae mostly takes place later than the algal bloom, the probability of occurrence of a mismatch caused by the delay of the bloom is much smaller than 1. Besides, the timing of both events shows a large year-to-year variation.

The occurrence of a mismatch can be schematised by the following simple equation.



$$fs = \frac{IM1 + IM2}{IM1}$$

fs = relative increase of the silt concentration [-]
IM1 = concentration of background silt [g.m-3]
IM2 = concentration of sand mining silt [g.m-3]

Figure 5. *fs* (relative increase of silt concentration during spring) from the 1st to the 8th year after the start of the mining activities (derived from model results of Deltares, Van Prooijen *et al.* 2006 and Desmit *et al.* 2007).

A mismatch only occurs if:

$M = A_{ref} + D - H > 0$ [Equation 1]

With: M = duration of the mismatch days)
H = moment of hatching of the larvae (days)
A_{ref} = moment at which the critical algal concentration is exceeded in the reference scenario (days)
D = delay of the moment at which the critical algal concentration is exceeded, caused by the sand mining activities (days).

A match occurs if $M \leq 0$. The critical algal concentration is defined as the minimal concentration at which the growth of larvae is not limited by the availability of food. The longer the duration of the mismatch period M, the larger the growth lag of the larvae will be.

In the deterministic approach of the EIA it was assumed that: $A_{ref} = H$, which leads to: $D = M$, and a probability of 1 that a delay of the bloom ($D > 0$) results in a mismatch.

Figure 6 shows an example of the probability density functions of the moment of the algal bloom and the moment of hatching. In this example the algal bloom (in the reference scenario) takes place on average on April 9th and the hatching on May 25th. The large year-to-year variation of the timing of the algal bloom and the moment of hatching is expressed by the standard deviations of the probability density functions. In this simplified example, a delay of the bloom D of 7 days is used. In case of an increased silt concentration caused by sand mining, the algal bloom takes place on average on April 16th.

The small overlap between the probability density functions of A_{mining} and H in Figure 6 indicates that the probability of occurrence of a mismatch $P(A_{mining}>H)$ is small. Mostly the algal bloom precedes the hatching and a match occurs. A mismatch will only occur if the algal bloom takes place relatively late and the hatching relatively early. As can be seen, a mismatch can also occur in the reference scenario. However, the probability of occurrence of a mismatch is larger in the sand mining scenario. Given the probability density functions of H, A_{ref} and the delay D, the probability of occurrence of a mismatch can be calculated, which in the example of Figure 6 is only $7*10^{-3}$.

On the basis of data and expert judgement, the mean values μ and standard deviations σ of the normal probability density functions of H and A_{ref} were estimated by Van Kruchten (2008). Unfortunately, as the amount of data and expert judgement on H and A_{ref} is limited, the accompanying probability density functions could only be estimated roughly. Because of this and the high sensitivity of the final result on these estimated probability density functions, the Monte Carlo analysis was done twice: One time for probability density functions which are expected to be realistic estimates, and one time for a conservative assumption on these probability density functions.

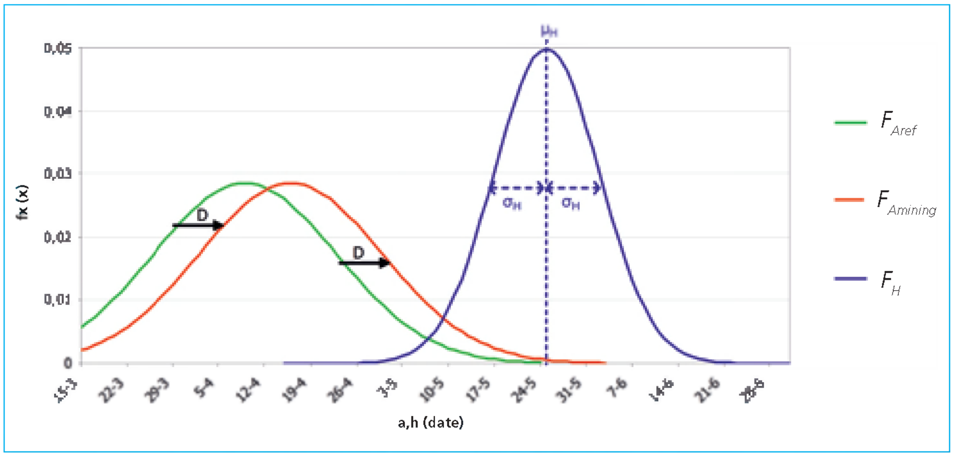


Figure 6. Probability density functions of H, A_{ref} and A_{mining} ($= A_{ref} + D$).

RELATION BETWEEN MISMATCH AND GROWTH LAG

Based on laboratory results reported by Bos *et al.* (2006) and Bos *et al.* (2007), a relation between the duration of the mismatch period, the algal concentration during this period and the growth lag of the larvae has been derived. Bos *et al*. (2006 and 2007) investigated the effect of a mismatch on the growth of *Macoma balthica* larvae. In the Monte Carlo analysis, the uncertainty of this relation has been taken into account by using a normally distributed correction factor. This probability density function was derived by the difference between the measured growth lags in the laboratory experiment and the growth lags as calculated by using the relation. For the uncertain algal concentrations during the mismatch period probability density functions were also derived, which are partly dependent on the duration of the mismatch M.

In the deterministic approach of the EIA the worst-case assumption was made that bivalves are not able to catch up a growth lag. In case of a growth lag of a larva of, for example, 20% (the larva is 20% smaller than it would have been without a mismatch), the bivalve will be subject to a growth lag of 20% for its whole life. However, it is likely that bivalves are able to catch up with a growth lag partially. Unfortunately, the amount of available literature on the growth of bivalves is also limited. Therefore the Monte Carlo analysis was again done twice for two different growth models: According to one growth model bivalves are not able to catch up with a growth lag (worst-case assumption) and according to the other model the bivalves can partially catch up the growth lag.

DYNAMIC POPULATION MODEL

As a mismatch only affects the growth of larvae, only one year class (all individuals that are born in the same year) of bivalves will be affected by a mismatch that occurs in one specific year. The total bivalve population in a given year consists of several year classes. As a result, the total bivalve

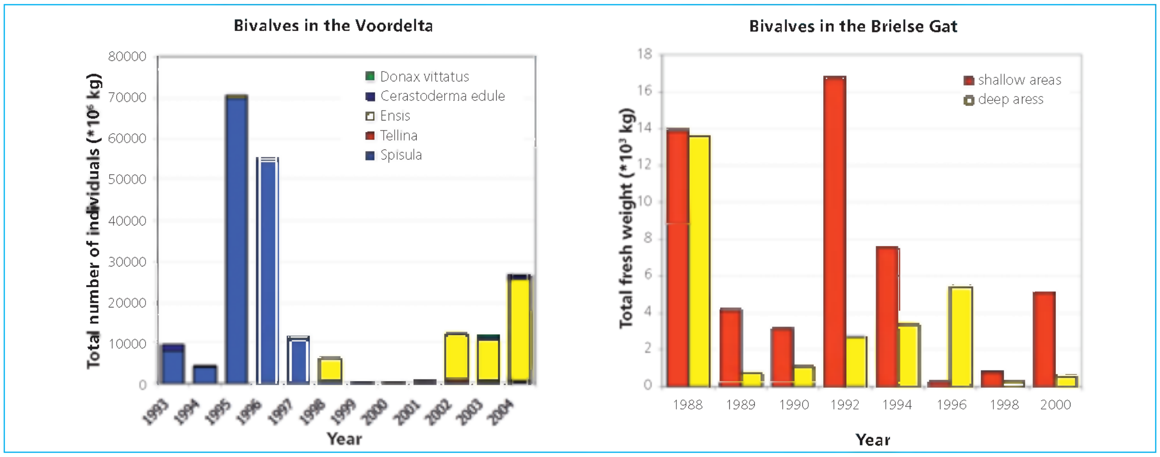


Figure 7. Variation of total amount of bivalves in the Voordelta and Brielse Gat (northern part of Voordelta. Left figure: data from KNAW-CEME, edited by F. Heinis (not previously published), Right figure: data from Heinis *et al*. (2002).

population size depends on the number of births, growth and survival rates of bivalves during the current and previous years.

From measurements of the size of the bivalve population in the Voordelta, it can be derived that the natural year-to-year variation in these survival and birth rates is large. Figure 7 shows the large variation of the population sizes.

As a result of this large, unpredictable variation the impact of a growth lag of a particular year class on the total population is uncertain. A year class with a large number of individuals will form a relatively large part of the total population. If such a large year class is affected by a growth lag, the impact on the biomass of the total population will be much larger than in the case that a relatively small year class is affected. Because of this, the decrease of the total biomass of the population, given a certain growth lag, cannot be predicted accurately.

In a probabilistic approach it is possible to take into account the effect of the natural variation of the number of births and survival rates. On the basis of literature research and data of measurements, probability density functions for survival rates and the number of births have been derived. Both variables are not influenced by the sand mining activities. By using these probability density functions, the natural variation of the population size and composition can be simulated. In this way the natural, stochastic dynamics can be incorporated into the model. This is an important difference between probabilistic and deterministic approaches. In a deterministic approach mostly constant values are used for survival and birth rates, which leads to the false suggestion that accurate predictions of ecological effects are possible. The large uncertainty margin of this prediction, which is a result of the stochasticity of nature, can be quantified in a probabilistic analysis.

IMPACT ON EIDER DUCKS

The last part of the model deals with the relationship between the number of eider ducks (*Somateria mollissima*) (Figure 8) and the bivalve population in the Voordelta. Eider ducks mainly forage on two species of bivalves in the Voordelta: *Ensis directus* (American razor shells) and *Cerastoderma edule* (cockles) (see Figure 9). As only small razor shells are edible for eiders, the effect of a growth lag of this species on the total amount of food for the eider ducks will be negligible. Because of the elongated shape of these bivalves, eiders are not able to eat the older, longer razor shells. In case of a growth lag, the razor shells reach the minimal "edible length" later, but are on the other hand edible until a higher age. Besides which, since 1993 the quantity of American razor shells has been much larger than the consumption by eider ducks.

As a worst-case assumption, the abundance of razor shells was neglected in the deterministic approach of the EIA. For the EIA it was assumed that all eiders in the Voordelta depend on the size of a bivalve population which would be affected by a mismatch. The relationship was assumed to be linear.

Figure 8. Male (left) and female of the Common Eider (*Somateria mollissima*).

Figure 9. Left, American razor shell (*Ensis directus*) and, right, cockles (*Cerastoderma edule*) are the main food source for the eider duck.

Observations show that some of the eiders in the Voordelta feed on American razor shells (Leopold *et al.* 2007). The other eiders forage mainly on cockles. Only the total biomass of edible cockles can be affected by a mismatch. Possibly all eiders can change their diet to razor shells in case of a shortage of cockles. However, as it is not possible to prove this by data, the Monte Carlo analysis is done for two different conservative assumptions. One time the analysis is done for the worst-case assumption that all eiders in the Voordelta are dependent on the amount of cockles. Secondly the analysis is done for the conservative assumption that 40% of the eiders depend on the total biomass of cockles in the Voordelta.

In the probabilistic analysis the non-linear relation as shown in Figure 10 is used. During years with a large population of cockles, a certain decrease of the total fresh weight will not lead to a decrease of the number of eiders. The total amount of food will still be sufficient.

MONTE CARLO ANALYSIS

The natural variation of the bivalve population size has been simulated for a period of 13 years after the start of the sand mining by using the values of birth and survival rates chosen randomly from the determined probability density functions. The same simulated variation is used to model the number of eider ducks in the reference scenario as well as in the sand mining scenario.

The only difference between these scenarios is the value of the delay of the algal bloom *D*; in the reference scenario *D=0*, while *D* is randomly chosen from the probability density functions in the sand mining scenario. For each year within the simulated period of 13 years, the impact on the number of eider ducks is calculated as:

$$Impact = 1 - \frac{(Number\ of\ eiders)_{sandmining}}{(Number\ of\ eiders)_{reference}} \quad \text{[Equation 2]}$$

The Monte Carlo analysis was done several times, for various sand mining scenarios (see Figure 5) and various assumptions on the probability density functions of A_{ref} and *H*, various growth models and various relations between the number of eiders and the bivalve population size (see Table I). The difference between the results for the various sand mining scenarios proved to be negligible. The results of the various Monte

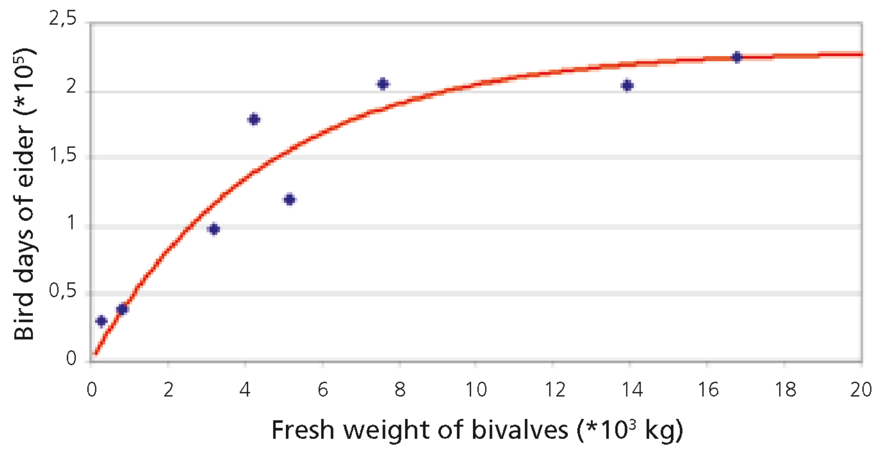


Figure 10. Relationship between eiders and bivalves for the measurements at the Brielse Gat (data from Heinis *et al*. 2002).
fresh weight: total mass of a living bivalve, including the shell and the enclosed water.
bird day: equivalent to one bird that spends one day in a specific area.

Table I. Different assumptions for Monte Carlo analyses.

Analysis	Percentage of eiders possibly affected	Bivalves catch up a growth lag?	PDF* of timing of algal bloom A_{ref}		PDF* of timing of hatching *H*		Sand mining scenario
			μ [day]	σ [day]	μ [day]	σ [day]	
A	100%	No	April 15	15	May 18	8	s1a
B	40%	No	April 15	15	May 18	8	s1a
C	100%	Partly	April 15	15	May 18	8	s1a
D	100%	No	April 9	14	May 25	8	s1a

*The mean value μ and standard deviation σ of the normal probability density functions of A_{ref} and *H* are given.

Carlo analyses are shown in Figure 11. The horizontal axis shows the possible, maximum impact *X* (see Equation 2) that occurs during a period of 13 years after the start of the sand mining. The vertical axis shows the probability that the maximum impact, which will actually occur, is larger than *X* (horizontal axis).

CONCLUSIONS

Impact of sand mining on eider ducks

For the ecological effect of the sand mining for Maasvlakte 2 it can be concluded that the probability that the sand mining has a significant effect on eiders in the Voordelta is very small and can be considered negligible.

From Figure 11 it can be derived that, even in case of conservative assumptions (analysis A, see Table I), the probability that the sand mining leads to a decrease of the number of eiders larger than 10% is only 0.03.

A maximum decrease of 10% was initially predicted in the EIA by using a deterministic, worst-case approach. As the effects of the sand mining will be temporary and the natural variation of the number of eiders in the Voordelta is relatively large, an impact of 10% is considered not to be significant. The results also show a large probability (>0.7) that the sand mining activities do not have an impact on eiders in the Voordelta at all. (P(maximal impact > 0%) = 0.27, see Figure 11).

The results of the Monte Carlo analyses for the less safe assumptions (analyses B, C and D, see Table I) show that the probability on a decrease larger than 10% is even smaller than $5*10^{-3}$. It is very likely that the assumptions for analyses B, C and D correspond better with reality than analysis A. However, proving this conclusively on the basis of data is not possible.

Predicting ecological effects

The probabilistic analysis showed that factors like weather conditions and the variation of the composition of bivalve populations have a large influence on the impact of sand mining activities on eiders in the Voordelta. As a result of the influence of these factors which show large and unpredictable variations, the uncertainty margin of the magnitude of the possible impact will always be large. Also, the lack of knowledge about processes in the impact-effect chain influences the uncertainty margin of the result. In addition, even if all knowledge were available, it would still not be possible to

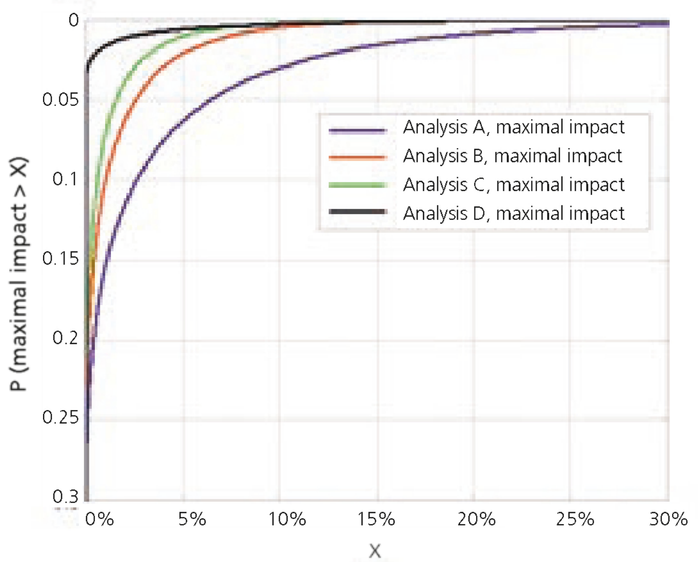


Figure 11. Monte Carlo results: Probability distribution for the maximal relative impact *X* analyses A, B, C and D.

express a realistic prediction of ecological effects in only one number because of the influence of the natural variation.

The following recommendations are suggested:

Advantages of a probabilistic approach

By using a probabilistic approach to quantify ecological impacts, insight is given into the probability of occurrence of certain impacts. Especially when significant impacts cannot be excluded on the basis of a deterministic approach, insight in the probability of occurrence of these impacts is useful in order to decide if mitigating or compensating measures should be taken.

Drawing conclusions on the basis of the results of a deterministic approach only, may lead to the decision that measures should be taken, while the probability that significant effects will occur is very small or even negligible. Because of this, an additional probabilistic analysis is recommended when a deterministic, worst-case approach leads to the prediction of significant effects.

Applicability of a probabilistic analysis for EIAs

This study demonstrated that applying a probabilistic analysis for the quantification of the impact on eider ducks by the sand mining for Maasvlakte 2 is possible. Although not all uncertainties could be incorporated into the probabilistic analysis and some conservative assumptions had to be made, it could be proven that the probability of occurrence of significant effects is small.

It is expected that also for the quantification of ecological impacts of other projects, part of the relevant uncertainties can be taken into account in a probabilistic calculation. If worst-case assumptions can be prevented in this way, applying a probabilistic approach will be useful.

Assessment framework

After the quantification of the magnitude of ecological effects and the accompanying probability of occurrence, the following questions remain:

- Which effects are considered significant for a population and which are not?
- Which probability that significant effects occur is unacceptable.

The development of an assessment framework for ecological effects is recommended to make it possible to answer these questions on the basis of objective criteria. Amongst other things the natural variation of a population size and the resilience of a population should be taken into account in the assessment of ecological impacts.

REFERENCES

Berkenbosch, R.J., Meulepas, G.J.M, Brouwer, L., Van Ledden, M., Heinis, F., Vertegaal, C.T.M., Van Zanten, M. and De Mars, H. (2007). "Milieueffectrapport Aanleg Maasvlakte 2 Hoofdrapport" *Havenbedrijf Rotterdam N.V. – Projectorganisatie Maasvlakte 2, report 9R7008. A1/R011/MVZ/Rott1*.

Berkenbosch, R.J. (2007). "Milieueffectrapport Aanleg Maasvlakte 2 Samenvatting" *Havenbedrijf Rotterdam N.V. – Projectorganisatie Maasvlakte 2, report 9R7008.A1/R012/MVZ/Rott1*.

Bos, O.G., Philippart, C.J.M. and Van der Meer, J. (2007). "Effects of temporary food limitation on development and mortality of *Macoma balthica* larvae" *Marine Ecology Progress Series, 330, 155-162*.

Bos, O.G., Philippart, C.J.M., Cadée, G.C. and Van der Meer, J. (2006). "Recruitment variation in *Macoma balthica*: a laboratory examination of the match/mismatch hypothesis" *Marine Ecology Progress Series, 320, 207-214*.

Desmit, X., Boon, J., Van Kessel, T. and Nolte, A. (2007). "Sensitivity analysis sand mining scenarios Maasvlakte-2" *WL | Delft Hydraulics, report 9P7008.O9*.

Heinis, F., Sistermans, W. and Hummel, H. (2002). "Evaluatie Milieueffectrapportage Slufter 1986-2000, Deelrapport Bodemdieren" *Report for RIKZ*.

Leopold, M.F., Van Stralen, M.R. and De Vlas, J. (2007). Zee-eenden en schelpdiervisserij in de Voordelta, *Wageningen IMARES (Institute for Marine Resources and Ecosystem Studies), draft report, 14 November 2007*.

Philippart, C.J.M., Van Aken, H.M., Beukema, J.J., Bos, O.G., Cadée, G.C. and Dekker, R. (2003). "Climate-related changes in recruitment of the bivalve *Macoma Balthica" Limnology and Oceanography, 48 (6), 2171-2185*.

Vertegaal, C.T.M., Heinis, F. and Goderie, C.R.J. (2007). "Milieueffectrapport Aanleg Maasvlakte 2 Bijlage Natuur" *Havenbedrijf Rotterdam N.V. – Projectorganisatie Maasvlakte 2, report 9P7008. A5/Natuur/R006/KVE/Rott1*.

Van Kruchten, Y.J.G (2008). "A probabilistic analysis of the ecological effects of sand mining for Maasvlakte 2" *MSc Thesis Faculty of Civil Egineering and Geosciences, Delft University of Technology, Port Research Centre Rotterdam – Delft, ISBN/EAN: 978-90-5638-197-4*.

Van Ledden, M., Van Haselen, C.O.G. and De Jong, W. (2007). "Milieueffectrapport Aanleg Maasvlakte 2 Bijlage Kust en Zee" *Havenbedrijf Rotterdam N.V. – Projectorganisatie Maasvlakte 2, Report 9P7008.A5/KustenZee/R005/MVLED/Nijm*.

Van Prooijen, B., Van Kessel, T., Nolte A., Los, H., Boon, J., De Jong, W. and Van Ledden, M. (2006). "Impact sand extraction Maasvlakte 2, Mud transport, nutrients and primary production" *Royal Haskoning, Svašek Hydraulics and WL | Delft Hydraulics, report 9P7008.O9/ R002/MVLED/Nijm*.