Decision Support System for Nature Development and Valuation of Land Reclamation in the Netherlands

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ABSTRACT: Nature development and nature valuation are of increasing interest for decision-makers. In the Netherlands, losses of nature area by large infrastructure works have to be compensated for by assigning new nature areas, or by developing new nature. As an example the large land reclamation plan "Maasvlakte 2", in the North Sea, can be mentioned. The Maasvlakte 2 forms an extension of the Rotterdam harbour. Of a total area of 1750 ha, 750 ha of aquatic nature (coastal sea) will be changed into terrestrial nature (dunes). The remaining 1000 ha will be used for industrial and harbour activities. The development of new nature in terms of succession, species richness and landscape composition are important aspects in the design of the land reclamation area. The valuation of this new nature, in terms of economical, ecological and perception values is important in order to find a proper balance of costs and benefits.

The "Decision Support System for Nature Development and Valuation" computes the development and the valuation of nature in land reclamation areas. This DSS offers the possibility to design different land reclamation plans in a particular study area. The user can draw the contour of a plan with a GIS-tool and can define the type of sea defences. The origin and succession of coastal nature types and landscapes is derived from local abiotic conditions and dimensions of the plan. The user can edit several abiotic boundary conditions for nature development such as the height of the surface level, the dimensions of the nature development area and soil characteristics. One of the most important abiotic conditions is the depth of the groundwater. A built-in groundwater model computes the time dependent groundwater levels, using the user-defined model settings. Subsequently, based on a set of decision rules containing distances of grid cells to the coastline, groundwater levels, soil type, etc., the origin and succession of nature types through time and space is computed. The user can edit the decision rules for nature development. For each nature type it is defined from which nature type it evolves and after how many years it will change into the next succession stage. Then the spatial distribution of nature types and cultural types is evaluated to give a landscape composition of the land reclamation plan. Finally, the species diversity and density of flora and fauna is computed and a valuation of the nature and landscape composition is given. The nature valuation is expressed in economic, ecological and perception values. In a final step, the results of different land reclamation designs can be compared and evaluated.

Summarising, the DSS for Nature Development and Valuation enables a rapid assessment of the nature development in a land reclamation area and gives a valuation of nature and landscapes. Its structure allows a planner to edit decision rules for nature development and to use built-in models to optimise the design of a land reclamation plan with respect to ecological and economic values.

1. INTRODUCTION

The harbour of Rotterdam has a shortage of space. One of the possible solutions for this problem is land reclamation on the coast. However, in the Netherlands, losses of nature area by large infrastructure works have to be compensated for by assigning new nature areas, or by creating new

nature. The planned land reclamation of the second Maasvlakte forms an extension of the Rotterdam harbour, and development of new nature is one of the objectives. Of a total area of 1750 ha, 750 ha of aquatic nature (coastal sea) will be changed into terrestrial nature (coastal dunes). The remaining 1000 ha will be used for industrial and harbour activities. The development of new nature in terms of succession, species richness and landscape composition are important aspects in the design of the land reclamation area. The valuation of this new nature, in terms of economic, ecological and perception values is important in finding a proper balance in the costs and benefits. Therefore, a Decision Support System has been built that computes the development and the valuation of nature in land reclamation areas. This Nature Development and Valuation DSS is a tool to support the decisions on changes in land use. Its two main objectives are (1) to predict nature development, the occurrence of species and the formation of landscapes, and (2) to support the trade-off between ecological and economic interests by valuing nature.

2. GENERAL METHODOLOGY

The Decision Support System for Nature Development and Valuation is based on a systematic description of the structures and processes in coastal dune development. The development of a coastal dune landscape is dependent on several natural and anthropogenic factors, such as height differences, groundwater table, wind influence and bottom composition. These factors determine the diversity in the structure of the landscape and the floral and faunal composition (Bakker et al., 1981).

In order to describe the nature development in time with a mathematical model, it is necessary to simplify the real world situation. This simplification is also due to the limited knowledge we have of coastal dune development. The advantage of a model approach is the formalised way of prediction. The predicted results are reproducible; they follow from the methodology and assumptions. An instrument has been made to compute and compare the nature development and valuation of a number of land reclamation designs in a formalised way.

The basic principle of the mathematical description of nature development is that abiotic conditions determine the different types of nature and their succession. These types of nature are interpreted as recognisable landscape structures, such as dry pioneer dune, or beach. In this study, the types of nature are taken from a Dutch ecological classification described by Bal et al. (1995). In connection with the prediction of nature types, species richness of flora and fauna is computed on the basis of habitat suitability and other limiting factors, such as dispersion. Based on the predicted distribution and types of nature, a valuation of the dune landscape is carried out.

Important technical features of this DSS are:

- Nature development is computed in space and time;
- For each grid cell, the probability of multiple types of nature is computed;
- Natural succession from multiple previous types is modelled;
- The development of a freshwater aquifer is modelled in time;
- Aggregation of results for larger areas is possible;
- The later extension of a land reclamation area and the subsequent nature development can be modelled;
- The species diversity for flora and fauna is computed;
- Multifunctional land use can be defined;
- Landscape composition is computed based on the interconnected surface areas and the composition of nature types;
- Valuation of nature is carried out in terms of economic, ecological and perception values.

3. SET-UP AND STRUCTURE OF THE DSS

This DSS offers the user the possibility to evaluate the development of coastal nature in space and time, the floral and faunal composition and the nature valuation for land reclamation areas. In its present form, it is a dedicated tool for the Dutch coast. The user has to follow the next three steps:

1. In the first step, *design of land reclamation*, several designs for the land reclamation plan can be defined.
2. In the second step, *nature development and valuation*, a sequence of models will compute the nature development and valuation for a specific case.
3. In the third step, *case analysis*, the output for different cases can be compared.

Next, the DSS set-up and structure will be explained in more detail.

Design of land reclamation

Within the study area, which is bordered by the size of the computational grid, the outer contours of a land reclamation plan can be defined with a

GIS-based drawing tool. When designing a land reclamation area with this tool, the user can define the type of sea defence for sections of the area. A selection can be made between revetments, rubble mounds or soft defence. Here the distance of each computational cell to the nearest soft defence is calculated.

Nature development and valuation
This part of the DSS is structured around a Case Management Tool. The user can open existing cases, or define new ones. A case consists of a combination of a selected design and selected decision rules for the computations. After selecting a case, the user can spatially define the values of various abiotic parameters in the land reclamation design. The user can also define clusters of computational cells. The output of the DSS is generated on a spatial grid with cells of 4 hectare, but it is also possible to define larger spatial units.

The groundwater depth is one of the most important forcing abiotic parameters for the nature development. The user has three possibilities to map the groundwater level. One is to use the built-in groundwater model that will compute the groundwater level for each grid cell over a period of 75 years. A second possibility is to import the results of a comprehensive groundwater model. The third possibility is to define a static groundwater level for each grid cell manually.

After the definition and mapping of the abiotic parameters the development of coastal dune nature types is computed based on the spatial and temporal distribution of abiotic parameters and the decision rules for natural succession.

The later extension of a land reclamation area and the subsequent nature development can also be modelled. This is for instance the case when after 20 years it is decided to supply extra sand in order to expand the land reclamation. In this part of the DSS it is also possible to decide to perform nature management, such as mowing, for certain parts of the nature area. This will stop the natural succession.

Subsequently, the DSS splits in two parts. One part computes the floral and faunal composition in space and time. The base information needed is the presence of various nature types. Additional information concerns the possibilities for dispersion and the rarity of species.

The following step in the second part is to fill in the reclamation area with cultural and multifunctional units that will not develop naturally. Examples of these units are villages, industry and recreation areas. Subsequently, landscape composition is computed based on the interconnected, i.e. unfragmented, surface areas and composition of nature types and cultural units. From here the nature valuation is carried out.

Output of the DSS
With the aid of a Case Analysis Tool, the results of each case can be compared and evaluated. Output of this DSS consists of:

- Areas of nature types, cultural or multifunctional units and landscapes;
- Species composition of breeding birds, plants and other fauna;
- Valuation of nature in terms of economic, ecological and perception values.

4. KNOWLEDGE RULES ON NATURE DEVELOPMENT

Abiotic parameters
The DSS for nature development and valuation contains knowledge rules that describe the development of a coastal dunes landscape in time, dependent on the local abiotic conditions. These knowledge rules define the suitability of a gridcell for each type of nature in the form of an index between 0 and 1 per abiotic parameter. The probability of the occurrence of nature types is computed on the basis of the abiotic conditions presented in Table 1. Some of these parameters are expressed as classes; others are expressed as continuous functions.

Table 1. Abiotic parameters and their ranges

Abiotic parameter	Range or classes
distance to coastline	0 tot 10.000 m
surface height	-10 to +10 m sea level
groundwater level	0 to 10 m below sea level
chloride in groundwater	<0.3% or >0.3% Cl^-
nutrient level of soil	Poor, medium or rich
Silt content of soil	<2% or >2% silt
lime richness of soil	Lime poor or rich

Most of these abiotic parameters are static; they do not change over time in this DSS. The only exception is the groundwater level. The Nature Development and Valuation DSS has a built-in groundwater model that computes the gradual development of a fresh water body under the surface of the originally saline land reclamation area. The computed groundwater processes include rainfall, evaporation, drainage and density fluxes

between salt and fresh water. The groundwater levels are dependent on the surface heights, the run-off and the permeability of the soil. The development of a fresh water body is a very important prerequisite for various types of nature.

The distance of a location in the land reclamation area to the coastline is calculated by the DSS. The DSS computes the distance to the most nearby soft sea defence.

The user defines and maps the other parameters manually. The Nature Development and Valuation DSS has a geographical user interface with which the user can draw its desired settings.

Decision rules for nature types
Empirical knowledge rules for the development of in total 15 different coastal dune types were implemented. Table 2 lists the various nature types incorporated in the DSS.

Table 2. Coastal nature types in the DSS.

Dry nature types:	
1	Mobile dune
2	Pioneer dune
3	Dune grassland
4	Dune shrub
5	Dune forest
6	Dune heath
Wet nature types:	
7	Dune riverlet
8	Dune lake
9	Open dune valley
10	Dune shrub
11	Dune forest
12	Dune scrub
13	Dune reed land
Intertidal nature types:	
14	Salt marsh
15	Beach

In the DSS application, there is a sixteenth remaining type that denotes the absence of true nature, namely *fallow land*. Furthermore, for some of the nature types a specification is made in 'natural' types and 'managed' types.

For each of these nature types, suitability rules are derived that denote the suitability of certain abiotic conditions for the nature type to exist. These rules are called here 'decision rules'. The decision rules for nature development can be edited and saved as a new set.

Succession
Besides the abiotic conditions, the succession of nature types from a previous nature type is defined. For each nature type it is defined from which nature type it evolves and after how many years it will change into the next succession stage. The most likely succession pathways of an originally wet and dry fallow land are presented in Figures 1 and 2. The wet fallow land will develop either into a dune reedland or an open dune valley, dependent on the nutrient richness. Subsequently, a wet dune scrub will develop, followed by a wet dune forest. The dry fallow land will develop either in a nutrient poor pioneer dune or a nutrient rich dune scrub. Eventually, a dry dune forest will develop, unless the soil is very poor in lime, than a dune heath may develop (not shown in the Figures).

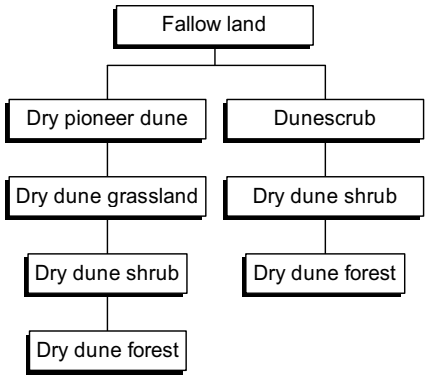

Figure 1. Succession of a wet fallow land

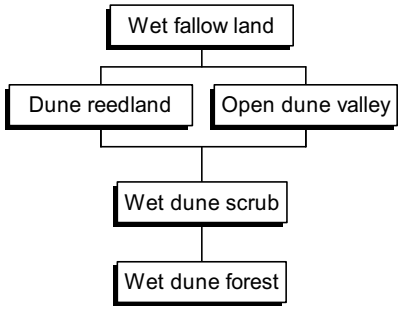

Figure 2. Succession of a dry fallow land

To model the succession of nature types, knowledge rules are incorporated into this DSS that define the previous nature type(s) and the timespan necessary for a type of nature to fully develop. The development time in years is derived from empirical studies and compared to aerial photographs of existing dune areas. These succession rules are also expressed as index numbers between 0 and 1. The suitability for a nature type will increase linearly from the moment that the previous type exists until it has reached its

full development. From that moment on, the suitability will decrease linearly in time with the development timespan of the next nature type. This way, a sequence of nature types in time is modelled. Table 2 presents the succession time in years starting from the presence of the previous type.

Table 2. Succession time for nature types

Time in years:	*For dry nature types:*
1	Mobile dune
1	Pioneer dune
15	Dune grassland
20	Dune shrub
20	Dune forest
100	Dune heath
Time in years:	*For wet nature types:*
1	Dune riverlet
1	Dune lake
5	Open dune valley
20	Dune shrub
20	Dune forest
1	Dune scrub
5	Dune reed land
Time in years:	*For intertidal nature types:*
5	Salt marsh
1	Beach

For two different cases, the number of nature types that was found in the land reclamation area through time is presented in Figure 3. It is interesting to note that for both cases at first the diversity of nature types is increasing, but after a while the number of types will decrease again. This is due to the fact that after many years the climax stage will be reached. For coastal management purposes this development is undesirable. The rarer and more valuable nature types, such as the open dune valley, will gradually disappear, together with its valuable flora and fauna. Therefore, this DSS gives the possibility to 'manage' certain parts of the nature area, in order to stop the natural succession.

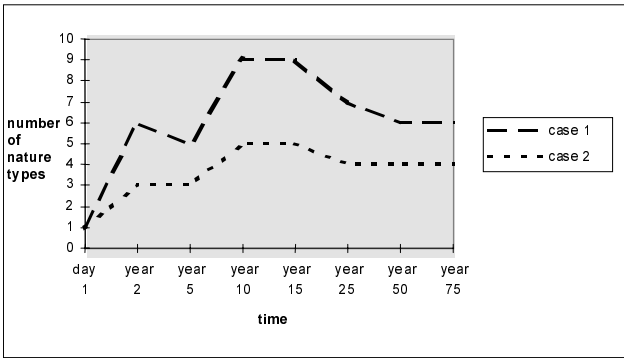

Figure 3. Number of nature types for two cases.

Implementation of nature development

The DSS makes its computations in a computational grid with a grid cell size of 200x200m. For each grid cell the suitability for each nature type is computed on each time step by evaluating whether the following conditions are met:

1. The abiotic conditions are above a threshold value for the presence of a nature type;
2. Enough time has elapsed for the nature type to develop;
3. A valid previous nature type was already present in the computational grid cell in the previous time step.

This way the DSS computes a suitability index score for each nature type, based on the minimum score for the abiotic suitability and the succession suitability. The time steps that are used are 0, 1, 2, 5, 10, 15, 25, 50 and 75 years after the land reclamation. For each grid cell the scores for all nature types are computed and when the final suitability score exceeds a certain threshold, it is assumed that this type of nature will occur. It is possible that multiple types of nature occur in the same grid cell with suitability scores between 0 and 1.

The results yield a map of nature types that will develop in time. Based on this map the species composition of flora and fauna is calculated. A selection of rare and endangered species was made for breeding birds, plants and other higher organisms, such as mammals and butterflies. The output of this DSS provides the number of breeding pairs per square metre for breeding birds, the number of expected plant species per nature type, corrected for dispersion and rarity and the presence or absence of other faunal species.

5. NATURE VALUATION

Generally, land reclamation involves economic benefits but also environmental costs. It is difficult

to make a fair trade-off between economic interests and ecological interests, because nature does not have a market value. Although nature does not have a price tag, it has a large value from both an ecological and a socio-economic perspective.

The ecological value reflects the quality and well functioning of nature. It is generally measured in terms of species diversity, rarity and space for natural processes. The economic value indicates how much welfare nature generates for society. Nature performs several welfare generating functions that can be valued in monetary terms. Nature performs various production functions (e.g. the production of fish and wood), regulation functions (e.g. water purification) and information functions. An important information function is the perception of natural beauty. These perception values are often an important aspect in the decision making process concerning planned land use changes. Therefore, next to ecological and economical values, special attention is given to perception values in this DSS.

In order to estimate the net economic, the net perception and the net ecological benefits of a land use plan, the Nature Development and Valuation DSS performs three cost benefit analyses: one using economic values, one using perception values, and one using ecological values of each type of nature. In these cost benefit analyses the values of the types of nature that disappear from the study area are regarded as costs, and the values of the types of nature that newly develop in the study area are considered benefits. In the case of the second Maasvlakte aquatic types of nature are lost, while terrestrial nature develops.

6. RESULTS

The Nature Development and Valuation DSS was applied on the Second Maasvlakte land reclamation and the New Holland land reclamation in the Netherlands. Figure 4 shows one of the possible designs for both reclamation areas.

The southern part in Figure 4 is the Second Maasvlakte reclamation, which is aimed at providing more room for the Rotterdam Harbour. This design is characterised by hanging beaches on the southern and western parts and a relatively small strip of coastal dunes bordering the industrial area.

The northern part is the New Holland land reclamation that is primarily aimed at providing housing for the densely populated west coast of Holland. This design consists of a relatively wide beach and extended dunes that are attached to existing dune areas.

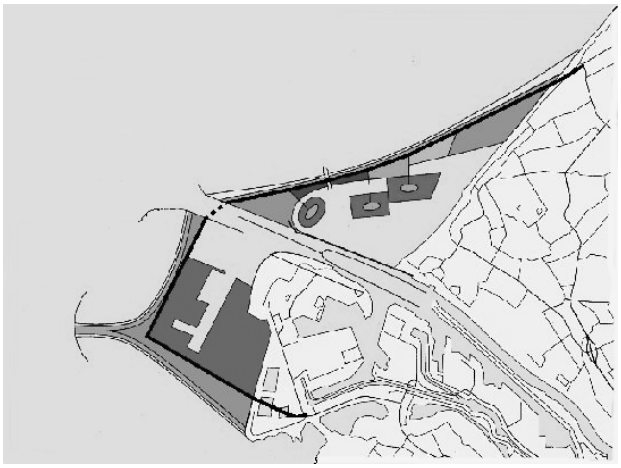

Figure 4. Possible design for land reclamation.

The results of the Nature Development and Valuation Module can be shown geographically in such a way that the development of nature in time is presented. Figure 5 shows the results as bar charts in which the relative distribution of different nature types is presented.

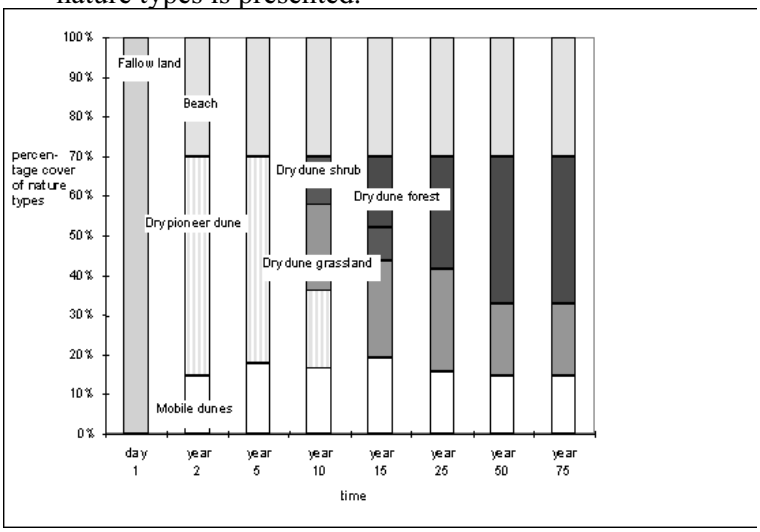

Figure 5. Percentage cover and development of nature types.

Figure 5 shows that the fallow land will first develop into a relatively stable area of beach, mobile dunes and pioneer dunes. The pioneer dunes will then show succession into grassland and scrubs, until eventually the climax stage of dune forest develops.

The results of the nature valuation are presented in Figures 6 through 8.

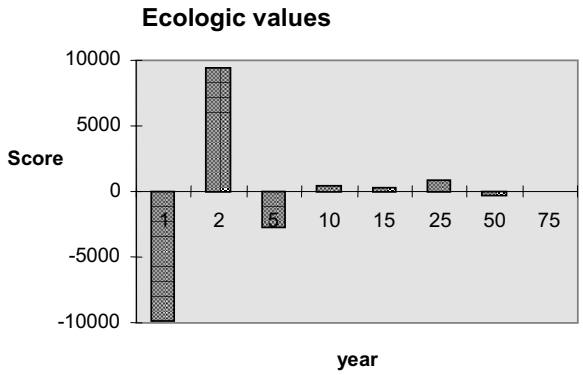

Figure 6. Ecologic nature values (in ecoscores)

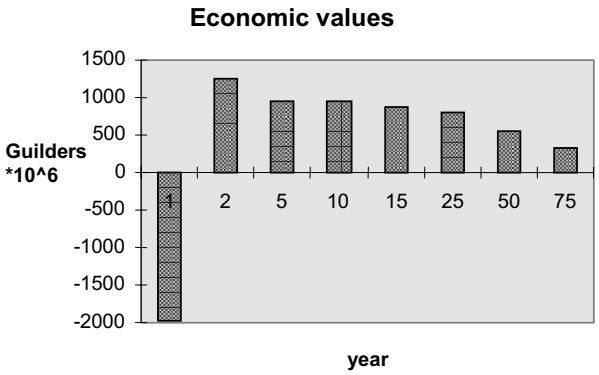

Figure 7. Economic nature values (in guilders)

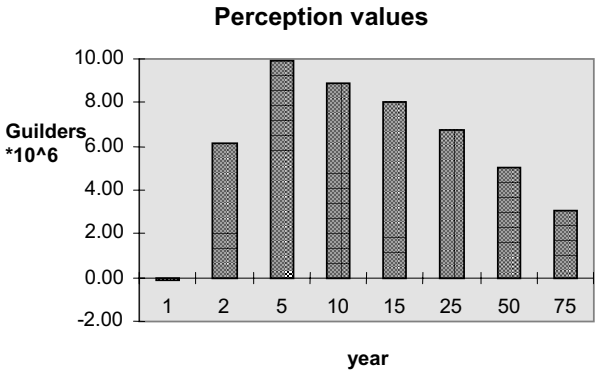

Figure 8. Perception nature values (in 1000 guilders)

7. CONCLUSION AND DISCUSSION

The Nature Development and Valuation DSS enables users to make a rapid assessment of alternative land use designs for land reclamation areas. It determines the possible development of nature types found in Dutch coastal dunes on a grid map of the area of interest. The development of nature is based on the abiotic conditions in the study area, natural succession and nature management. This DSS also accounts for multifunctional use of space within a plan area. Subsequently, it produces estimates concerning the composition of species, the composition of landscapes and the net ecological and economic benefits of various land use designs.

This DSS has a number of shortcomings with regard to the presentation and reliability of the predictions.
The scale of the computational grid cells is 200 by 200 metres, so the resolution of the predictions is 4 ha. However, the description of the nature types fits to this level of detail and there is the possibility of mixed types in one cell.
The development in time is presented in discrete time steps. However, the DSS uses linear interpolation for the succession of nature types.
The decision rules for nature development are simple and a limited number of abiotic parameters are used.
Morphological changes in the dune system are not dynamically modelled.
The model is not validated. The decision rules are based on literature and aerial photography. A validation on an existing land reclamation project has not been carried out, because this is hard to realise. A land reclamation of 750 hectares of dune is unique to the Dutch situation. No comparable land reclamation project exists on this scale or has similar abiotic conditions.

8. ACKNOWLEDGMENTS

This study was carried out within the framework of the Land Water Environment Information Technology (LWI) program.

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