Enabling Delta Life

The usability of the sand motor concept

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Summary
This report describes the usability of the Sand Motor concept for managing the Dutch coast as an alternative to regular sand nourishments. The evaluation of the usability is based on experience with the Sand Motor pilot project before, during and after the construction in 2011 and by making an inventory of the functions and values along the Dutch coast in the present situation and the coming decades.

Preparation and construction phase
The process for establishing the Sand Motor pilot project was thoroughly considered in accordance with Echoshape's (later developed) guidelines for developing and realising sandy Building With Nature concepts. There was a need for sand to nourish the coast and ensure coastal protection in the long term. On the other hand, there was a clear social need for more recreation and nature space in the province of South Holland. Knowledge development and export potential of the Sand Motor concept were also important factors. Bringing all of these wishes together into one attractive multi-functional design has drawn more stakeholders to the concept and made the implementation of the Sand Motor pilot a reality. The *lesson learned* is that the need for sand, a multi-functional design and an attractive concept are important elements for realising a sand motor.

Five years after construction
Coastal maintenance: Broadly speaking, the Sand Motor pilot is developing as expected. There appears to be a sufficient volume of sand for the coastal foundation to last almost 50 years. The current coastline is shifting seaward: first at the Sand Motor and later in the immediate surroundings. After four years, 95% of the sand volume that was added for the Sand Motor pilot project is still in the monitoring area. This leads to the conclusion that the lifespan of the pilot appears to be longer than expected. With regard to the primary flood defence, the erosion point in the direct sphere of influence is moving seaward. The current dune volume has grown following the construction of the Sand Motor within the monitoring area, but not as rapidly as prior to its construction (more on this under *Nature*). Furthermore, as the sand motor lagoon developed, a meandering channel formed. Such a channel may pose a potential threat to the primary flood defence, but this is not an issue for the Delfland coast, probably because of the already existing breakwaters. All things considered, from a coastal management point of view, the Sand Motor pilot project can be considered a success. As such, it is a successful innovation in the series that has characterised coastal management since 1990. The *lesson learned* is that in terms of design and functioning, the Sand Motor concept ties in with the sediment strategy, which is at the core of the coastal policy, as a potential tool.

The insights of 2010 on sand requirements and in combination with the sand prices at the time proved the construction of the Sand Motor pilot project to be attractive, even if the other functions and values that could be supported by creating an additional area were not taken into consideration. The current, substantially lower, sand prices and the new insights into the volume of sand that is required annually, changes the situation. The *lesson learned* here is that, from a financial feasibility point of view, a sand motor is 'usable' for coastal maintenance

if the agreed sand price for it is low and the sand contributes to the long-term maintenance of the base coastline or the coastal foundation. The lifespan will probably increase with increasing volumes and when the form of a sand motor will be more like a conventional coast nourishment. It is recommended that this is investigated further. The additional functions and values that can be provided by temporarily creating an additional area may be an argument for constructing a sand motor, even if it is not financially attractive from the point of view of coastal maintenance alone. A possible increase in the annual amount of sand required for coastal maintenance might change the perspective, because it would become financially interesting to nourish on a larger scale.

Nature: It is not yet possible to answer the question of whether a one-off large nourishment like the Sand Motor pilot project is better for the benthos than a regular programme that involves returning approximately every four years to nourish the sand. The Sand Motor has not been in place long enough to facilitate that and four years is too short a period for monitoring. The lagoon does, however, add a separate habitat to the coast and contributes to the diversity of benthic life species. In that respect the lagoon functions more efficiently when water circulation with open sea is better: this depends on the length of the channel that drains it.

Furthermore, it is possible that all kinds of nature developments will proceed more quickly when certain thresholds are exceeded by random processes. An example is dune formation, where it is known that this is successful once every few decades and then develops rapidly (see also under safety). The lagoon and the dune lake are probably not the best choices from the point of view of dune formation, because both trap sand to the detriment of the dunes. Observations further show that the existing management, particularly the relatively intensive driving across the sand and the daily cleaning of Scheveningen beach has an adverse impact on the development of embryonic dunes.

It is clear that there are many bird species on the Sand Motor; around 40 species visit the area regularly. No breeding has taken place. The disruption is probably too great for that. Disruption is probably also why seals hardly ever visit the area. It has been a conscious decision in the current management to avoid zoning and keep the area freely accessible, with the disadvantage that these specific ecological values do not or hardly develop.

The *lesson learned* is that the Sand Motor concept is potentially usable for the development of new ecological values, but that this greatly depends on the objectives, the design, the management and natural random processes.

Recreation and Layout: In its current dynamic form, the Sand Motor concept is particularly usable when an expanded area for extensive recreation, tranquillity, space, nature, vastness and dynamics is desired. A new, often different, design will have to be applied to future sand motors. Depending on the local requirements, a lagoon may be opted for again, but sand motor designs that look more like ‘traditional’ nourishments are also a possible option. This results in an area with a lower dynamic and less spectacular appearance, but more suitable for coasts with more seaside visitors and beach recreation.

Knowledge development and Innovation: The Sand Motor pilot project has given Dutch coastal engineering a significant impetus. The Sand Motor fundamentally functions differently than regular nourishments, which has led to new topics of research. Furthermore, the Sand Motor is a multi-functional solution that is linked to the layout of the landscape and its underlying processes. This has led to interdisciplinary research questions and themes. From this point of view, the Sand Motor can also be considered a successful innovation.

New sand motors will also promote knowledge development and innovation. The place of construction, the design, the volume and the user wishes raise new research questions. If these questions are related to large-scale implementation, then it is expected that the 'sand motor' product will continue to attract international attention as well.

Other functions and values: The presence of a sand motor may cause a disruption for shipping routes, water outlets, military interests and water extraction. These factors have to be taken into account when designing sand motors.

Requirements defined
The requirements for the Dutch coast have been defined for:

- The coastal management; existing sand requirements, location of the base coastline, coastal foundation, flood risk. These wishes give an idea of future management specifications.
- Nature: existing nature areas, new nature areas and the desire for long dynamic gradients from the coast up into the dunes.
- Layout and recreation: current intensity of coastal recreation and infrastructure plus the modest (legally established) desires for the future.
- Other values and functions: mineral extraction, groundwater extraction, shipping routes, military zones, salinity of bodies of water and risk of salinization.

Opportunities defined
The abovementioned requirements determine where there are opportunities for sand motors. From the point of view of coastal management, the greatest opportunities are present in areas with a high need for sand. These areas are primarily in the Wadden area and the South Western Delta. There is not yet sufficient knowledge available to successfully deploy a sand motor-type solution near the inlets (which are morphologically very different from the coast of the provinces of South and North Holland). In terms of coastal management, sand motors are particularly suitable along the straight parts of the Wadden coast and, locally, the coast of the provinces of South and North Holland.

For nature and recreation, sand motors are particularly attractive along the Holland coast. Sand motors may have an important added value for nature in realizing long gradients perpendicular to the coast. They offer little added value along the coasts in the Wadden and Delta areas, because sand motor-type landscapes are already being formed there by nature.

From the point of view of other values and functions, it appears that coastal expansion for the Dutch coast south of Scheveningen harbour may reduce salinization of the hinterland. Since

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dune formation plays a vital role here, this could be realised and maintained with sand motors.

From the above it becomes clear that chances for sand motors are determined by the local needs. It should be kept in mind that even a single function can be a reason to develop a sand motor. It is clear that there are many locations along the entire Dutch coast with the potential for realising sand motors and that the Sand Motor concept is usable. The locations where the Sand Motor concept can best be used is for a multi-functional application along the North Holland coast and the coast of Delfland where the first Sand Motor was constructed. Further exploration could focus on optimising the lifespan given the local functioning of the dynamic system and the resulting economic feasibility.

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	May 2016	Albert Oost		Marcel Taal		Frank Hoozemans	
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Appendices

1 Introduction

1.1 Feasibility study background and objective

In 2011, an experimental mega sand nourishment was placed along the coast of Ter Heijde and The Hague: Delfland Coast Sand Motor pilot (Figure 1.1). The sand was deposited in the form of a hook, with a dune lake at the base and a lagoon between the spur and the existing coast. At the same time as the construction, two foreshore nourishments were placed on either side of the Sand Motor. Chapter 2 gives more information about the design and development of the Sand Motor.

Figure 1.1 Overhead view of Sand Motor pilot, July 2011. Photo: Joop van Houdt

The Sand Motor is a pilot project for an innovative method for coastal maintenance in which a net sand volume of almost 19 million m^3 sand was placed as an alternative to the routine: regularly repeated placement of smaller beach and foreshore nourishments. Wind, waves and currents re-distribute the sand of the Sand Motor along the coast.

The following three objectives were identified for the Sand Motor pilot project:

- To stimulate natural dune growth in the coastal area along the Delfland coast, between the Hook of Holland and Scheveningen. The dune growth has different functions: protection, nature and recreation.
- Generate knowledge development and innovation in response to the question to what extent coastal maintenance, added value for recreation and nature can be jointly realised.
- Create an attractive recreation and nature area on the Delfland coast.

The fourth objective that has to be achieved is '*to manage the Sand Motor and its surroundings in an effective way*'. That mainly concerns recreational safety and preventing the Sand Motor having adverse impacts on ecological values in the existing dune area.

To keep track of how the Sand Motor pilot project develops, a monitoring and evaluation plan (MEP) was drawn up (DHV, 2010) during the preparation stage of the construction. In that context, all kinds of measurements have been conducted since 2011. This is done using university programmes, NatureCoast and NEMO. The observations made show the effects of placing a large volume of sand in one go, as compared to nourishment every four years.

When constructing the Sand Motor pilot project it was agreed that the first evaluation would take place in 2016 in preparation for the final evaluation in 2021. An important question that will have to be answered in 2021 is *'is the Sand Motor concept usable and possibly deployable at other locations in the Netherlands?'* To gain more insight into this an investigation into the usability (Dulfer et al, 2014) was conducted in 2014. In 2015-2016 a second usability study was done which is described here. The report provides insight into the lessons that have been learned before, during and after the construction of the Sand Motor pilot project, drawing on the Sand Motor Business case and the results of the Monitoring and Evaluation Programme (MEP). The second important building block for the usability is the functions and values along the coast and the wishes for the future that emerge from those functions. The opportunities for applying the Sand Motor concept elsewhere along the Dutch coast are defined as an alternative for or in addition to regular nourishments.

1.2 Coherence with other studies

This report has to be considered within the context of the other two evaluation reports on the Sand Motor pilot project that were published in Spring 2016 (Figure 1.1):

- *Monitoring and Evaluation Programme (MEP) report, first four years*
  This report describes the changes that occurred and answers to the evaluation questions that were identified in the implementation programme, Sand Motor MEP (Tonnon *et al*, 2011; Taal, 2016). The report is based on detailed reports on coastal protection, morphology, ecology and recreation.
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- *Policy evaluation 2016*
  This document evaluates the extent to which the Sand Motor pilot project contributes to the set policy objectives: protection against floods, added value for nature and recreation, manageability of the Sand Motor and developing knowledge in these fields. In addition to this, the policy evaluation focuses on the cooperation and context management concerning the Sand Motor pilot.

- *Sand Motor - Guidelines & Tools and Business case*
  This product was introduced by the Ecoshape Foundation, which aims to develop knowledge and expertise on 'Building with Nature' (including the sandy strategies), to spread it and put it into practice (De Boer et al, 2015).

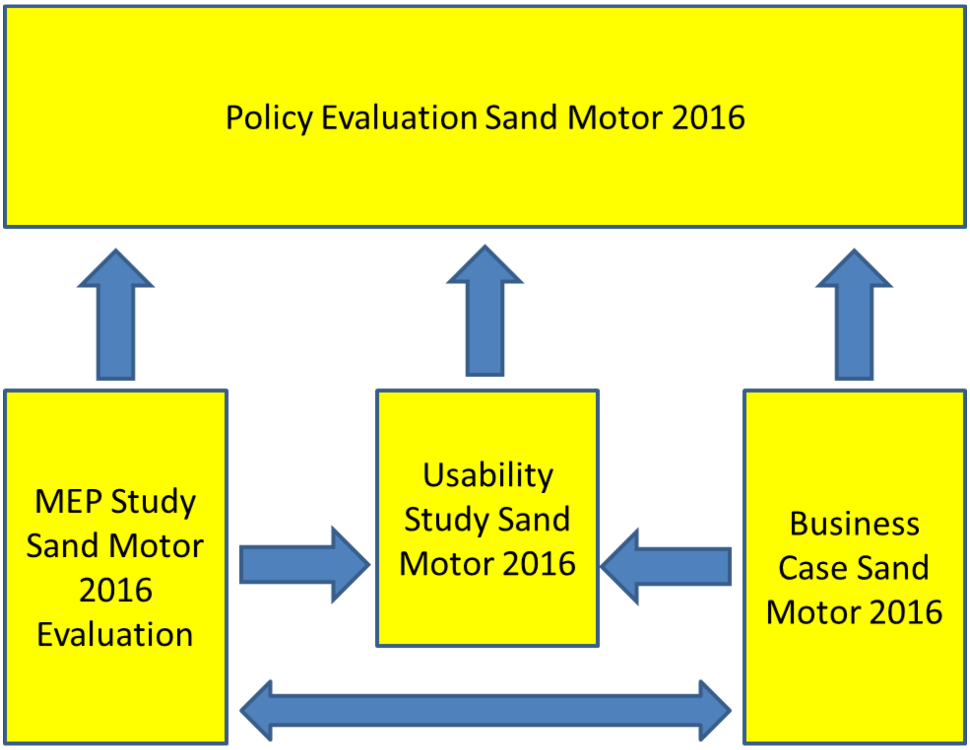

Figure 1.2 overview of coherence between the four studies.

All of the studies were conducted more or less parallel. It should always be kept in mind that the Sand Motor pilot project has only been in place for 5 years and that the natural processes will occur over a longer time. This means that an initial impression can be obtained based on the current monitoring and preliminary results on the usability of the Sand Motor pilot project, but monitoring over a longer period will reveal a more complete picture.

1.3 Approach

This usability study applies the following definition of the Sand Motor concept: *'The addition of a surplus of sand to the coastal system, which is then redistributed by natural (drift) processes and usually leads to temporary coastal expansion and contributes to one or more functions and values, like recreation, nature, protection against flooding, possible other functions and values or knowledge development.'* This means that the concept may differ from the existing Delfland Coast Sand Motor pilot project in terms of design, volume and location in relation to the coastline. The term 'usability' is applied as follows (according to Royal HaskoningDHV, 2014):

- The extent to which a 'sand motor-based measure' meets the objectives.
- The extent to which a 'sand motor-based measure' can be applied without major adverse side effects.
- The extent to which a 'sand motor-based measure' is physically applicable.

Lessons learned

This study contains lessons learned deduced from existing information that is important for the possible option of placing sand motors along the Dutch coast in the future and how they will be designed. The lessons learned concern coastal management, nature, recreation and layout, knowledge development, other functions and cost effectiveness. To this end, the developments, the extent to which the objectives have been achieved and the knowledge that has developed have been examined. The Sand Motor pilot project is regarded an *innovation*. Innovations come with a certain risk, but a lot can still be learned when they do not live up to the expectations. In addition to this, some success factors are so valuable that the entire innovation can be deemed a success. In this study, it was decided to deduce lessons learned from the success and failure factors that were identified during the pilot project.

Identifying the usability prior to the realisation
The steps resulting from a framework that was developed within the 'Sand Motor Business case' project were applied to identify the possibilities for certain sandy solutions (Figure 1.3; for a full description, please refer to de Boer et al, 2015). The cost effectiveness was also defined based on the Life Cycle Cost approach (see also de Weerdt, 2015).

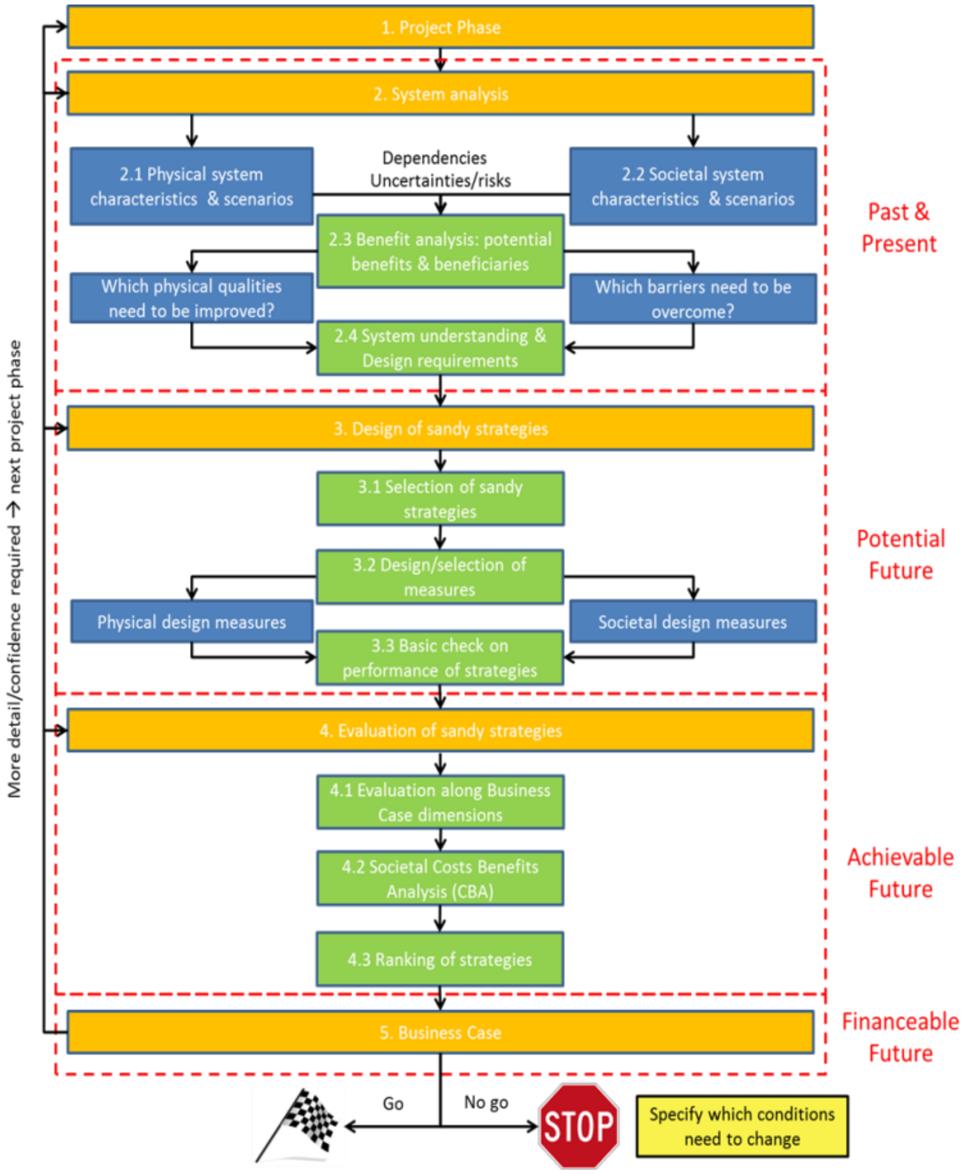

Figure 1.3 Framework for the development of a sandy strategy (de Boer et al, 2015)

Requirements for present and future functions and values
In order to gain insight into the usability of the Sand Motor concept, a breakdown was made of the functions and values that will play a role in the Dutch coastal system in the future (chapter 5).

To this end, coastal management, nature, recreation and layout and other functions and values were examined. Maps were made of requirements for existing functions (based on the assumption that these will be retained in the future) and future wishes (based on the assumption that these have already been planned for and have a legal status within the Dutch Spatial Planning Act). Plans that do not have this status were not included, with the exception of insights on salinization of Deltares (Oude Essink & Waterman, 2016) and a more natural development of the dunes (Lammerts and van Haperen, 2015). More information can be found on this in insert III in Chapter 4. When placed on top of each other, these maps form the ‘wish lists’ for the coming 20-30 years.

Opportunity maps
Based on the requirement maps, individual opportunity maps for sand motors were produced for coastal management, nature, recreation and layout and other functions and values. The criteria on which these opportunities are based are described in Chapter 6.1. The combined opportunity maps subsequently show the areas with the greatest potential for a sand motor-based solution. The exact design of such a solution in not included in this usability study. Recommendations for a sound design are, however, given.

Conclusions and recommendations
Conclusions on the usability of sand motors were drawn from the lessons learned, requirements for coastal use and opportunity maps. Based on this, recommendations are formulated that are relevant to the application of the Sand Motor concept, or elements thereof, at other locations in the Netherlands.

2 Background to the pilot Sand Motor

2.1 Dutch coastal policy

The coastal policy is defined in the Water Act. Coastal protection is assured in three ways:

- The provision for safe flood defences (application of the safety standard, which has been set for primary flood defence)
- Coastline maintenance (using the base coastline as standard)
- Maintain the balance of the coastal foundation with relative sea-level rise. The coastal foundation is the zone with the greatest sand movement. The boundaries of the coastal foundation are located at the seaward side on the continuous NAP -20m line and at the landward side on the line where the dunes border the hinterland (inner dune margin).

The three traces are correlated as follows: to protect the hinterland against the sea, the dunes have to have sufficient strength and enough sand. It is therefore important that the coastal zone contains enough sand to be dispersed by the wind and water between the surf zone, beach and dunes. If there is enough sand in the coastal zone, structural erosion of the coast can be prevented. Maintaining balance of the coastal foundation ensures that (in the long term) the Dutch coastline grows along with the rising sea level.

This is why the Rijkswaterstaat (Dutch Public Works) have been placing sand nourishments every year since 1991, using the base coastline (roughly speaking, the coastline of 1990) as standard. The sand used for this is dredged from the deeper North Sea (below the continuous -20m Dutch Ordnance Level (DOL) line). To promote the natural character, coastal zones where this is possible are ‘dynamically managed’. The impact of wind and sea is permitted or even promoted.

2.2 Sediment strategy

The strategy for replenishing sand losses is also referred to as ‘the sediment strategy’. Most people are unaware or scarcely aware of how successful and innovative the Dutch sediment strategy is in protecting the Dutch coast. The approach is made possible because, right from the start, the coastal system has been regarded as one coherent whole on which a vast amount of knowledge has been developed. This awareness forms a basis for a series of significant innovations, for which the Netherlands is a world leader in implementing coastal protection, namely (Figure 2.1):

Annual coastal measurements

The annual measurements of the profile height transverse to the coast have been digitally stored in a database since 1964. Since 1990, the locations that require sand nourishments for maintaining the coastline have been annually determined based on this data. The systematic monitoring using transects was unique in the world at the time.

Foreshore nourishments

During 1990-2000, 7.5 million m^3 of sand was nourished annually, in particular beach nourishments of volumes of sand up to 1 million m^3. Gradually, the sand was added to the foreshore more frequently, because it was discovered that foreshore nourishments were also effective against erosion (Hoekstra et al,1994) and, moreover, relatively cheap (cost price of sand per m^3). Adding more and more foreshore nourishments proved to be an important innovation in Dutch coastal management. Sediment management was also expanded to include nourishments along the walls of channels, to maintain the sand supplies at level and to prevent the channels from shifting landward. The strength of the innovation is that rock filling procedures (which are less suitable for the sandy system) are avoided.

Nourishment scale-up
The total nourishment volume in 2001 increased to 12 million m^3 of sand per annum. The figure corresponds with the coastal foundation sand requirement for ‘increasing along’ with the current sea-level rise (2 mm/year). If it is necessary in the future, because, for example, the sea level rises faster, this volume can be increased: another advantage of flexible coast maintenance using sand nourishments. Over the course of time the sand volume of individual nourishments also increased, which meant that nourishments with a volume of approximately 5 million m^3 were added several times. Mega-nourishments like the Sand Motor pilot project for which a gross sand volume of 21.5 million m^3 was supplied (including two additional foreshore nourishments) fit in with this scale-up trend. The reinforcement of the Hondsbossche and Pettemer Sea Defence by constructing a seaward extension also involved a high volume of sand: 30 million m^3 sand.

Long-term contracts
Another important development is the long-term contracting of the nourishment volume for coastal maintenance from 2012. With this, the government achieved a substantial reduction of the nourishment price per m^3, amounting to approximately 25%. As we will see from the economic evaluation of the Sand Motor pilot project (Chapter 4.5), this is a key factor in the assessment. After all: the choice of nourishment type always entails assessing the costs and benefits and the (morphological) possibilities of the area. On the one hand, the placement of excess sand is more expensive than ‘just in time’ nourishment, because payments have to be made earlier. On the other hand, a large nourishment is cheaper per m^3 because much of the work is performed in one go. The one-off placement of a high volume of sand as an alternative to adding smaller nourishments more frequently offers the possible advantage of less ecological disruption and that more use is made of the forces of nature. It may also temporarily create an area with space for other purposes like nature and recreation. This is in keeping with the government’s intention to serve more social objectives with the amount of money available for coastal nourishments. By contracting nourishments in the long-term, they become cheaper and sand motors become relatively less cost effective.

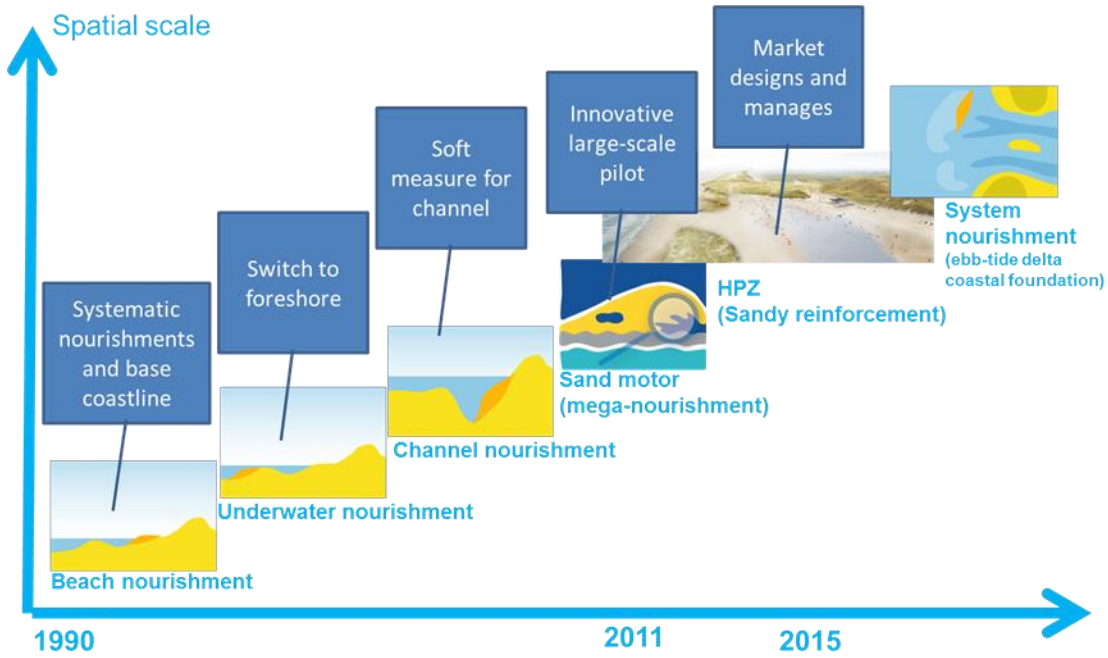

Figure 2.1 Sand Motor as part of the sediment strategy (according to: van Gelder and Bruens)

2.3 Construction of the Sand Motor pilot project

After the Delfland coast was reinforced in 2010 within the framework of 'Weak Links', whereby a new strip of dunes was created, the construction of a peninsula measuring 128 ha (200 football fields) along the coast of The Hague and Ter Heijde commenced in March 2011, 101 ha of which are + 1m above NAP. In addition to this, two foreshore nourishments were placed on either side of this Sand Motor pilot project. The last shipment of sediment for the peninsula was deposited on 29 June 2011. The northerly (small) foreshore nourishment was virtually complete at the same time and connected to the point of the Sand Motor. The second nourishment is situated a couple of kilometres south of the Sand Motor and was completed in November 2011. Dredgers extracted the sand 10 kilometres from the coast and deposited it into the project area, a total of 21.5 million m^3 in the cradle (= approx. 18.7 million m^3 net). 19 million m^3 of this was used for constructing the peninsula and 2 and 0.5 million m^3 for the southerly and northerly foreshore nourishment respectively. The design of the Sand Motor pilot project is an optimisation of the preferred alternative 'Haak Noord' (Northern Hook) from the Environmental Impact Assessment (DHV and HNS, 2010). The design (called 'basis-150') spreads 150 metres less seaward than the preferred alternative. Additional control and planning measures were taken during the construction of the Sand Motor pilot project. Among other things, these measures are described in the Environmental Impact Assessment (DHV and HNS, 2010).

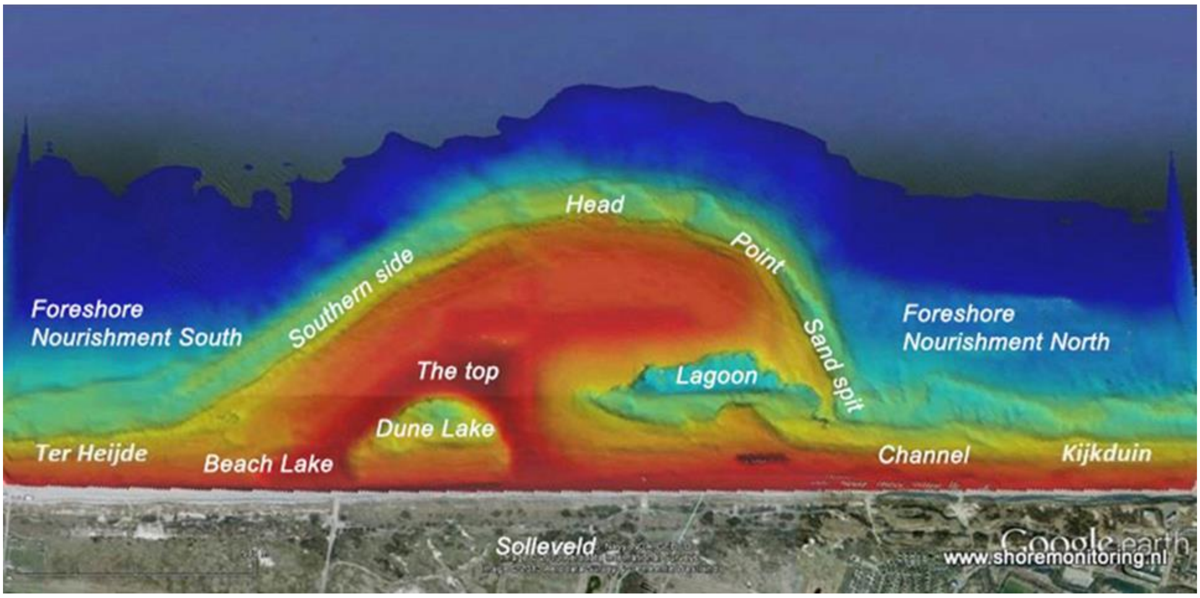

Figure 2.2 map of the Sand Motor pilot project with naming and components. Source: Shore, 2013.

Components of the Sand Motor pilot project
Different components can be distinguished within the Sand Motor pilot project (see Figure 2.2). Sand has accumulated on the south side of the Sand Motor, causing a beach plain to develop here. 'The top' (intentionally constructed at +6 m NAP), the dune lake (also constructed intentionally) and the lagoon (that has evolved through the formation of an elongated sand shoal: 'the sand spit') are in the middle section. 'The head', which is subject to erosion, is also situated here. The sand tip and its landward situated meandering channel that connects the lagoon to the North Sea are situated to the north. As is the case in the south, the coast is also expanding seaward here.

Since the construction of the Sand Motor pilot project in 2011, the shape has changed from an almost symmetrical bell shape into a more triangular shape with hollow arch-shaped coastlines. The sand body became approximately 260 metres narrower and 2.2 kilometres longer over the course of four years. The largest dynamic is on the north side, where the lagoon and channel are situated.

3 Lessons learned, Sand Motor pilot project: before and during the construction

The international interest in the Sand Motor pilot project and the opportunities this offers for the Dutch business sector prompted the Ecoshape foundation to establish a framework for developing and realising sandy 'Building With Nature' concepts (De Boer et al, 2015). The usability of this framework was also examined in that study. Among other things, this was done by (hypothetically) restarting based on the situation of the Delfland coast in 2006. If the actual Sand Motor case is considered, then it appears that the steps followed at the time and the strategy during the preparation and construction of the Sand Motor pilot are highly consistent with the methodology developed later on. This suggests that the framework is of great use for developing sandy solutions.

For the realisation of a Sand Motor pilot, it proved to be essential (both in retrospect and according to the Ecoshape methodology) that there was a demand for sand in terms of coastal maintenance as well as in terms of the need for other functions. The coastal segment was nourished regularly to maintain the coastline and the province of South Holland had a demand for more space for recreation and nature, because the region has become highly urbanised (DHV and HNS, 2010). Knowledge development and export potential of the Sand Motor concept were also important factors (Baltissen, 2015; De Boer et al, 2015; Stive, interview Trouw, 20 February 2016). Bringing all of these wishes together into one multi-functional design was an interesting idea that triggered the enthusiasm of more stakeholders (Baltissen, 2015). The province of South Holland proved to be the most relevant initiator. In particular, deputy Dwarshuis played an active role in the decision-making.

It was already apparent in 2005 that beach visitors did not generally have any noteworthy objections to a sand motor at Delfland. That came more so from local stakeholder groups that either didn't want any coastal expansion or did, but without buildings (Berendsen et al, 2005). This was one of the reasons that in 2005 improving the protection of that coastal zone was considered essential, but the ideas about the utilisation and the layout of a possible coastal expansion varied considerably. Key stakeholders within Rijkswaterstaat raised questions and/or conditions (Rijkswaterstaat, 2005; Brendsen et al, 2005). The Rijkswaterstaat had studies conducted on this (DHV et al, 2007; Bruens, 2007). Shortly after that, at the beginning of 2008, the Ambition Agreement between the relevant authorities and the South Holland Environmental Federation was signed, which defined the ambition to develop the Sand Motor (Sand Motor Ambition Agreement, 2008). The decision to implement the Sand Motor was taken in 2010 (Rijkswaterstaat, 2010; PHZ, 2010). Local groups (LPF Westland, 'Stop the Sand Motor' action committee) still oppose the project, among other things, referring to the drinking water and swimming safety. The drinking water safety was safeguarded with the installation of a pump system to combat salinization. The 'Cooperation Agreement on Sand Motor Beach Monitoring and Swimming Safety Supervision' guaranteed adequate swimming safety.

The key lessons learned:

- The Sand Motor pilot ties in with both the physical as well as the social system (viewed from a Business case perspective), which is essential for the usability.
- The Sand Motor pilot is a relatively fast development of a sound and interesting multi-functional concept in the field of coastal management, ecology, recreation and the develop-

ment/export of knowledge. The opportunities for a sand motor are determined by a multi-functional design and the existence of an interesting concept.

- The design of the Sand Motor pilot was primarily guided by the desire to create more space for (temporary) recreation and attractive nature. The coastal management was more so a precondition. The lesson learned here is that the design of a sand motor should be determined by different needs.

4 Lessons learned, Sand Motor pilot project: after the construction

4.1 Usability from a coastal protection perspective

4.1.1 Findings

Bearing in mind the Dutch coastal policy and the sediment strategy (see Chapter 2), the following conclusions were drawn on the usability of the Sand Motor concept:

The Sand Motor concept ties in logically with the sediment strategy and the tradition of innovation and knowledge development that is characteristic of the Dutch coastal policy. It is a tool that could be deployed for coastal management. Naturally, the construction of a sand motor for coastal maintenance requires a great deal of sand, which has consequences for the nourishment programme of 12 million m^3 sand annually. The option of using a sand motor within the regular nourishment programme therefore implies saving sand over a number of years. This, off course, is different if there are other sources of funding for sand, such as the High Water Protection Programme. These options are not given any further consideration in this study.

The interim evaluation (Taal, 2016) shows that the Sand Motor pilot where this is constructed has made a positive initial contribution to the coastal protection by shifting the erosion point. There was also an increase in dune volume, but not as strongly as expected (see marginal notes). The development in recent years shows that by dispersing sand parallel to the shore an increasingly greater part of the stretch of coast has a higher level of safety thanks to the seaward expansion. All in all, it can be established that the protection-level of the primary flood defence is heightened in the sphere of influence of the Sand Motor and the lifespan of the coastal reinforcement is extended. During construction, the momentary coastline has also shifted seaward at the site of the Sand Motor, while this also happened later on in the accretion areas. After four years, only 5% of the sand volume that was added for the Sand Motor pilot project has disappeared in the monitoring area. Based on this, the conclusion can be drawn that the lifespan of the Sand Motor is longer than 20 years. The volume of sand used for constructing the Sand Motor is sufficient to nourish the coastal foundation for almost 20 years (Taal, 2016).

The fact that the Sand Motor pilot generally functions as expected, while the lagoon and dune formation are somewhat below expectations, implies that, on average, the innovation can already be deemed a success for coastal management.

4.1.2 Marginal notes

There are also marginal notes for the usability of the Sand Motor concept for coastal protection:

- With the chosen design of the Sand Motor pilot, the protection along the coast will not be higher everywhere all at once. This, however, is the case with mega beach nourishments and, after a short time, mega foreshore nourishments (see also Bruens, 2007 and DHV and HNS, 2010 and Insert I). In such case, a more conventional and more streamlined shape would most likely have needed relatively the least amount of sand to maintain the base coastline in the entire Delfland stretch of coast (Bruens, 2007). All in all, this still remains to be seen during the further development of the Sand Motor, which is becoming more streamlined. It would also be worthwhile to compare the experiences with the Sand Motor pilot with those of large existing nourishments like on Ameland and future mega-nourishments. The possible advantages are points of attention for the design of new sand motors.With the Sand Motor in Delfland, the positive effect on the dunes during the early years are disappointing. In some respects, this is due to the morphological adjustment of the coastal reinforcement constructed in 2010 (causing the foot of the dunes to recede) and in other respects, the chosen design with lagoon and dune lake. The sand that is not taken up by the water drifts to the dunes that are situated landward of the dune lake and the lagoon (Taal, 2016).

- The lagoon has led to the growth of a sand spit and a meandering channel, as was also expected (Figure 4.1; Deltares, 2009; DHV and HNS, 2010). The channel has not had any negative impact on the primary sea defence dunes in Delfland, probably thanks to the presence of breakwaters. In the case of a sand motor design that includes a lagoon, precautionary measures will have to be taken to prevent any negative impacts like those caused by meandering channels on Ameland (Israel and Oost, 2001).

Insert I The shape of a sand motor

The design chosen for the current Sand Motor pilot extends approximately 1 km into the sea, which makes it highly dynamic, making it possible to obtain many new insights into how it is functioning. A new sand motor could be designed differently. Alternatives have been examined during the design phase, including the design of the Delfland coast reinforcement and later for the Hondsbossche sea defence. Knowledge about sand spits can also add insights. The most important conclusions are set out and shortly discussed below.

Acreage

- Any immediate gain in acreage only occurs with the variants that are constructed above water. The best way to gain as much as possible immediate acreage per m^3 of sand nourishment would be to place nourishments close to the existing shore (shallow water), but this could lead to higher costs (Bruens, 2007; Arcadis, 2013).

Protection

- Variants that do not have a streamlined shape (i.e. extend into the sea) may cause erosion elsewhere, which will have to be compensated for with additional nourishments reducing the expected reduction in coastline maintenance (Bruens, 2007; Tonnon et al, 2008).
- The location of the sand motor largely determines its effectiveness in combatting coastal erosion and therefore the required coastal maintenance (Tonnon et al, 2008; DHV and HNS, 2010, Taal, 2016).
- The more local the sand motor is, the less the decline in additional coastal maintenance (cumulative over the entire area; Bruens, 2007).
- Virtually all of the shapes examined result in a decline in the coastal maintenance for protection in the medium term (Bruens, 2007; Tonnon et al, 2008).
- All sand motors contribute to raising the coastal foundation and therefore protection in the long term; the extent of this depends on how quickly the sea level rises and the volume of the sand motor (Bruens, 2007; DHV en HNS, 2010; Arcadis, 2013).
- The wider (transverse to the coast) a mega-nourishment is, the more it will provide sustainable protection and vertical accretion with sea-level rise (DHV et al, 2007).

Dynamics

- Shapes that are less streamlined create greater dynamics than streamlined designs. In the case of extending shapes, strong dynamics with local erosion of the sand bodies with tens to hundreds of metres per annum and vertical changes of a few metres per annum will have to be taken into account, particularly in the early years (Tonnon et al, 2008).
- In time (according to models up to 10-20 years), all sand motor shapes along the coast will have ‘spread out’ (Oost, 1995, 2012; Israel & Oost, 2001; Löffler et al, 2008; Tonnon *et al*, 2008; Taal, 2016).

Figure 4.1 The virtually non-meandering - probably thanks to breakwaters - channels of the Sand Motor pilot, 12-11-2015 (RWS, van het Houdt).

4.1.3 Lessons learned

The Sand Motor concept ties in with the Dutch sediment strategy and can be used as a potential tool for coastal management. Opting for a sand motor implies that sand from the coastal management budget will have to be saved, or that other sources providing the sand will have to be used.

The design determines the morphological development (at detail level as well as the level of the entire stretch of coast), the expected lifespan and possibly the volume of maintenance nourishments. The currently chosen shape improves the protection and position of the coastline, particularly at the site of the Sand Motor pilot itself and within the sphere of influence, which is becoming bigger due to the coast parallel dispersal of the sand. A sand motor shaped like a more conventional, streamlined mega-nourishment on the beach, would have an immediate positive impact on a greater part of the stretch of coast. It is unclear which of the now existing recreational and ecological values would then develop. These two extremes in the design spectrum also illustrate the high flexibility of the Sand Motor concept.

4.2 Usability from an ecological perspective

4.2.1 Developments

The MEP report (Taal, 2016) shows that the variety in environments and therefore the potential for ecological values by constructing the Sand Motor pilot has increased. The sand spit, the highly dynamic stretch of coast with shoals, the lagoon and dune lake are landscape formations that are not or are hardly ever present along the Holland coast. Due to the shape of the Sand Motor pilot, the variety of habitats for benthos, birds and fish has increased along the coast as a whole. In particular, the sheltered, shallow part of the lagoon and the surrounding borders are attractive areas for benthos and birds. In 2015, the ecological values in the deep part of the lagoon were lower than previously as a result of the limited exchange of water with the North Sea and the reduced oxygen levels. This restricted the function for juvenile fish.

At less than 1 hectare, the newly formed dune acreage is still modest. These dunes are mainly situated on the eastern edge of the Sand Motor pilot, against the foot of the early applied coastal reinforcement and to the southwest of the Sand Motor pilot. Most of the dune formation takes place on the outer slope of the coast reinforcement, whereby less ecologically valuable marram grass was replaced by the 'white dunes' habitat. The new dunes are highly dynamic and therefore scenically attractive.

The number of plant species and habitats is increasing, but as a whole, the Sand Motor pilot is scarcely vegetated. This concerns typical sand couch grass and marram vegetation, habitat types that the Netherlands is under an international obligation to preserve. The Red Listed species *sea holly*, even grows in some areas. Between 2011 and 2015, 40 bird species were observed on and around the Sand Motor on a more than incidental basis. To date, no birds have been breeding on the Sand Motor. Not much can be said of what the Sand Motor means for marine mammals like the seal due to the small number of official counts available. However, there is some evidence to suggest that attempts of birds to breed and establish seal resting spots have failed due to disturbances by man (Taal, 2016).

4.2.2 Pilot Sand Motor marginal notes

Both the organic and inorganic nature has increased in diversity since the construction of the Sand Motor pilot. In its present form and under the current management, the Sand Motor does not appear to be an optimal tool for achieving nature objectives. There are five reasons for this:

- The development of the dunes, the dune lake and the lagoon greatly depends on variable and incidental factors, such as the weather. One example of this is the intermittent water exchange of the lagoon with the North Sea because of growth in the channel and the sudden recovery after a new channel has broken through. Another example is dune development. Dunes develop successfully on beach plains, with a sufficient beach width of 200 m or more (DHV *et al*, 2007), a random process that occurs once in 1 to 2 decades (De Groot et al, 2015). It is quite possible that after years in which there has been little development, dunes will form rapidly and establish vegetation, due, for instance, to the beach becoming higher or the capture of mud, as observed on Ameland (Tooren and Krol, 2005). It still remains to be seen whether this also will be the case with the Sand Motor. Whether a more conventional, streamlined mega-nourishment of 200 m or more wide transverse to the coast would lead to new dune formation on the beach sooner will have to be looked into further. More knowledge will be acquired on this as the Sand Motor 'spreads out' further along the Delfland coast.
- Constructed landscape formations may also hinder the development of ecological values. The lagoon and the dune lake, for example, trap sand and in doing so delay the growth of dunes (Tonnon and Nederhoff, 2016; Taal, 2016).
- The connection between the lagoon and the sea became increasingly longer through the formation of the sand spit and the channel behind. The restricted the exchange of water between the North Sea and the lagoon, which reduced the quality of the water and therefore the ecological value of the lagoon (Imares, 2016).
- With regard to benthos, in 2015, 4 years after the Sand Motor was constructed, there was no evident shift towards longer living benthos species compared with the regular sand nourishments. It remains to be seen whether longer living species can develop in the dynamic environment of the Delfland coast. The high sand transport rates and corresponding sorting

of the sand possibly hinder the successful establishment of aging benthos species. Few aging species were observed at Ameland around the rapidly evolving natural sand hook (P. Herman, pers. med.). However, it is not yet possible to make any decisive statements on the ultimate success of the Sand Motor pilot for nature development. The Sand Motor has not been in place long enough for that (Taal, 2016).

- The management of the Sand Motor pilot is more focused on man and less on the development of specific ecological values. Cleaning the beach hinders dune formation (see insert II) and a conscious decision was made not to apply zoning by means of allocating resting, breeding and growing zones. The recreational sharing disturbs birds and sea mammals. There are examples of management in which nature and recreation management go together well. This is evident in everyday practice on the Wadden islands, where fencing, flag routes and zoning are generally applied.

Insert II Management of the Sand Motor pilot

Unlike the municipality of Westland, the municipality of The Hague cleans the beach daily during the tourist season by sieving the top layer. This does not only remove unwanted waste from the sand, but also the natural debris like seaweed, wood and large shells. The debris, however, is important for initiating dune formation. There is a visible difference between the beach along the Delfland coast, where embryonic dune formation occurs and the beach at Scheveningen, where there is no dune formation.

Tracks of the sand cleaner on the beach of the Sand Motor pilot. (October 2015)

The clean Scheveningen beach without debris or dune formation on the Sand Motor pilot; the sign indicates the border with Westland with the dune formation immediately behind it. (October 2015)

The Westland beach on the Sand Motor pilot with the sea rocket on the beach debris in the foreground; the sign indicates the border with Scheveningen. (October 2015)

4.2.3 Lessons learned

The Sand Motor and the development of naturally comparable situations, such as the beach hooks of northwest Ameland and Schiermonnikoog, show that the development of nature is largely determined by random processes and cannot be controlled very precisely. The development of nature may suddenly proceed rapidly when certain thresholds are exceed by 'random processes'. From that perspective, issues like the development of dunes, a lagoon and a dune lake are difficult to control. That does not necessarily have to pose a problem once this is taken into consideration right from the start.

Furthermore, the design of a sand motor can contribute to dune formation. If new dune formation is the primary goal, a beach width of 200 m (up to GLW) would suffice and the opportunities will possibly increase as the beach component of the sand motor becomes more elongated. The construction of lagoons and dune lakes also hinders dune formation.

Choices in the recreation management also determine the development of ecological values. Zoning, cordoning off areas and less intensive cleaning help raise these values.

The lesson learned is that the Sand Motor concept is potentially usable for the development of new ecological values, but that this greatly depends on the objectives, the design, the management and natural chance processes.

4.3 Usability from a recreational perspective

4.3.1 Developments

The Sand Motor pilot temporarily adds an extra area to the Holland coasts, offering possibilities for nature and recreation that were previously unavailable. The developments that have taken place show that the current design of the Sand Motor pilot has resulted in a landscape that is otherwise absent along the Holland coast and offers space for extensive recreation (as defined in Decisio, 2004). The initial recreational study following the construction of the Sand Motor shows that the four most important recreation groups are seaside visitors, dog walkers, walkers and (kite, wave and wind) surfers. Together with the various outdoor activities like horse-riding, mountain bike riding, fishing and jogging, this creates more forms of recreation on the beach between Ter Heijde and Kijkduin than was the case prior to the construction of the Sand Motor (Taal, 2016).

The visitors are becoming more familiar with the different aspects of the Sand Motor. During and immediately after the construction of the Sand Motor, various stakeholders examined the Sand Motor in a critical to moderately critical light (Chapter 3; Berendsen et al, 2005). An increasing bigger group is now positive about the Sand Motor and the project has gained wider support.

4.3.2 Marginal notes

The design of the current Sand Motor pilot appears to be less usable for locations where mass recreation is present or has to be developed, because the distance to the waterline can be extremely far. The dynamic development is probably also too strong. If people do not want to change the character of a seaside resort but do want to avail of the Sand Motor concept, a more restricted temporary expansion of the beach could be pursued.
A meandering channel has developed (as already anticipated; DHV and HNS, 2010) that connects the lagoon to the North Sea. Since the currents in such a channel can be strong, this poses a risk for recreational users, particularly when they become closed in at high tide and find themselves seaward from the channel (Figure 4.2); this has led to dangerous situations at the Ameland sand hook. When the lagoon (for the most part) becomes cut off from the North Sea, so the water can no longer be refreshed, decay processes are likely to occur. This was also the case on

Ameland. On the other hand, a lagoon is very appealing to kite surfers. While the risks have been kept under control in the case of the Sand Motor pilot, whether a lagoon with channel formation is desirable should be taken into consideration for a future sand motor.

- The currents in the seawater at the tip of the Sand Motor pilot flow very fast. This is a point that requires continuous attention, even though it has not yet caused any problems. The far protruding tip has also resulted in an extremely wide sandy beach. Both developments diminish the usability for swimmers at the location.
- The accessibility and connection to the Sand Motor pilot is mediocre. A better connection could possibly lead to more recreation, but this has not been investigated (DHV and HNS, 2010; De Boer et al, 2015).

4.3.3 Lessons learned

The Sand Motor pilot shows that the Sand Motor concept in its present form is useable for certain types of recreation. It offers rest, space, nature and vastness and is particularly usable for extensive recreation.

Any future sand motors should take into account to what extent the construction of a lagoon, with channel formation as a consequence, is usable for beaches with high visitor rates and beach recreation. Other designs should also facilitate the deployment of the Sand Motor concept for such intensive recreation.

Figure 4.2 Risk of becoming closed in on the Sand Motor pilot, the notice board reads: Do not cross this point – entrapment risk, 9 February 2016

4.4 Usability from a knowledge and innovation perspective

4.4.1 Developments

The Sand Motor functions differently to regular sand nourishments, which raises new topics of research. Furthermore, the Sand Motor is a multi-functional solution that is linked to the layout of the landscape and its underlying processes. This has led to interdisciplinary research questions and themes (nature-based design/ecosystem services/blue and green). A comprehensive and long-term knowledge development programme is therefore linked to the Sand Motor pilot. Dozens of researchers from various universities and knowledge institutions are following the developments closely. Key research themes: the development of the beach and surf zone morphology, the sand transport rate by wind, the ecology of the shallow sea and surf zone and the ecological impacts of mega-nourishments (Taal, 2016). It can be concluded from this that, given the comprehensive setup of the abovementioned tracks, the 'knowledge development' goal will be sufficiently achieved (Taal, 2016). The Sand Motor pilot can also be deemed a success from that perspective.

The Sand Motor pilot is innovative, drawing a lot of international interest (Van der Valk, pers. inf.; Stive, inf. Trouw). The extreme seaward extending shape and the dynamic nature of the Sand Motor contribute to this interest. The Sand Motor pilot offers the business community and knowledge institutions the opportunity to gain experience in innovative coastal maintenance. The principle 'Building with Nature, on which the Sand Motor pilot is based is a spearhead of the marine engineering sector and, among other things, is implemented in collaboration with the business community, the knowledge sector and government. The Sand Motor allows these sectors to demonstrate that marine engineering and ecology can go hand in hand on matters of safety, economic development and the living environment. There are several places in the world where sand motor-type solutions have been implemented, both within Europe (Sweden, United Kingdom, Belgium) and beyond (United States, Mexico).

4.4.2 Marginal notes

- There is relatively intensive motorised traffic on the Sand Motor, which is partly caused by researchers. The traffic has an impact on the developments on the Sand Motor by way of disturbance and tyre tracks. This interferes with the research and knowledge development. As yet, there is no strategy to deal with this specifically.
- Some areas (groundwater, tourism, beach management) are yet to be extensively researched.
- New sand motor-type solutions are likely to lead to new questions about the location where the sand is deposited and the design, the volume and the realisation of usage functions and values and the corresponding development of knowledge. The steady accrual of knowledge may be expected to keep the international focus on the 'Sand Motor' product.

4.4.3 Lessons learned

The Sand Motor pilot has proven to be extremely usable from the point of view of knowledge development and innovation. Future sand motors are also expected to contribute to this and help market the Sand Motor concept internationally.

There are still many areas on which new knowledge can be accrued with respect to sand motor development.

4.5 Usability from a cost perspective

4.5.1 Background

A cost assessment (see Appendix A) was conducted to find out to what extent the Sand Motor pilot is cost effective. In other words: how does the Sand Motor pilot work out compared to the regular coastal maintenance when the price of sand, interest, maintenance requirements and lifespan are taken into account? This study is based on a Life Cycle Costing (LCC) calculation from the point of view of the cash flow for the Rijkswaterstaat, for which a statutory fixed discount rate applies (The statutory fixed discount rate for LCC was adjusted from 2.5% to 3% with effect from 1 April 2016, see also Appendix A for further information). The benefits for nature and recreation have not been included in this assessment because there is not enough statistical information available. For the various points of departure, the alternatives and statistical substantiation, please refer to Appendix A.

The LCC study permits the following conclusions:

- The construction of the Sand Motor pilot was a good idea, if only from the point of view of costs for the maintenance of the coast, based on the insights on sand requirements and the sand prices that applied at the time of the decision-making. This is unrelated to the advantages that the Sand Motor pilot offers for other functions and values.
- Based on the current sand price for regular nourishments and the current insights on sand requirements for the Delfland coast, from the perspective of costs for maintaining the coast alone, it is no longer a good idea, unless a significantly lower sand price can be obtained or it is possible to create a design that functions effectively for a longer period than the regular nourishment programme with the same volume of sand.
- The important reason for this change is that the coastal maintenance is contracted out in the long term as of 2012. This led to a reduction in the nourishment price of approximately 25%. With the current price for regular sand nourishments (€ 3.52 per m^3 on average) a sand price for a mega-nourishment which corresponds with the Sand Motor pilot of at least €1.74 per m^3 will have to be attained. Only then a sand motor is cheaper for coastal maintenance alone.
- Whether a sand motor-type solution is efficient for the coastal management can be estimated using models. Which sand price makes a sand motor-type measure a more favourable alternative for maintaining the coastline or maintaining the equilibrium of the coastal foundation than regular nourishments can be determined based on different designs, at different locations, with different volumes of sand and different shapes . Particularly with low sand prices, a sand motor-type solution will probably deliver substantial cost savings for the coastal protection and preservation of the coastal foundation and base coastline.
- A more complete assessment framework requires more knowledge of the costs and benefits of various mega-nourishment shapes, so that the benefits for safety, nature, recreation can also be included.

4.5.2 Lessons learned

With the insights on sand requirements and sand prices available at the time, the construction of the Sand Motor pilot was attractive for the coastal maintenance, irrespective of other functions and values that are provided by creating an additional area. The current, substantially lower, sand prices and the reduced sand requirement changes this situation. From the point of view of coastal maintenance alone, a sand motor is an ‘instrument of opportunity’ for coastal management that can be deployed when sand is available at low cost (work with work; DHV, 2009) compared to the expected long-term (decades) average. The latter may be the case at present, see Appendix A. However, in choosing a sand motor, the possible benefits (and own funding streams) for other functions should also be taken into consideration.

4.6 Other values and functions

4.6.1 Discussion

Apart from recreation and nature, there are other functions that are affected by the construction of a sand motor, like mineral extraction, groundwater extraction, shipping routes and military zones. This section describes the opportunities or hinder that a sand motor may have for these functions.

Shipping routes
The construction of a sand motor may lead to sediment flows, which hinder shipping routes or access to harbours. This should be explicitly taken into account when designing a sand motor, as was the case when constructing the Sand Motor pilot for Scheveningen harbour, for example.

Water outlets
Water outlets should also be taken into consideration. One of the reasons why the Sand Motor pilot was not constructed further south was that it would have required radical measures to guarantee the runoff.

Military interests
To date, it is not possible to anticipate whether this could be hindered by the construction of a sand motor. They are, however, mentioned here for the sake of completeness.

Water extraction
For any future sand motor-type solutions, due consideration will have to be given to the groundwater level development and any initial landward migration of salt water. In general, any seaward coastal expansion will initially lead to more salinization from the underlying coastal areas (typical value of 6% increase). Drinking water extraction may be threatened, because some of the saline groundwater will flow landward. Over the course of a few decades, this may, however, form a freshwater lens (see Insert III).

In Solleveld, close to the Sand Motor pilot, drinking water has been extracted for 140 years now; volume of drinking water is currently 5 million litres per annum. From the reinforcement of the Delfland coast in 2010 and the construction of the Sand Motor, it has been calculated that this will have an impact on the groundwater flows, whereby currents could carry salt from the coast to the drinking water extraction area. Furthermore, the drinking water could become contaminated by construction waste, which is stored in the so-called ‘Puinduinen’ (Rubble Dunes), constructed from demolition waste from The Hague. To minimise the risks for the production of drinking water, drainage pumps were placed in the new strip of dunes of the coastal reinforcement.

Raising the groundwater level in the hinterland
Coastal expansions may lead to a rise in the groundwater level in the hinterland and dune area (see insert III). In Solleveld, the dune area situated landward of the Sand Motor, this rewetting has not yet been observed, probably because saline water is being pumped off to protect the drinking water. In some cases, a rise of groundwater levels is desirable, for example for ecological functions, and the construction of a sand motor-type measure may contribute to this (temporarily). A rise in the groundwater level may, however, also be easily achieved with other measures.

Reducing salinization in polders
A possibility for deploying sand motors lies in the opportunity to realise and maintain dune-lined coastal expansions. Model studies show that a permanent large seaward expansion of the coast (of at least 200 m), after initial salinization, may (partially) prevent the saline water intruding deeper into the polders behind the coast over a period of 30-150 years (see Insert III; Oude Essink and Waterman, 2016). That is because the freshwater lens can grow so strong over a period of several decades that it connects to an impervious clay bed. This creates a barrier for saline intrusion in the groundwater system heading towards the inland. Primarily along the Holland and Zeeland areas south of Scheveningen harbour, where an impervious clay bed lies relatively shallow, salinization of polders situated deep behind the coast may be (partially) prevented

(Huizer et al, 2016). This is why the coast should be permanently expanded seaward. Sand motors can be deployed for expanding the dune volume and maintenance of the relevant stretch of coast.

Mineral extraction
Extracting minerals (salt, gas, sand) in the coastal zone will lead to subsidence. That is why the coasts needs additional sand nourishment to maintain the equilibrium. The extraction of minerals in underlying tidal basins, like the Wadden Sea, has an indirect impact: the basin 'draws' the sand from the coast, resulting in the need for additional nourishments. Initiative takers are currently required by law to replenish the deficiencies. In the case of gas extraction in the Pinkegat and the Zoutkamperlaag, this has become a component within the regular nourishment programme. At Ameland, where sand shortage occurs as the result of both impacts mentioned above, coastal erosion has been compensated by adding relatively large volumes of regular nourishments. During the period 1990-2012, $19x10^6$ m^3 were nourished and $13x10^6$ m^3 subsidence occurred (Oost et al, 2015). In such cases, sand motor-type solutions could also be used to capture the coast erosion. The extent to which this has added value compared with regular high volume nourishments would have to be considered on a case by case basis. It is important to emphasize that the sand motors would have to be designed in such a way that the cure is not worse than the disease, so to speak.

4.6.2 Lessons learned

A sand motor design has to take the impact on the freshwater management into account. In the short term, landward groundwater flows may result in slight salinization of the dune area, with possible consequences for the drinking water extraction. In the long term, a substantial seaward expansion of a coastal dune area, which will then have to be of a more permanent nature, may potentially prevent the salinization of the polders in the hinterland, for the coastal area south of Scheveningen harbour. Such an area may be formed and maintained with sand motors.

The Sand Motor pilot should take matters like water outlet points, harbours and sailing routes into account. There may (also) be possible military interests at other locations that have to be taken into consideration. In addition to this, a sand motor-type solution has the potential to capture large-scale sediment shortage that, for example, occurs as the result of mineral extraction.

Insert III Impact of land reclamation on the water management

Growth of freshwater lenses (figure 1)

The following applies for coastal expansion and build-up: The higher the surface level, the higher the groundwater level will rise and the further it may expand downward. The freshwater lens will also grow seaward. The volume of extra fresh groundwater in the larger freshwater lens can be estimated using a 3D numeric model of the Sand Motor (Huizer et al, 2016) and conceptual 2D profile models (Oude Essink en Waterman, 2016), taking the width of the dune, the underlying polder system and the thickness of the aquifer to the hydrogeological basis into account. By way of illustration: the strip of coast from the Hook of Holland to Den Helder may store around 1000 million m^3 additional fresh groundwater in the case of a 200 m land reclamation.

Initial saline seepage then fresh (figure 1b)

The formation of a freshwater lens after the expansion of dunes takes approximately 80 to 150 years (Huizer et al, 2016). The process can proceed two to three times quicker by actively injecting pre-treated water and/or extracting saline groundwater. The expansion of dunes and the growth of the freshwater lens may initially result in increased saline seepage in the hinterland. That may continue for at least dozens of years. Solutions are available for this, e.g. drainage systems (Stuurman, 2010). The seepage in the hinterland will become fresher over a yet longer period of 80-150 years.

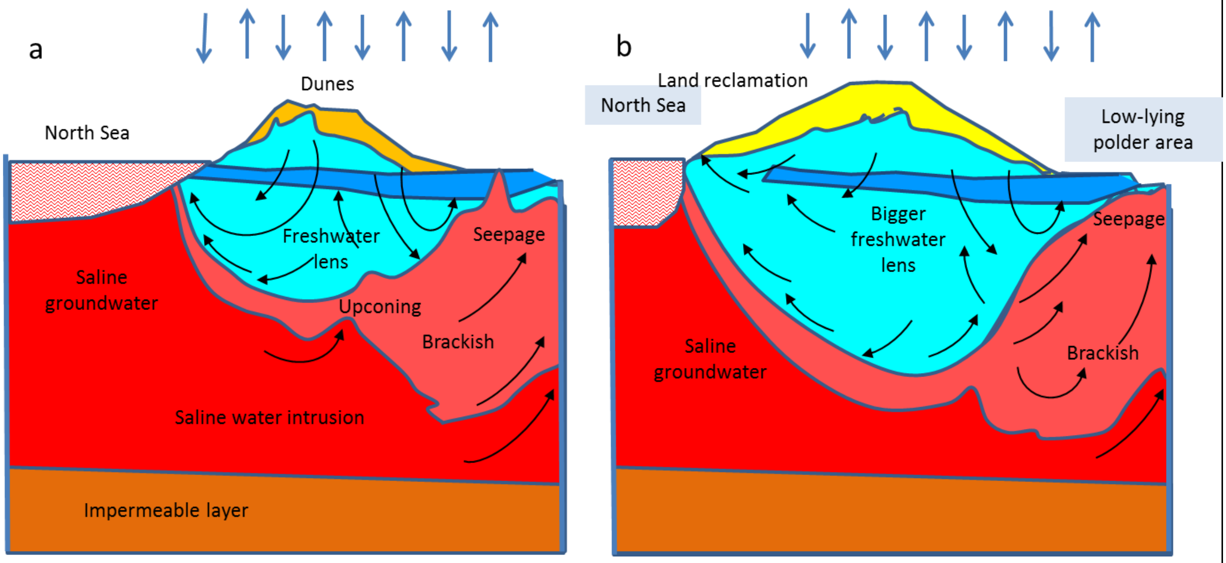

Figure 1: a. Original situation in conceptual form; b. Impact in the early decades after the land reclamation on the freshwater stock beneath the dune area: unless the lens becomes deeper and wider, the saline seepage will rise to the hinterland during this period (from: Oude Essink en Waterman, 2016).

Groundwater system becoming fresher (Figure 2)
The freshwater lens growing as the result of dune expansion may, in time, form a barrier for the saline groundwater that flows inland from the sea. This is why the groundwater system in the hinterland becomes fresher over time. This seems to be possible in the southwest of the Dutch coastal area, more or less from the south of Scheveningen to Cadzand.

In order to make detailed statements, the following factors have to be known:

- The circumstances under which the formation of a freshwater lens occurs in the coastal expansion. What is the exact geometry (topography, width and height), what is the geological situation (permeability of the sand and possible presence of resistive layers) and what are the hydrological conditions (possibilities for groundwater replenishment via net precipitation)?
- The degree to which the groundwater level may rise in the event of a seaward expansion of the land.
- The speed at which a freshwater lens can develop in a new (dune) area along the Dutch coast, and how this new lens interferes with an already existing freshwater lens.
- The exact impacts of dune expansion on the ground and surface water system in the hinterland, particularly in terms of seepage and saline intrusion.
- The extent to which the desired developments can be accelerated by salt water injection and extraction.

The Huizer et al study (2016) addresses a number of the abovementioned factors in relation to the Sand Motor.

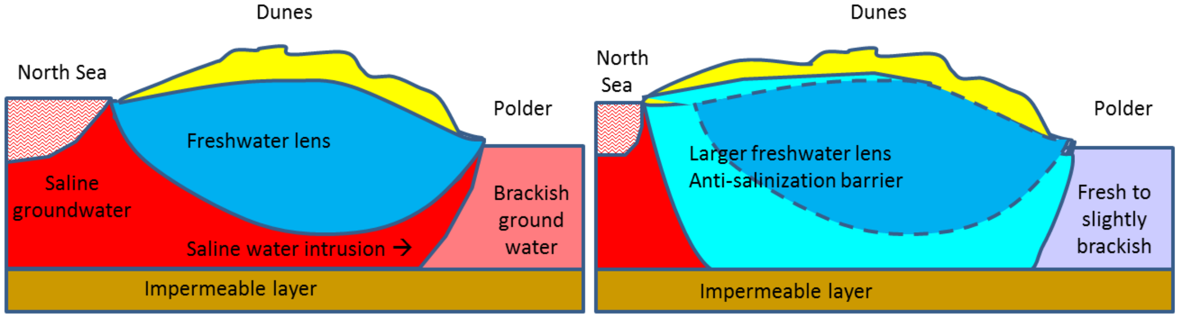

Figure 2: The freshwater lens grows due to the seaward land reclamation , which may form a barrier for the salt water intrusion heading inland. This is why the groundwater system in the hinterland becomes fresher over time. The situation can be realized in the southwest of the Dutch coastal area in particular, more or less from the south of Scheveningen to Cadzand.

5 Requirements for functions and values along the Dutch coast

5.1 Introduction

To identify which requirements for functions and values play a role along the Dutch coast, maps have been made of the current and future functions and values (see maps Appendix B and C, appended to this document). This concerns coastal management, nature, layout and recreation in or near the coast and ‘other functions and values’. Combined, these maps form the ‘wish lists’ for the coming 20-30 years. Point of departure is that existing functions and values are retained. Furthermore, information has been recorded on the salinization of the coastal area (for the existing functions and values), as a means to determine to what extent coastal expansions can play a role in combatting this.

The future functions and values are based on development plans with a legal status[1]. These are relatively few, so the addition of these does not change the picture much. To indicate the direction of future ecological wishes, ecological functions have been included along with those with legal status as described by Lammerts and Van Haperen (2015) for the purposes referred to in the Approach to Nitrogen Programme. More information is available on this in insert IV.

5.2 Coastal management

Existing functions and values (Figure 5.1)

A map has been made of the Dutch coast sediment requirement over the period 1990-2005, excluding nourishments, expressed in vertical change of the sand volume (van der Spek and Elias, 2014; van der Spek and Lodder, 2014a&b). This is regarded as guiding for the future sand requirement along the Dutch coast for the coming decades. Furthermore, the base coastline and the type of coastal defence and the safety level are indicated.

Future wishes functions and values

It is not possible to say to what extent additional measures will be necessary in the future to guarantee the safety of the flood defences. The first statement ensues from the fourth review round (2017-2023), in which the flood defence managers check that their dune flood defences are in good order based on the Statutory Assessment Instruments 2017. Since this information is not yet available, we have not included this in the present consideration.

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[1] *The latter case concerns plans for which an indication has been given, which has been approved and laid down by Royal Decree, on which the Administrative Jurisdiction Division has ruled, same, which has yet to be approved, has been laid down, which fall under the prevailing policy and for which temporary measures have been taken.*

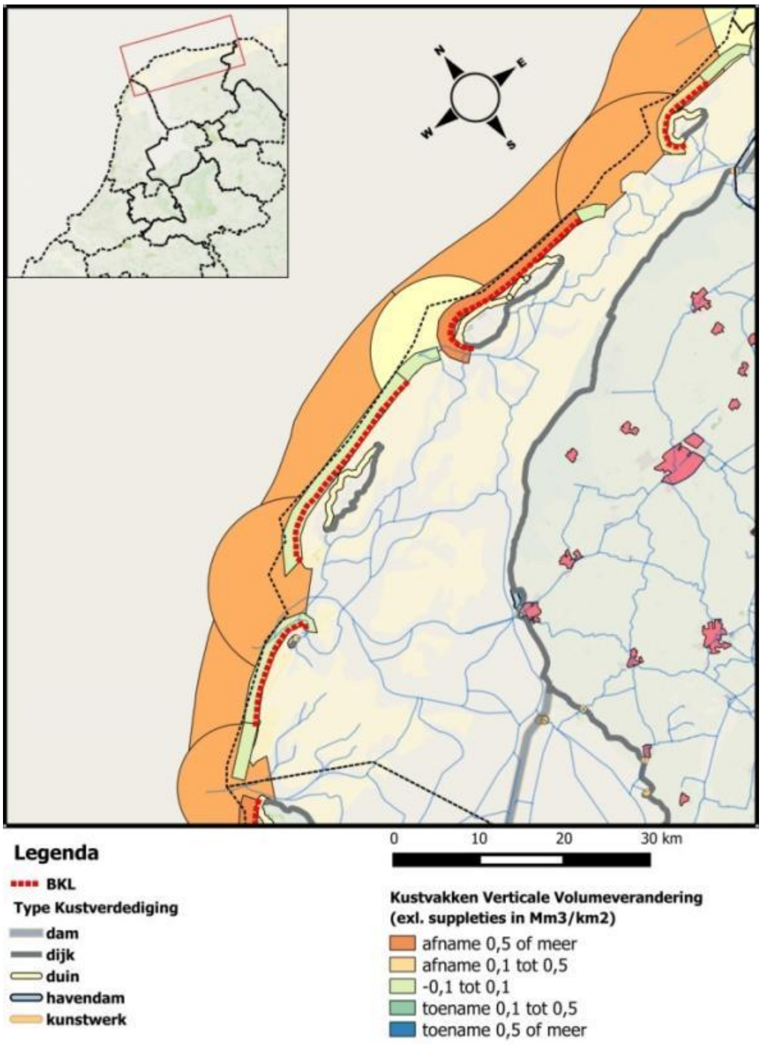


Figure 5.1 Fragment of map with existing 'coastal management' functions and values (for legend: see Appendix B)

5.3 Nature

Existing functions and values (Figure 5.2)
Natura2000 areas and other nature areas are identified here, which may legally restrict the implementation of large-scale measures like sand motors.

Future wishes functions and values
To gain an impression of future wishes, a map was made of developments that have been legally approved, like plans for the development of an agricultural zone, wetlands, new nature areas and water storage. Few plans have been established for nature at a distance of less than 10 km from the coast: the volume of water will only be expanded in the Delfland coastal area. In North Holland, a small nature area has been provided at Beverwijk.

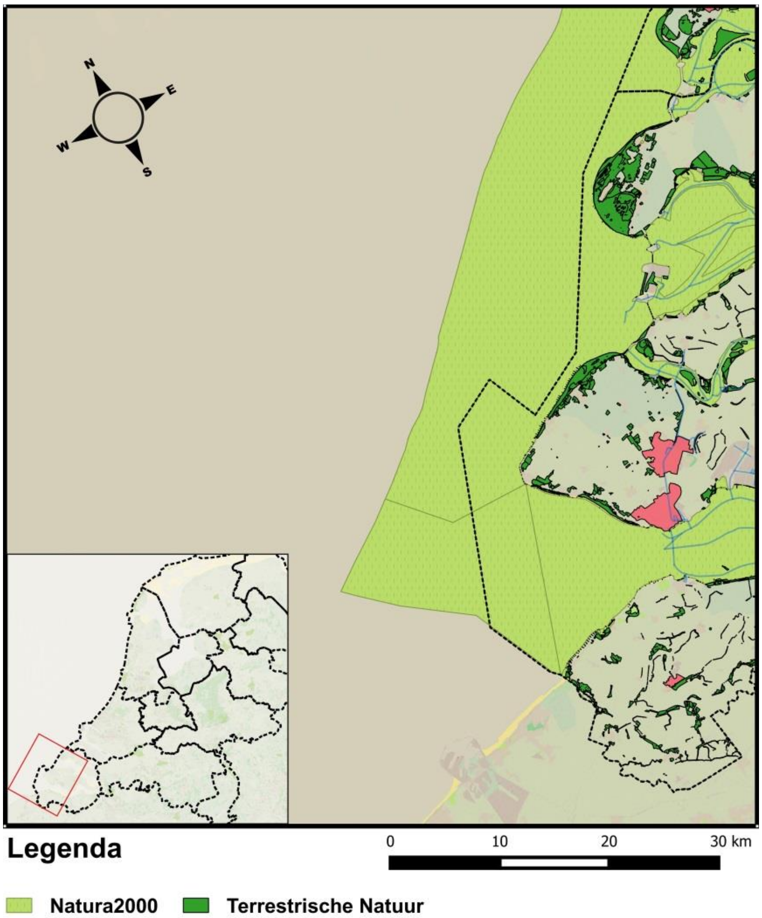
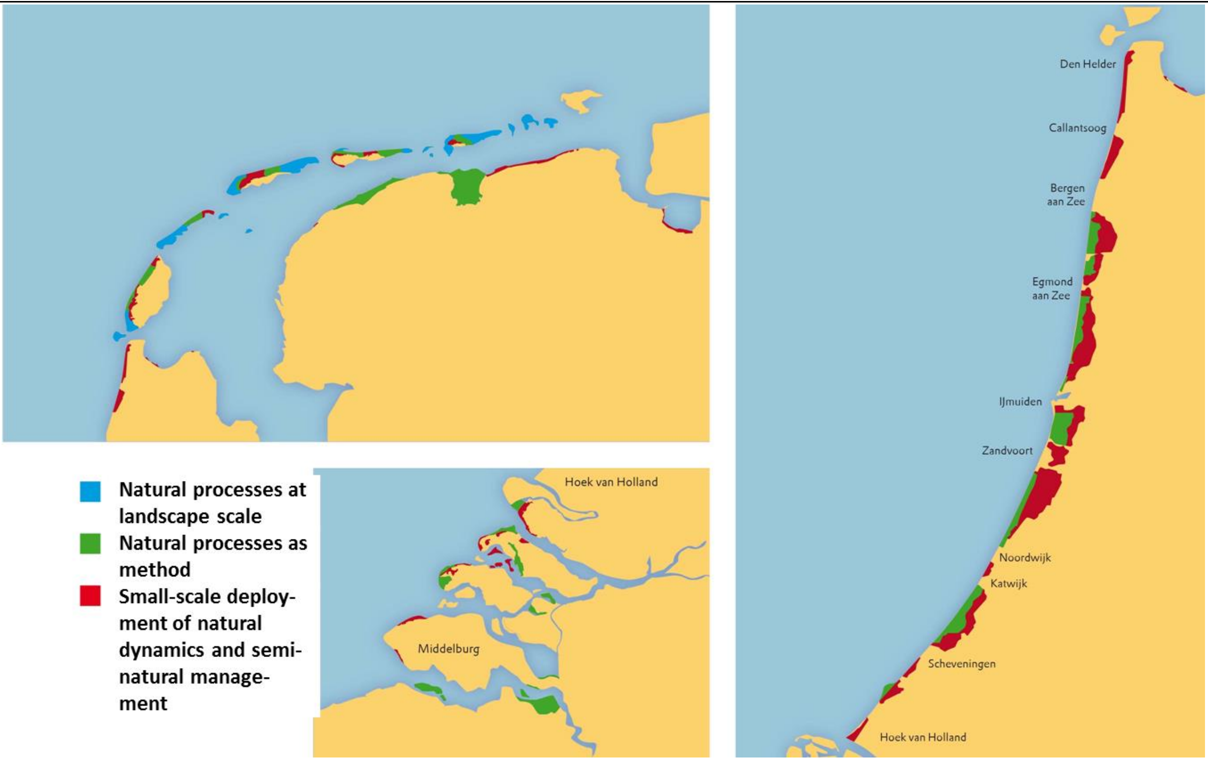


Figure 5.2 Fragment of map with existing ecological functions and values (for legend: see Appendix B)

All in all, no clear indications have been given for developing new nature areas along the Dutch coast. There are, however, many dune areas where the nature managers are struggling with the fast dense growing brushwood and scrubs on the open dunes. This ‘accelerated succession’ is the result of atmospheric nitrogen deposition in combination with the lack of dynamics (Löffler et al, 2008; Lammerts and van Haperen, 2015). The stimulation of dynamics is therefore also a measure to reduce the effects of nitrogen deposition. The measure is included in the Nitrogen Approach Programme (PAS). To find out where dynamics can still offer a remedy, the future nature wishes are identified based on Lammerts and Van Haperen (2015) using four levels of scale (Insert IV). The scale that best corresponds with the dimensions of a sand motor and may have an added value is scale 2, where long sea to land gradients can be created.

Insert IV: desired processes
From an ecological landscaping perspective, the coast is currently undergoing huge changes influenced by human activities. Notable changes have occurred in the vegetation structures of dunes and cultivated marshlands. Bare sandy spots and sparse vegetation changed into monotone closed grassy vegetation across vast areas. This is mainly caused by the establishment of the dunes and the dramatic increase in nitrogen deposition. Under pressure from these changes, the focus is shifting from the nature management of a more location-oriented nature management to a management that responds to natural processes on different scales of space and time. To improve coordination of nature management, dune management and coastal management, Lammerts and van Haperen (2015) suggested, also on behalf of the knowledge network Nature Quality Development and Management (OBN), four strategies (Figure):

1. Deploy natural processes at landscape level, whereby processes can spontaneously proceed on the scale of undisturbed gradients without noteworthy human influence. For the Dutch coast, this entails as complete as possible gradients of the coastal foundation up to and including the inner dune edges or high salt marshes. This only seems to be possible on uninhabited parts of the Wadden islands and is often already a given fact there.
2. Deployment of natural dynamics within the limitations of the physical and social environment. These are situations where an undisturbed run of natural processes is no longer possible on complete gradients, but is possible on related components, where long sea to land gradients can be created. For the Dutch coast, this mainly concern connections between the coast and underlying dunes and salt marshes. This is possible for the large dune complexes of Holland and on some parts of the Wadden islands and Schouwen-Duiveland.
3. Deployment of dynamics on the scale of individual dune and salt marsh habitats. This boils down to the technical and planned deployment of measures that are derived from natural processes. An example is the reactivation of blowouts.
4. Active semi-natural management in fixed coastal areas. Examples are mowing, cutting, chopping and regulated forms of grazing.



Wishes for a more natural management strategy (Lammerts and van Haperen, 2015)

Possible use of a sand motor within the 4 strategies

In strategy 1, the human influence is minimal. The possibilities for this strategy are mainly at the locations where nourishments only have a minor role. A sand motor would not be logical there. In strategy 2, a sand motor could play a role. The coastal management and the dune management could be brought into line with each other such that the surplus in sand can shift to the dunes, while coastal protection is safeguarded. This is not so easy everywhere, because infrastructure, like roads and pipelines, hinder the spraying of sand. The funding could possibly be obtained from the PAS regulation. The scale level for landscape processes is so low in strategies 3 and 4 that sand motors would not have any significant role.

5.4 Layout and recreation

Existing functions and values (Figure 5.3)

To this end, industrial estates, harbours and buildings along the coast have been identified, as well as the degree of recreational pressure according to Decisio (2014). This gives an impression of the heavily visited coastal areas and areas there the coast is densely populated.

Future wishes functions and values

This concerns a few areas within 10 kilometres of the coast, for which plans for expanding recreational facilities and sport accommodations close to the coast have been legally approved (including recreational accommodation). Recreational expansion is being considered in Noord-Beveland, Goeree-Overflakkee, an area south of the municipality of Westland and at Velsen. In addition to this, an area near Hellevoetsluis is being developed to facilitate sport.

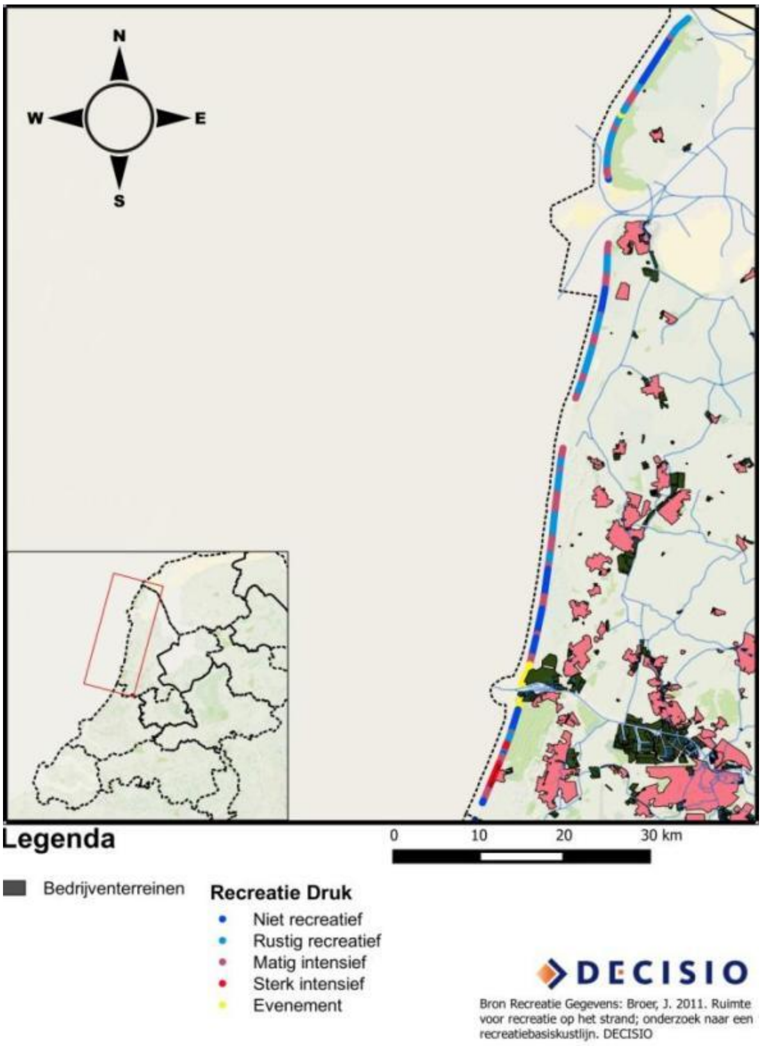


Figure 5.3 Fragment of map with existing layout and recreational functions and values (for legend: see Appendix B)

5.5 Other functions and values

Existing functions and values (Figure 5.4)
Mineral extraction, groundwater extraction, shipping routes and military zones have been identified for this purpose. An impression is also given of the salinity of water bodies, which penetrate the coastal area, and the risk of salinization. The information can be used to determine to what extent sand motors may be useful for limiting salinization in coastal expansions.

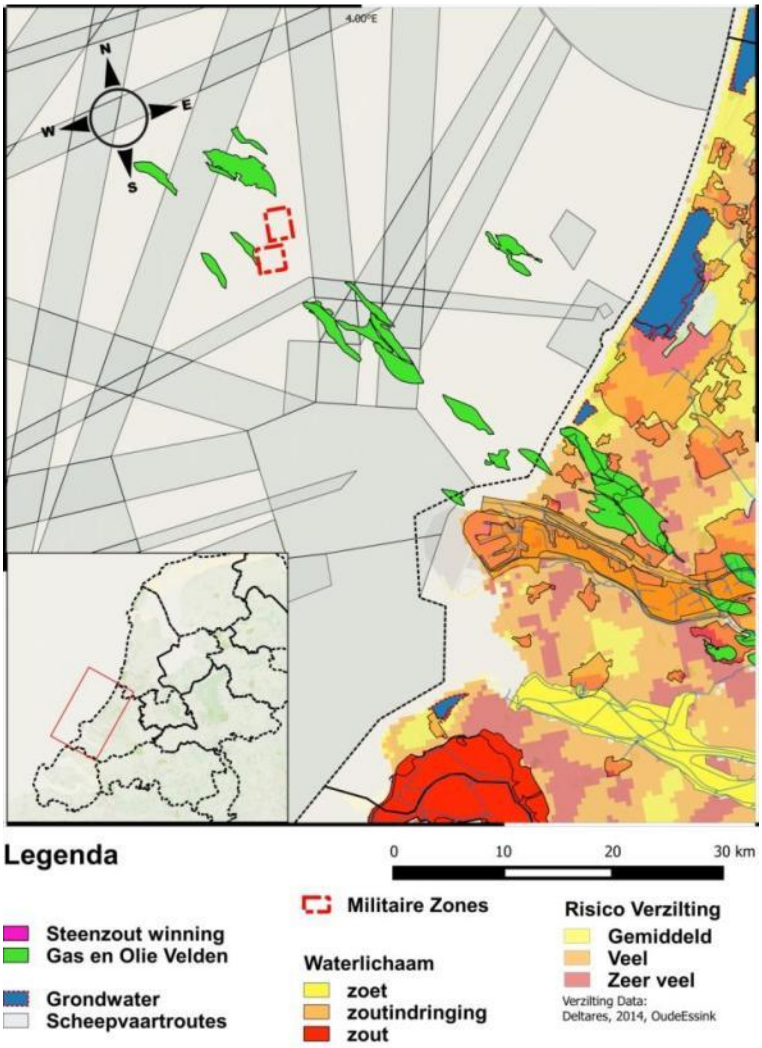


Figure 5.4 Fragment of map with existing other functions and values (for legend: see Appendix B)

Future wishes functions and values

This concerns a few areas within 10 kilometres of the coast, for which plans for expanding for agricultural use, industrial estates, urbanisation, horticulture, office space, utilities, traffic, water, water storage and living space have been legally approved. This is mainly needed in the southern area from the North Sea canal where small areas close to the coast are being developed to facilitate industrial estates and living and traffic. This does not leave any room for alternative developments.

6 Opportunities for sand motors along the Dutch coast

6.1 Criteria for determining opportunities for sand motors

Based on the requirement maps (chapter 5), individual opportunity maps were produced that indicate the opportunities of sand motors for coastal management, nature, recreation and layout and other functions and values (see the maps in Appendix D for a complete overview). The maps show:

- moderate opportunity for a sand motor
- good opportunity for a sand motor

No indication is given where no opportunity is identified for a sand motor. The section describes the criteria that the opportunities are based on.

6.1.1 Criteria for determining opportunities for coastal management

1. There are opportunities in areas where a lot of sand is expected to be needed for coastal management. These are retained areas where the vertical decline of the coastline after correction for sand nourishment of 0.1 m or more covered the period from 1990 to 2005. It is assumed that the sediment requirement will remain comparable in the coming decades.
2. If this first condition has been met, there should also be sufficient knowledge available on the functioning and effects of a possible sand motor before it can be safely constructed:
   - ✓ Along and within the outer deltas of the Delta and Wadden Sea tidal inlets, the risks are estimated to be high (Oost et al, 2014) due to the relative unpredictability of a sand motor's behaviour. More knowledge will have to be developed before a pilot project can be carried out in such a setting. For the Dutch research programme, Kustgenese II (Coastal Genesis) it is currently being considered to conduct further research on this in order to 1) find out if there is a need for sand motor-type solutions for such areas and 2) to develop the missing knowledge to be able to implement a sand motor (pilot) in a responsible way, if there is a need. The combination of a high sediment requirement with insufficient knowledge in the coming years to responsibly decide on a sand motor, leads to the qualification 'moderate opportunity'. It is recommended to do parallel research and develop a vision on the use of sand motors for those areas from the perspective of policy and management.
   - ✓ More knowledge about the effects of a sand motor is available for the straight coastlines, such as the Holland coast and the middle portions of the Wadden Islands. These places qualify as a 'good opportunity for a sand motor', if there is also a sediment requirement. For these Wadden coastlines, in terms of design, a sand motor should probably look like a large, conventional sand nourishment to minimise unwanted effects from the tidal inlets.
   - ✓ Finally, for all harbours and deep channels, a sand motor is not an opportunity.

6.1.2 Criteria for determining opportunities for nature

Sand motors are expected to have a positive effect on ecological values, preferably by providing room for ecological values that are not yet present locally. That is why sand motors would not be suitable for the coastlines of the Delta and the Wadden Sea, because the type of nature that is linked to sand motors and wide sand flats already exist there naturally (Figure 6.1). This means that a sand motor would have to be justified primarily based on other functions and values, or would follow on from a specific wish from nature management.

1. In principle, the entire South and North Holland coastlines qualify as a moderate opportunity, unless there is a wish for more dynamic management (Lammerts and Van Haperen, 2015). These qualify as a 'good opportunity', because funds can probably be more easily obtained there.
2. However, when there are Natura2000 areas in the sea, which hinder construction, these are labelled as a 'moderate opportunity'.
3. If there is a port estuary or coastal town or a channel, no opportunity is identified for a sand motor for nature preservation.

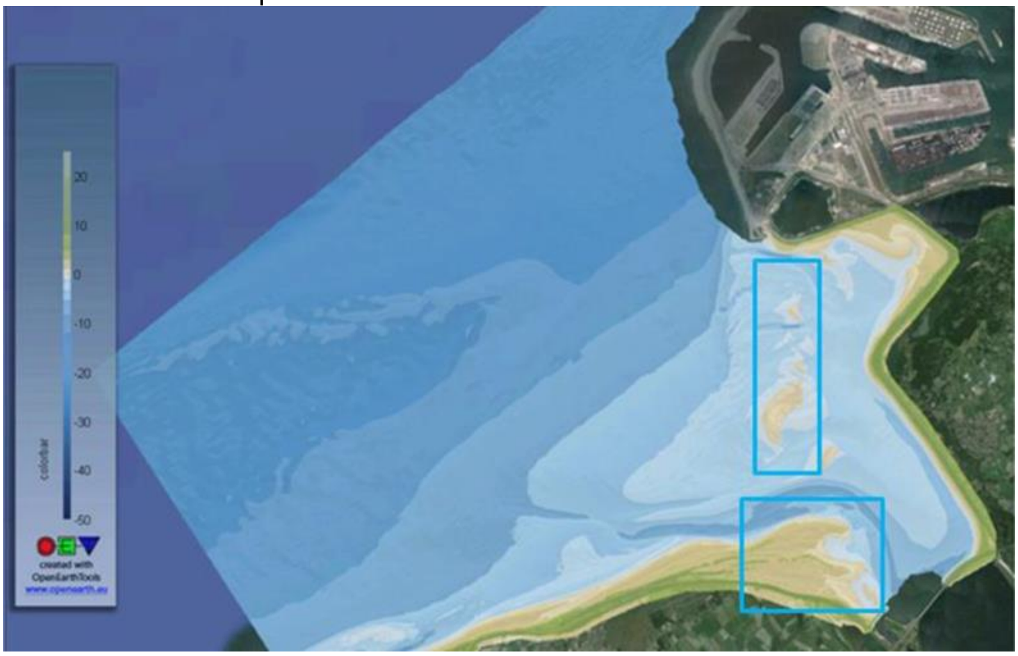


Figure 6.1 'Natural sand motors' at Haringvliet in the blue sections (soundings RWS, 2012; Wegman, 2016)

6.1.3 Criteria for determining opportunities for recreation

1) The possible sand motors should be able to offer an expansion of the existing opportunities for recreation. This cancels out the Delta (except for the narrow beach of Vlissingen) and the Wadden Sea, because the types of recreation that are linked to sand motor-type nature are already possible to a sufficient extent.
2) If this condition is met, existing and future recreation wishes will be examined:
   - ✓ Areas with a high recreational pressure (according to Decisio, 2014) qualify as a 'good opportunity', because the money for using a sand motor for recreation will probably be more easily available. Of course, the local desirability of lagoons, a very wide beach or high dynamics will have to be taken into consideration in the design.
   - ✓ Areas with low recreational pressure qualify as a 'moderate opportunity'. The sand motor would largely contribute to new forms of extensive recreation and other amenity values there. The Decisio data shows that there are many places along the Holland coast that already offer a lot of space for extensive recreation.
3) An opportunity for a sand motor is only identified in areas where there are no harbours and no deep channels (Vlissingen and the area east of it are therefore excluded).

6.1.4 Criteria for determining opportunities for other functions

For the rest, as far as it has been possible to ascertain, there are few functions that are important enough financially to justify an expensive measure like a sand motor. The presence of harbours and harbour sea lanes also reduces the opportunities here, although the situation at the long, artificial beach of Maasvlakte 2 may be an exception to this (not further indicated on map, as it is too uncertain at the moment). Two types of functions have now been identified, namely mineral extraction and combating salinization through a permanent coastline expansion, supported by sand motors.

For mining, possible opportunities have been identified for gas extraction on Ameland-east and the tidal basin of the Pinkegat and Zoutkamperlaag and possibly for Vlieland-east in relation to (future) salt extraction. Because the volume needed annually to supplement the subsidence caused by this extraction (at least according to model calculations for extraction at Pinkegat and Zoutkamperlaag) is low in relation to the total nourishment volume in these eastern island areas, a ‘moderate opportunity’ is given for the time being.

The following criteria are applied for salinization:

1) There is a risk of salinization and there is an impervious clay bed at shallow depth, so that salinization can be completely stopped (Insert III).
2) If the previous conditions have been met and groundwater extraction plays a role, the area qualifies as a ‘moderate opportunity’. If this is not the case, a ‘good opportunity’ applies.

Finally, for all harbours and deep channels, no opportunities have been identified for safety by means of a sand motor. Vlieland-east is therefore excluded.

6.2 Conclusion and points of special interest per usage function

This section provides conclusions based on both the lessons learned and the requirement maps.

6.2.1 Coastal management and coastal protection

Applicable to places that have a high sand requirement

It is a matter of choosing between regular small sand nourishments, or a very large sand nourishment once in a while. Where there is a great need for sediment, a very large sand nourishment becomes an option (Figure 6.2). The Sand Motor concept ties in with coastal management as a possible instrument. For a number of places, such as Ameland, relatively large sand nourishments have already become so normal that the step to sand motor-type measures does not seem that great. The volume of sand would then have to ‘fit’ the current profile. If that is not the case, it will have to be determined whether it is possible to shift the profile drastically seaward. In the case of channels, this could cause problems due to anticipated rapid erosion.

Applicable for coastal areas on which there is sufficient knowledge

For the possible construction of a sand motor, it is important that there is sufficient knowledge about the long-term effects in order to thoroughly assess any possible risks. For coastlines with tidal inlets, island headlands and sandbanks, such as in the Delta area and the Wadden area, this is not yet the case. Research on this is provided in Kustgenese II. Parallel to this, the discussion about the need for sand motors from the perspective of policy and management nearby or in outer deltas may commence. For the coast of the Holland provinces and the straighter island sections there seems to be enough knowledge about the long-term effects and sand motors should already be possible now from that perspective.

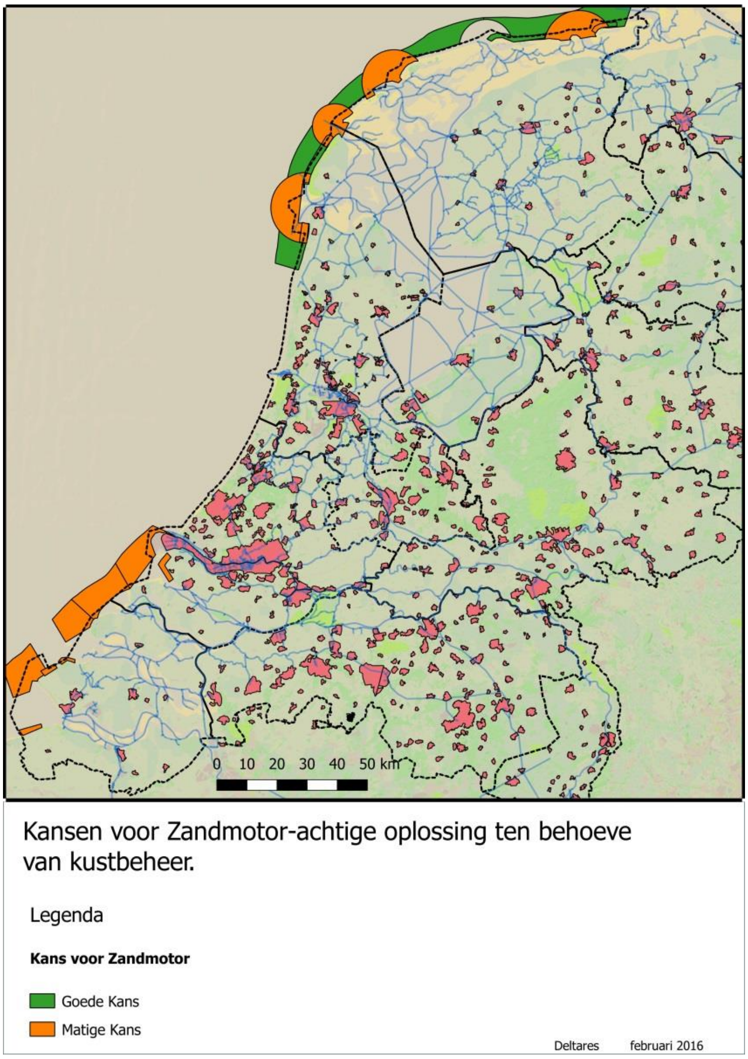


Figure 6.2 Opportunity map coastal management (for legend: see Appendix B)

Take the lifespan into consideration

The following generally applies: the larger the sand volume and the less dynamics occur in a sand motor, the more suitable it is for keeping the coastline in place and the longer the lifespan of a sand motor will be (Bruens, 2007). The lifespan and the sand price determine whether the construction of a sand motor-type solution is feasible in terms of costs for coastal management. In addition, possible advantages for other functions also play a role in the financial feasibility.

Design aspects

In the model studies that preceded the Sand Motor pilot, the expectation was expressed that a streamlined sand motor requires less coastal maintenance during the period following construction (Bruens et al, 2007, DHV and HNS, 2010; Insert I). The results of the Sand Motor (Taal, 2016) pilot cannot confirm this (yet). In addition, elongated coastal sand nourishment would probably increase the chances for embryonic dune formation, because there is more length over which this can occur (a strong stochastic process). In addition to the aforementioned studies based on the knowledge of 4 years of Sand Motor Delfland, it is recommended to find out to what extent there actually are significant differences between a streamlined large conventional sand nourishment and the non-streamlined Sand Motor pilot.

Take care when creating lagoons

Based on the experiences with the Sand Motor pilot and north-west Ameland, it is recommended not to design large lagoons on coasts without breakwaters, due to the safety risks. The formation of a sand spit may result in meandering channels being formed, which may damage the primary flood defence (like on Ameland, where this almost happened). The Sand Motor pilot shows that a lagoon and a dune lake trap a lot of sand, which delays the dune formation. This causes the sand to improve coastal protection at a slower pace.

6.2.2 Nature

Added value compared to existing dynamics

Possible sand motors, with vast beach plains, dune formation or lagoons, have to add something to the existing nature. On the Wadden islands and in the Delta area, however, many sand flats with dune formation, with or without lagoons, can be found and constructing sand motors for nature is not the obvious choice (Figure 6.2 and Figure 6.3). Creating vast beach plains is therefore a possible goal, particularly along the coast of North and South Holland. The reduced frequency of sand nourishment is also possibly more beneficial for the recovery of the benthic fauna.

Sand motors for vital nature and protection

Providing more space for the natural processes of sea, wind and sand stimulates the formation of vital nature through embryonic dunes, drifting foredunes, striated foredunes, parabolic and wandering foredunes, wash-overs and tidal creeks.

Tests are currently being carried out with dynamic coastal management on a relatively extensive scale. In a number of cases, extra sediment is transported from the beach to the hinterland. The safety of the primary flood defences must continue to be guaranteed. Sand motors, which are connected to the dune area behind it through the exchange of sand, offer the opportunity for restoring the dune nature, while at the same time the safety of the flood defences can be guaranteed. The design may depend on the more exact wishes for nature and other functions.

Lagoons and dune lakes

From the Sand Motor pilot it has become clear that the edges of a lagoon, in particular, represent an added value with respect to the diversity of species. These may, however, have an adverse impact on the formation of embryonic dunes.

Management aspects

To a large extent, management of the sand motor may also be a determining factor in the development of ecological values to a large degree. This is evident from the examples of the Sand Motor pilot. It is recommended to make this an integral part of the design process for future sand motors.

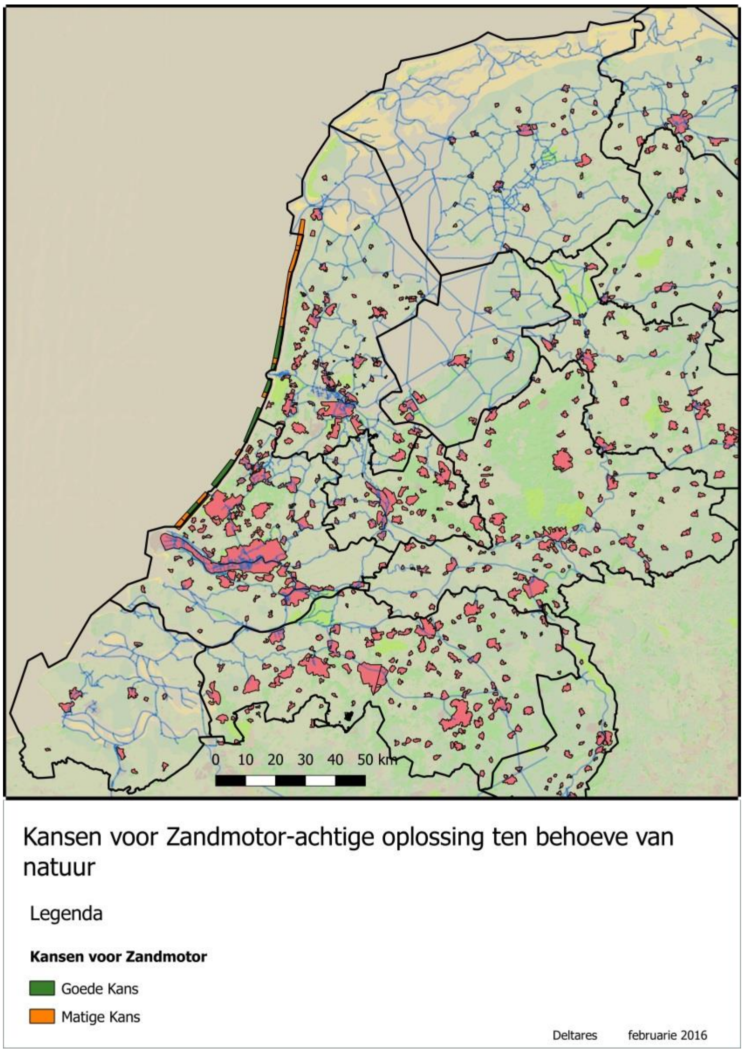


Figure 6.3 Opportunity map nature (for legend: see Appendix B)

6.2.3 Recreation

Added value?

Possible sand motors also have to bring added value to the existing recreational use. Dynamic and non-streamlined sand motors, like the Sand Motor Pilot, offer opportunities for more extensive recreation, in particular. Certainly, in the Wadden region and the Delta region, sand motor-type shapes already occur there naturally: construction of new sand motors does not make sense there. It appears that the coast of the provinces of North and South Holland, in particular, remains as a possibility for recreation (Figure 6.4).

Also determine the opportunities for intensive recreation

At coastal towns along the coast of the provinces of North and South Holland, with many seaside visitors and intensive beach use, there might be a need to be confronted with sand nourishment activities less frequently. In addition, strong dynamics probably would not be accepted, because they cause limitations and unpredictable behaviour. Under such preconditions, a sand motor-type solution would probably take the shape of a not too large, seaward, temporary beach expansion, which would probably take the form of a large sand nourishment. The reinforcement of the

Hondsbossche and Pettemer flood defence is a good example of how such an expansion can contribute to intensive seaside tourism. The province of North Holland is committed to assisting in the implementation of 21 projects that are intended to promote industry at the new beach. In addition, the municipalities of Bergen and Schagen, the Society for the Preservation of Nature, landscape foundation Landschap Noord-Holland and the province of North Holland have created a programme with 25 projects for redesigning the region.

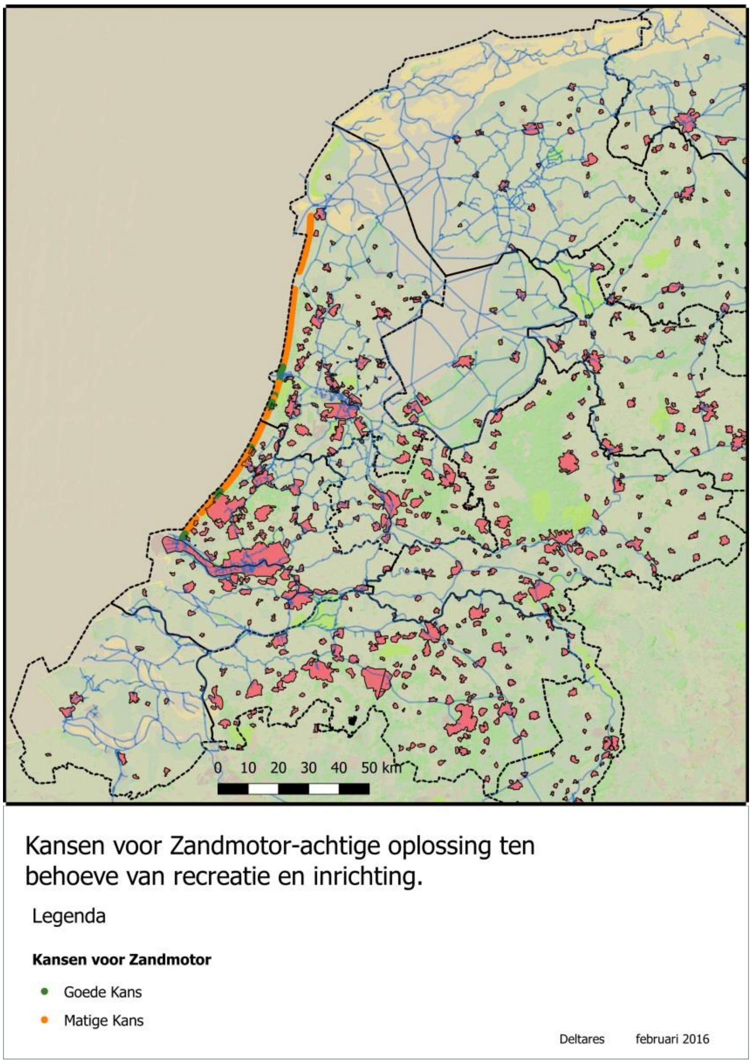


Figure 6.4 Opportunity map, recreation and layout (for legend: see Appendix B)

6.2.4 Other functions and values

As far as it can be ascertained, salinization and mining (partially due to the great financial interests involved) are the only other functions and values that sand motors could be used for in a meaningful way (Figure 6.5).

Salinization

Sand motors have proven to be of limited use for ‘other functions and values’. Expansion of the coast of North and South Holland and Zeeland possibly offers the opportunity to push the hinterland back. This can be constructed and maintained with sand motors. Where there is a clay bed at a shallow depth, the freshwater lens can be expanded to reach to the deeper clay beds and reduce the salt water intrusion in the underlying polder. The salinization in the delta area cannot be prevented like this everywhere, because of the high volume of salt water that surrounds the islands (Grevelingen, Oosterschelde and Westerschelde). This should be investigated further.

Minerals
Where minerals are being extracted on a large scale and a lot of sand has to be added, using sand motors may be a consideration. This pertains to east Vlieland, in relation to the possible salt extraction near Harlingen and east Ameland in relation to gas extraction on Ameland and in the back-barrier area.

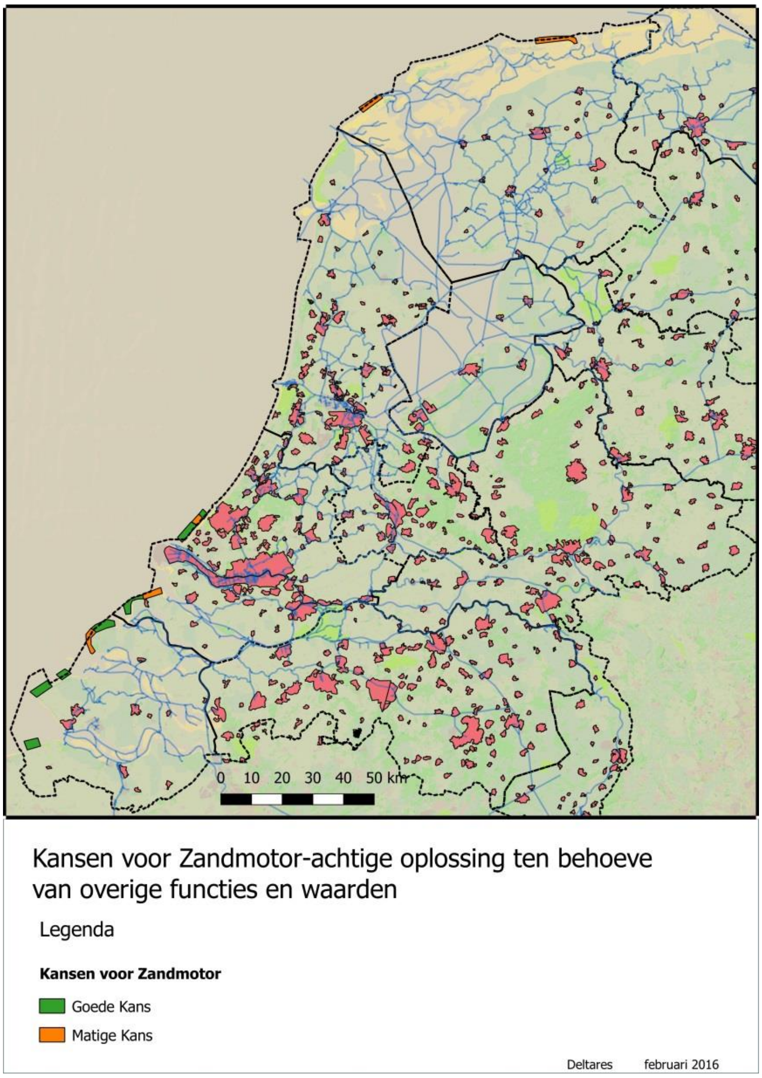


Figure 6.5 Opportunity map, other functions (for legend: see Appendix B)

6.3 General usability

If all the opportunities are added up together (without giving one particular function more weight than another and with exclusion of the deeper coastal zone and the outer deltas), it seems that the opportunities for sand motors lie particularly along the coast of the provinces of North and

South Holland (Figure 6.6). There are less opportunities along the Delta coast and the least opportunities are along the Wadden coast. The latter is the result of the assumption that it is not useful to construct sand motors along the coasts of the Delta and the Wadden for the sake of nature or recreation, as areas with beach plains already exist there.

As a longer lifespan (in terms of maintenance of the base coastline or the coastal foundation) or a lower sand price (considering the long-term developments) can be accomplished, sand motor solutions become more attractive for use in coastal management.

The strong need for sand on the Wadden and Delta coasts means that the greatest opportunities lie there related to coastal management. However, there are still unknown risks in the Delta region and near the tidal inlets of the Waddenzee. Knowledge about the long-term behaviour and the effect of sand motors in such areas is not yet adequate: there is a plan to research this in the Kustgenese II programme. Sand motors could be used already along the straight parts of the Wadden islands. The opportunities for sand motors related to coastal management are more limited along the coast of the provinces of North and South Holland, because the need for sediment is much lower there.

Where ecology is concerned, using sand motors seems to particularly offer opportunities in areas where there is a desire for ‘longer gradients transverse to the coast’. If co-financing is available for ecological goals (for example through the PAS monies) the possibilities and opportunities increase. Disturbance to the existing Natura2000 areas must be taken into account, however.

With respect to recreation, sand motors seem to particularly offer opportunities for busy coastal towns, in order to limit the sand nourishment frequency. Co-financing will probably also be easier there. The design for this should probably look similar to large, conventional coastal sand nourishment.

An expansion of the coast to combat salinization is possible along the Holland and Delta coasts (south of the Scheveningen harbour). Near east Ameland it is possible to use sand motors to nourish and to compensate for mineral extraction.

Figure 6.6 shows a combined overview of the opportunities. There are opportunities along the entire Dutch coast, but the best opportunities for a new sand motor, according to the figure, are along the North Holland coast and along the coast of Delfland, where the first Sand Motor was constructed.

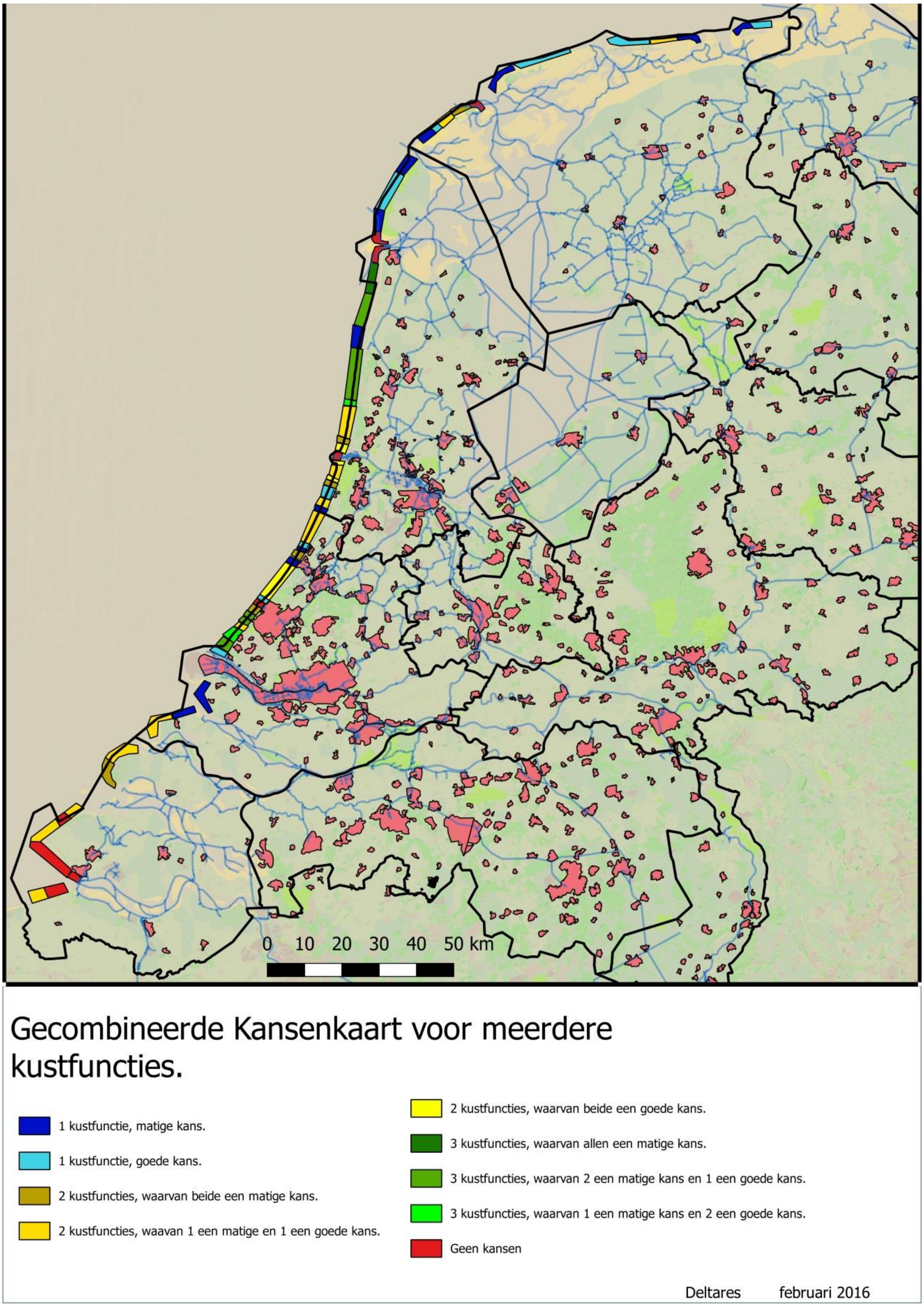


Figure 6.6 Combined opportunity map (for legend: see Appendix B)

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A Cost assessment

A1 Introduction

This cost assessment examines to what extent the Sand Motor pilot is cost effective. In other words: how will the comparison between regular coastal maintenance and the Sand Motor pilot work for different scenarios of: interest, price of sand and the maintenance needs and lifespan of the Sand Motor? In an earlier social cost-benefit analysis, as a starting point for the construction it was estimated that the Sand Motor pilot would be approximately twice as expensive as regular coastal maintenance (DHV, 2009). As we do not have an overview of the various benefits of the Sand Motor at our disposal at present, and we assume that regular maintenance and the Sand Motor (including maintenance sand nourishments) perform equally, the study is limited to a comparison of the alternatives based on an analysis of the costs by means of the cash flow in the time from the perspective of RWS, which are made transparent with a Life Cycle Costing (LCC) calculation (see also: de Weerdt, 2016).

A2 Points of departure and considered alternatives

Based on the meeting on 3 February 2016 in Lelystad, a number of alternatives were used for the LCC analysis of the Sand Motor. This included the following points:

1) The Water Act Project Plan Decree for the realisation of the Sand Motor pilot (Rijkswaterstaat, 2010) dated 21 September 2010. The prevailing insights at the time were that 0.5 Mm^3/year would be required for maintaining the base coastline and 1.1 Mm^3/year for maintaining the coastal foundation, the latter stating losses related to Eurogeul. These points of department were also used in the social cost-benefits analysis. It should therefore be recommended to use an LCC to analyse whether the construction at the time, at the sand prices (price level 2011) applicable at the time, was a good idea for the regular coastal maintenance and the price.

2) In the meantime, the Ministry of Infrastructure and the Environment has successfully implemented a new innovation since 2012 whereby the sand nourishments for the regular coastal maintenance will be contracted out for the long term and the cubic metre price will be brought down. The experience period is perhaps short and it is conceivable that the cubic metre price will go up again in the long term due to the global economic developments, but it is clear that a substantially lower sand price will apply on average. It is therefore also important to consider this new reality within the scope of the Usability Study. To gain a nationwide impression, the average new cubic metre price could be compared to the construction of the Sand Motor. This gives an initial indication of how favourable a Sand Motor would be with respect to the current coastline maintenance. The marginal note is that based on economies of scale it should be possible to construct a Sand Motor for less than it would cost when contracted out long term (see further under point 4).

3) Furthermore, it is now common practice that all losses related to Scheveningen harbour and Eurogeul are returned to the relevant stretch of coast between Scheveningen and the Hook of Holland with the Coastal Foundation (pers. info. Lodder). Any losses resulting from that can be excluded. The required maintenance of the base coastline is still estimated at 0.5 Mm^3/year; maintenance on the coastal foundation is, however, estimated at 0.3 Mm^3/year.

4) Bearing in mind the possibility to tie in as much as possible with Echoshape's business case approach, the break-even point for the assumptions given for each of the alternatives in indicated; in other others, the values for lifespan and costs whereby a mega-nourishment is economically feasible in comparison with an LCC.

General points of departure

- Discount rate for the LCC analysis: 2.5 % or 3 %[2];
- Price level 2011;
- All prices are exclusive of VAT;
- All nourishments are net cubic metres (in situ);
- Regular nourishments with a ratio of 50/50 for foreshore and beach nourishments for point 1 and 70/30 (national trend) for point 2 (see above);
- Maintenance nourishments for the Sand Motor at 'regular' nourishment prices;
- Average inflation period 2011-2014 = 2% (in accordance with statline/cbs.nl);
- Harbour and Eurogeul losses will be reimbursed in full in the relevant coastal foundation stretch for point 2

Sand Motor

- Nourishment volume 18.7 million m^3 in situ;
- Additional maintenance first 20 years 4.45 million m^3 in situ;
- Construction price € 51,300,000 (excl. VAT, 2011).

Alternative 1

- Sand requirement for regular nourishments 0.5 Mm^3 (base coastline, Sand Motor lifespan 40 years) and 1.1 Mm^3 (coastal foundation + base coastline, Sand Motor lifespan 20 years) per annum in accordance with initial project plan. Nourishments will be placed once every 5 years. First nourishment in year 0;
- Discount rate 2.5 %;
- Sand Motor lifespan 20 or 40 years;
- Regular nourishment price € 6.5 ((4.5+8.5)/2 = € 6.5/m^3), price level 2011 excluding VAT per m^3 in situ.

Alternative 2

- Sand requirement for regular nourishments 0.5 Mm^3 per annum in accordance with current insights regarding nourishments required for base coastline maintenance. Nourishments will be placed once every 5 years. First nourishment in year 0.
- Discount rate 3 %
- Sand Motor lifespan 40 for base coastline
- Regular nourishment price € 3.52 (excl. VAT, 2011) per m^3 in situ. Price for regular nourishments based on OBR 2014, prices discounted to 2011. Foreshore/beach nourishment ratio 70/30 'Balance nourishments' during first 20 years of total 4.45 Mm^3 (model study average of 3.3 – 5.6 Mm^3 over 20 years).

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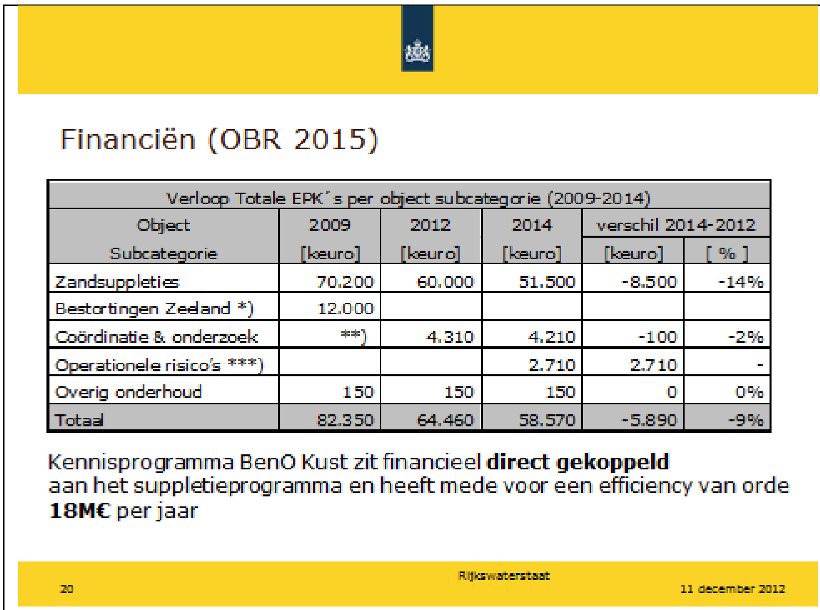
[2] With effect from 1 April 2016, the prescribed discount rate for LCC calculations has been adjusted from 2.5% to 3% (see also www.rws.nl/see). For the sake of comparability, it was decided to use a discount rate of 2.5% for the original situation (Alternative 1) , while the new discount rate of 3% was used for the future situation (Alternative 2).



Financiën (OBR 2015)

Verloop Totale EPK´s per object subcategorie (2009-2014)					
Object Subcategorie	2009 [keuro]	2012 [keuro]	2014 [keuro]	verschil 2014-2012 [keuro]	[%]
Zandsuppleties	70.200	60.000	51.500	-8.500	-14%
Bestortingen Zeeland *)	12.000				
Coördinatie & onderzoek	**)	4.310	4.210	-100	-2%
Operationele risico's ***)			2.710	2.710	-
Overig onderhoud	150	150	150	0	0%
Totaal	82.350	64.460	58.570	-5.890	-9%

Kennisprogramma BenO Kust zit financieel **direct gekoppeld** aan het suppletieprogramma en heeft mede voor een efficiency van orde **18M€** per jaar

20 Rijkswaterstaat 11 december 2012

- *70% foreshore cubic metres = 0.7 x 12 = 8.4 Mm^3*
- *30% beach cubic metres = 0.3 x 12 = 3.6 Mm^3*
- *Average cubic metre price = € 4.5 (incl. VAT, 2014) = € 3.52 m^3 (excl. VAT, 2011)*
- *BenO Coast Knowledge Programme is financially* ***directly linked*** *to the nourishment programme and also has € 18 million designed for efficiency per annum.*

A3 Results

A3.1 General

The calculations in table A.1 show that the construction of the Sand Motor pilot project in alternative 1, with the original Sand Motor points of departure, is substantially cheaper than the points of departure for the regular coastline maintenance. Points of departure here are the 20 year lifespan of the Sand Motor for a nourishment requirement of 1.1. Mm^3 or 0.5 Mm^3 per annum and a sand price of € 6.5/m^3 for the regular nourishments and € 2.74/m^3 for the Sand Motor (total investment of € 51.3 million), see Table A1 for more details.

Table A.1 Cash Value of Alternative 1 LCC calculations

Interest 2.5%				
Description	**Cash flow**	**LCC (CW)**	**Maintenance**	**Investment**
Sand requirement 1.1 Mm^3/yr (20 yr at € 6.5/m^3)	143,000,000	119,959,777	84,209,777	35,750,000
Sand requirement 0.5 Mm^3/yr (40 yr at € 6.5/m^3)	130,000,000	87,803,520	71,553,520	16,250,000
Sand motor (51.3 M€ at € 2.74/6.5/m^3)	80,225,000	74,011,122	22,711,122	51,300,000

The calculation shows that the Sand Motor is efficient both when the performance can be compared with the nourishment requirement of 1.1. Mm^3 (20-year lifespan) and a nourishment requirement of 0.5 Mm^3 (40-year lifespan). With a lifespan of 20 years and a nourishment requirement of 1.1 Mm^3 the LCC is € 120 million and with a nourishment requirement of 0.5 Mm^3 the LCC is € 88 million against an LCC of the Sand Motor of € 74 million. It follows from this that under the original points of departure of the pilot, the Sand Motor has much lower LCC. Under the prevailing insights at the time, the Sand Motor was a very good idea financially.

As a second alternative, it was examined whether it would still be an advantage to construct a sand motor under the current prices. The points of department described earlier were included to this end.

Table A.2 Cash Value of Alternative 2 LCC calculations

Interest 3%				
Description	Cash flow	LCC (CW)	Maintenance	Investment
Sand requirement 0.5 Mm^3/yr (40 yr at € $3.52/m^3$)	70,400,000	44,415,502	35,615,502	8,800,000
Sand motor (51.3 M€ at €$2.74/3.52/m^3$)	66,964,000	63,040,506	11,740,506	51,300,000

Table A.2 shows that when the current prices for regular nourishments are compared with the original costs of the Sand Motor, this has a higher LCC than regular nourishments, € 44 million and € 63 million respectively.

A3.1 Sensitivity analysis

In the sensitivity analysis, a number of points of departure significantly changed to gain insight into the LCC costs of the different alternatives upon changes in the points of departure. As costs for nourishments can vary considerably (see Figure A.1) the sensitivity analysis will place the emphasis on these price fluctuations and examine the consequences of changes in the cost price for mega-nourishments and regular nourishments.

Figure A.1 Sand nourishment activities price developments (price level 2014, from Oers and Jagernath, 2015)

Impact of applied cost price

With a cost price of the Sand Motor of € 2.74 per m^3 (€ 51.3 million investment) a one-off nourishment only works out cheaper when the expectation for future regular nourishments costs at least € 5.55 per m^3 (with a 40-year lifespan of the Sand Motor with additional nourishments). When the current cost price for sand of € 3.52 per m^3 is applied for regular nourishments, the sand price for a mega-nourishment should drop to at least € 1.74 per m^3 before a Sand Motor works out cheaper than regular nourishments.

Table A.3 LCC costs of alternatives and Sand Motor for different sand prices

Interest 2.5%				
Description	**Cash flow**	**LCC (CW)**	**Maintenance**	**Investment**
Sand requirement 0.5 Mm^3/yr (40 yr at € 5.2/m^3)	104,000,000	70,242,816	57,242,816	13,000,000
Sand motor (51.3 M€, 40 yr at € 2.74/5.2/m^3)	74,440,000	69,468,897	18,168,897	51,300,000
Sand motor (51.3 M€ at € 1.88/3.52/m^3)	50,820,000	47,454,946	12,298,946	35,156,000
Sand requirement 0.5 Mm^3/yr (40 yr at € 3.52/m^3)	70,400,000	47,548,983	38,748,983	8,800,000

A4 Discussion

Based on the insights at the time and the points of departure applied, the Sand Motor pilot was a good idea financially, because the realisation of a one-off mega-nourishment was significantly cheaper than the anticipated regular coastal maintenance. In light of the new current practice of multi-year outsourcing, and the current price for regular nourishments, it appears that a mega-nourishment is not feasible unless a significantly lower sand price can be obtained for a mega-nourishment than the prevailing nourishment price, or the long term expectation for regular nourishments are assumed to be higher than the current costs under the present economic climate.

As the preliminary design studies show, a sand motor-type solution performs differently depending on its sand volume, design and location. Model studies can therefore be applied to estimate the performance and lifespan of different types of sand motors. Based on the performance, an LCC analysis can be applied to calculate at which sand price a specific type of Sand Motor proves to be a more favourable alternative than regular coastal maintenance for the coastal foundation or base coastline only. This provides an assessment framework, which can be applied for comparing intervention planning (regular or mega-nourishment) based on performance and sand price. When sand prices are low, a decision may possibly be taken to construction a sand motor-type solution. According to the abovementioned study, this could deliver substantial cost savings on coastal protection and preservation of the coastal foundation for the RWS. To be able to develop this assessment framework requires more knowledge of the costs and estimated performance for coastal maintenance of different mega-nourishment design alternatives, as well as the performance of other functions (recreation, safety, building along the coast, etc.).

It can be concluded that sand motor-type alternatives for coastal maintenance are instruments of opportunity: the instrument can be deployed at the time that sand is available at extremely low costs (work with work; DHV, 2009), or the sand price is very low in relation to the anticipated long-term (decades) average. In order to be able to use these opportunities successfully, (dormant) plans for sand motor-type solutions will have to be readily available, and attention will also have to be devoted to the lifespan and possible performance for other functions.

A5 Conclusion

A sand motor is an “instrument of opportunity” for coastal management. A sand motor can be successfully deployed if a low sand price can be obtained in relation to the expected long-term average and if it is designed such that it delivers a performance comparable to regular nourishments, whereby a sand motor performance is potentially of benefit (in monetary terms) to other functions.

A6 References

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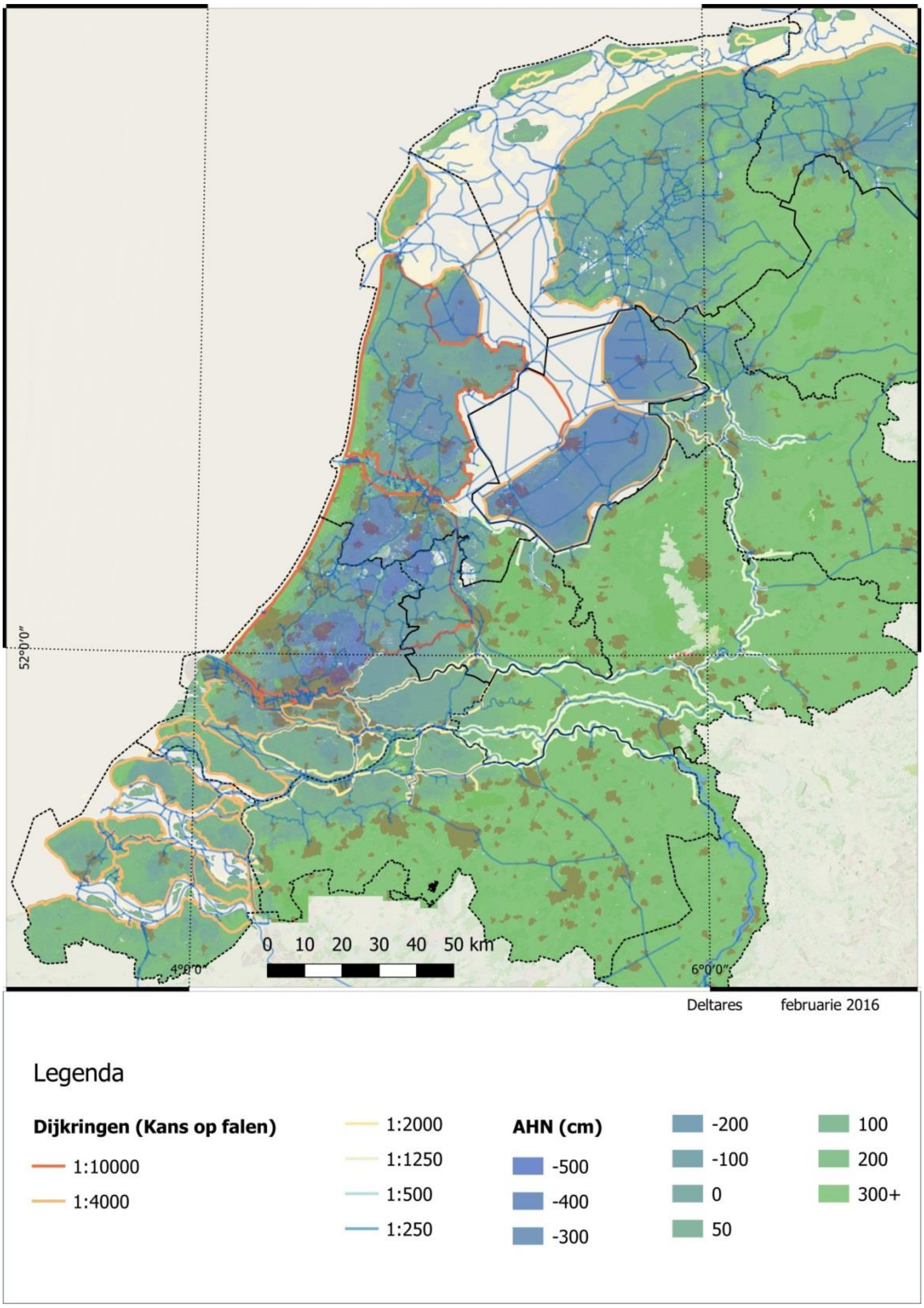
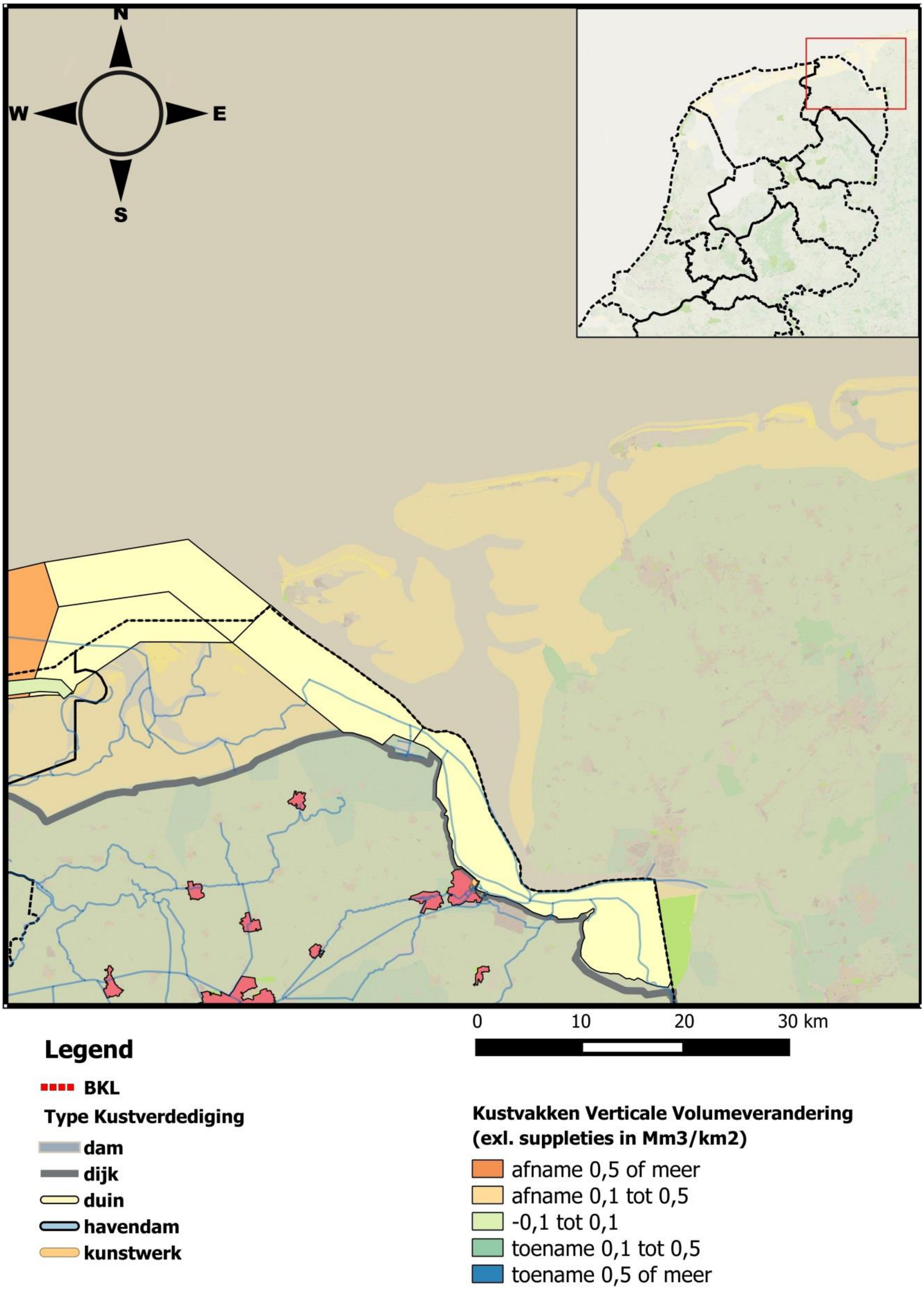
Translations of legends in Appendices B, C en D

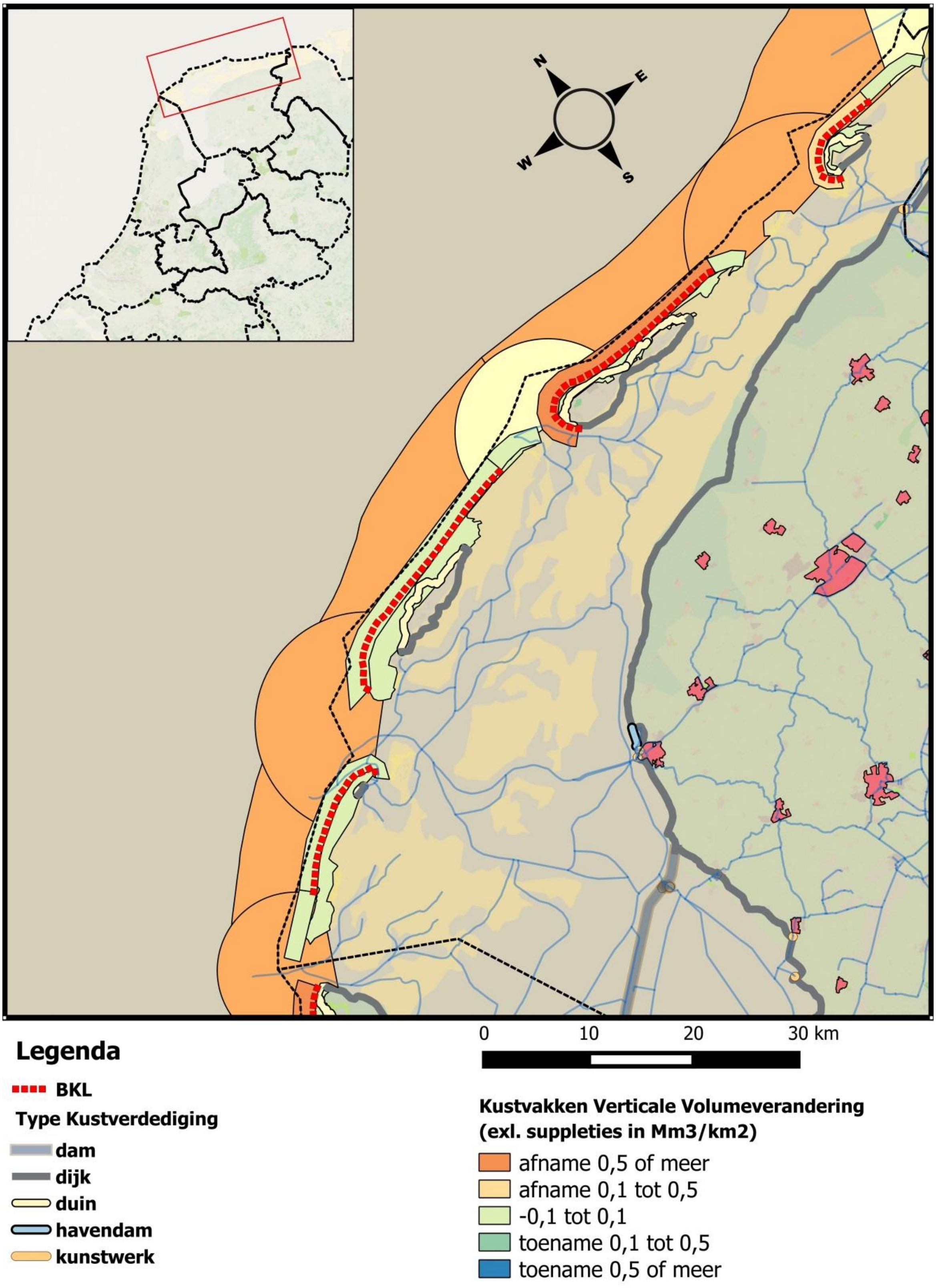
Nederlands	Engels
Legenda	Legend
Dijkringen (kans op falen)	Dyked area (probability of failure)
Project locaties	Project locations
Nieuwe kustkaart	New coastal chart
Groen	Green
Natuur	Nature
Dynamische kustbeheer	Dynamic coastal management
Natuurlijke processen op landschapsschaal	Natural processes at landscape scale
Natuurlijke processen als methode	Natural processes as method
Kleinschalige inzet van afgeleide natuurlijke dynamiek en half-natuurlijke beheer	Small-scale deployment of derived natural dynamics and semi-natural management
Bedrijventerrein	Industrial estates
Detailhandel	Retail
Gemengd: stedelijk	Mixed: urban
Glastuinbouw	Horticulture
Kantoor	Offices
Nutsvoorziening	Utilities
Recreatie	Recreation
Sport	Sport
Verblijfsrecreatie	Recreational accommodation
Verkeer: spoor	Traffic: rail
Verkeer: weg	Traffic: road
Wonen	Residential
Water	Water
Waterberging	Water storage
Onontwikkelde gasvelden	Undeveloped gas fields

B Existing usage function maps

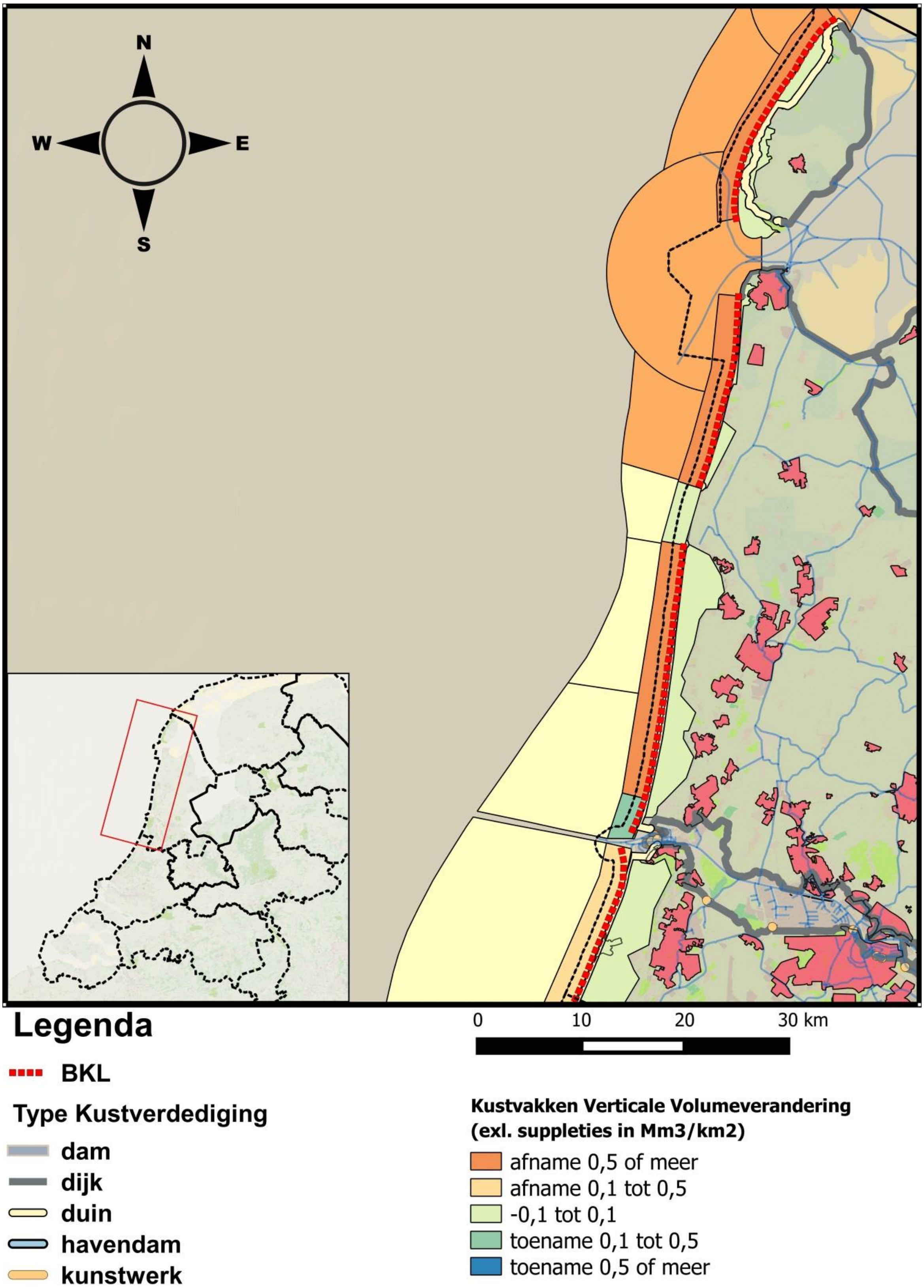




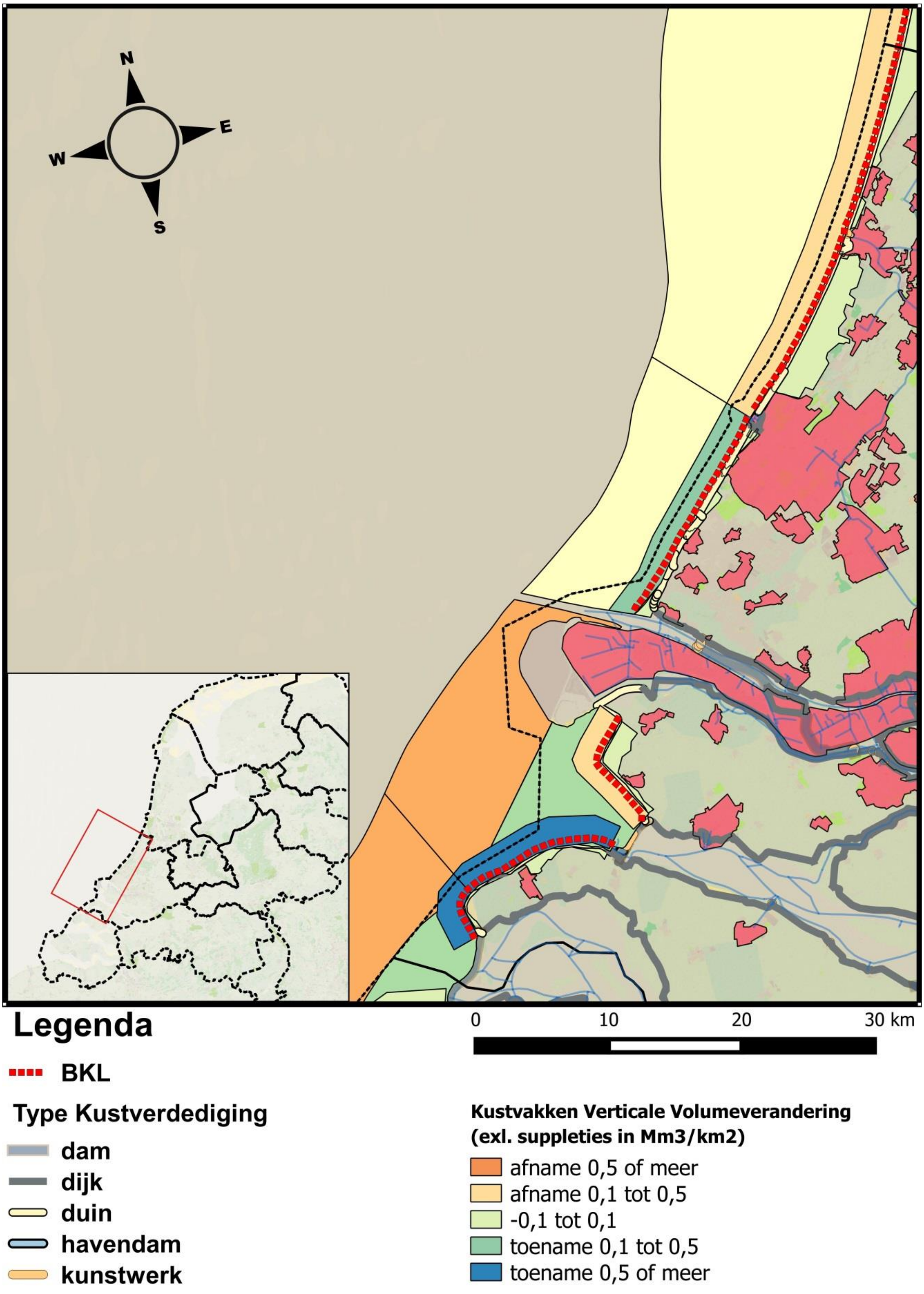
Groningen Safety



Friesland Safety



North Holland Safety



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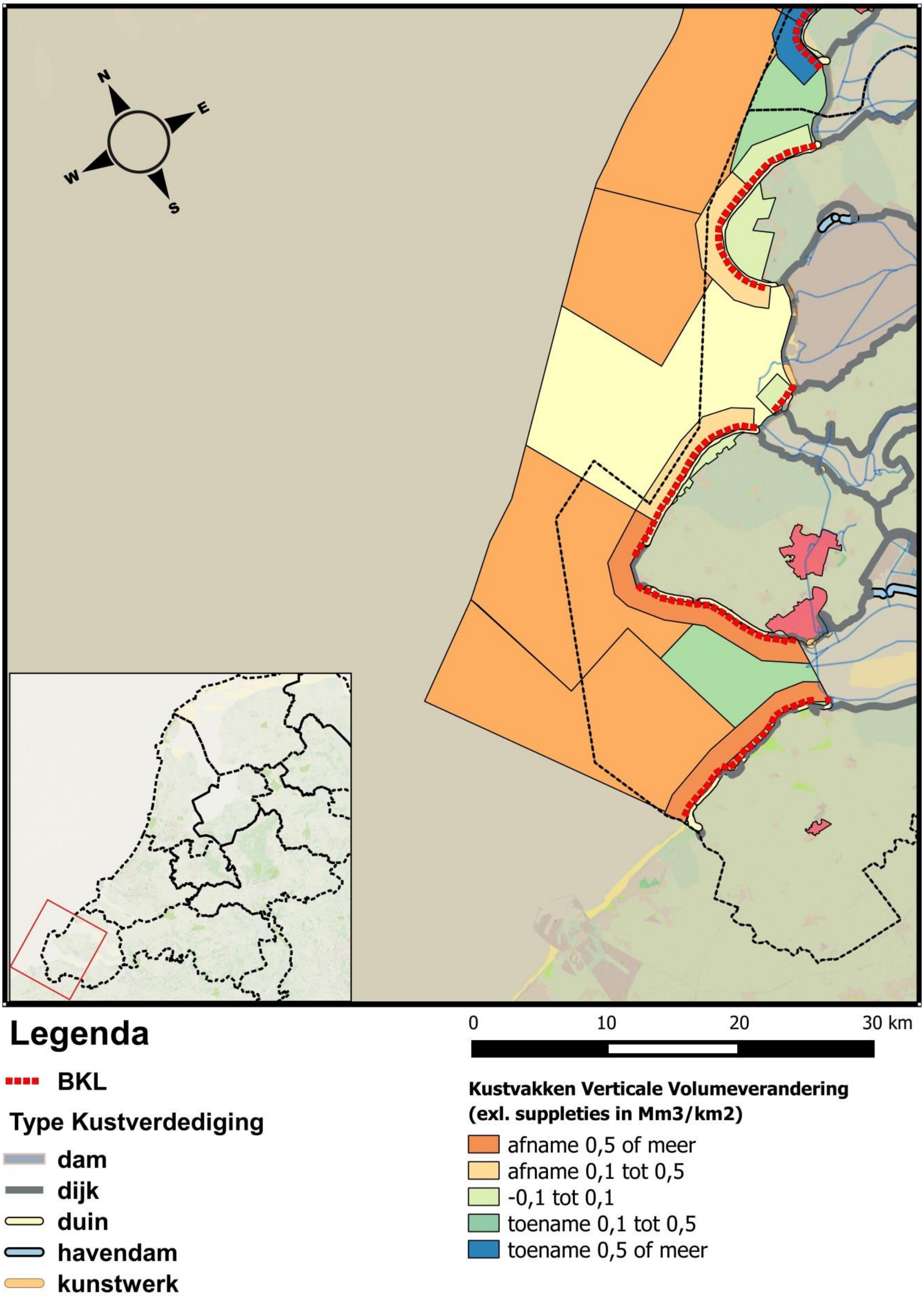
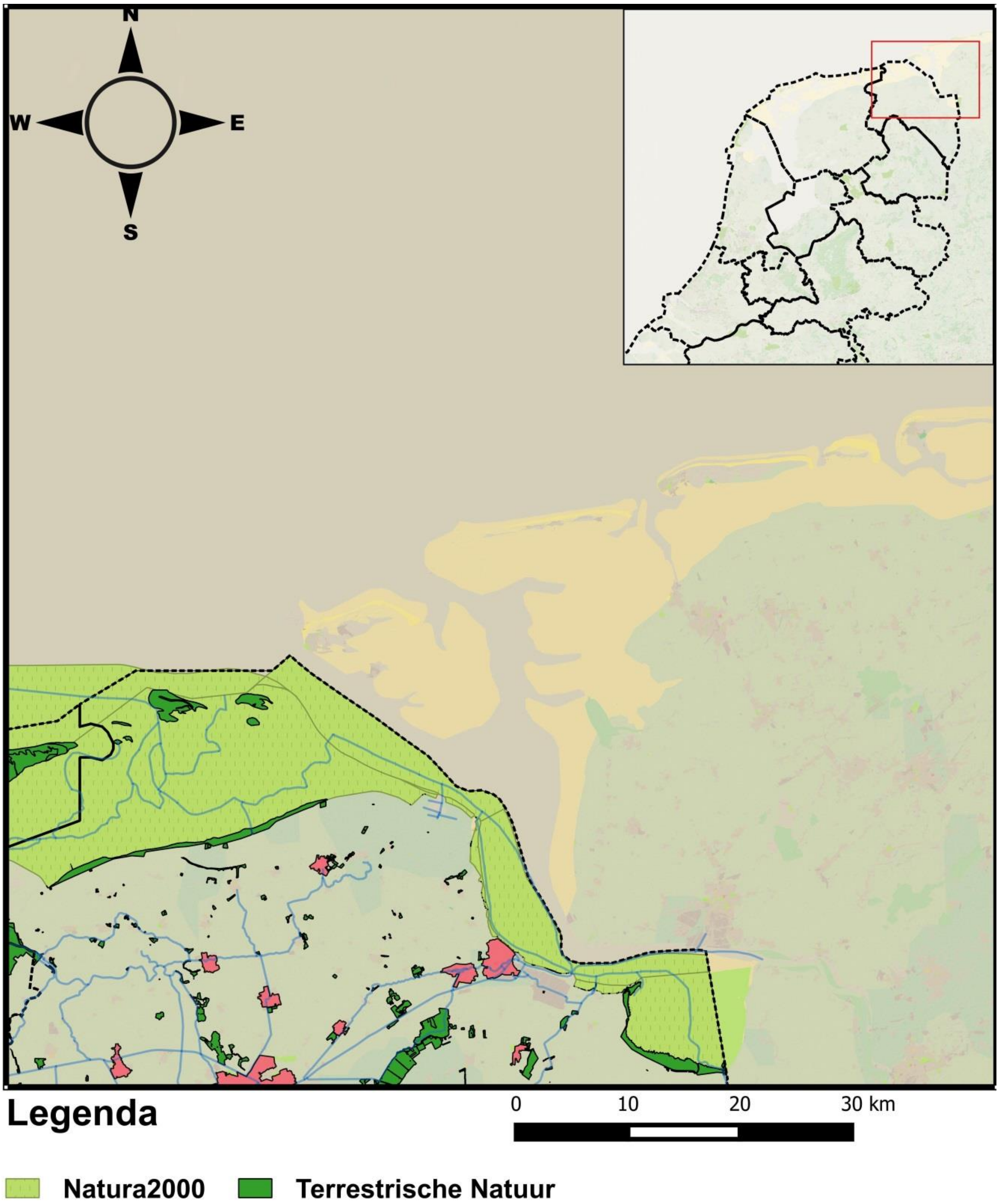
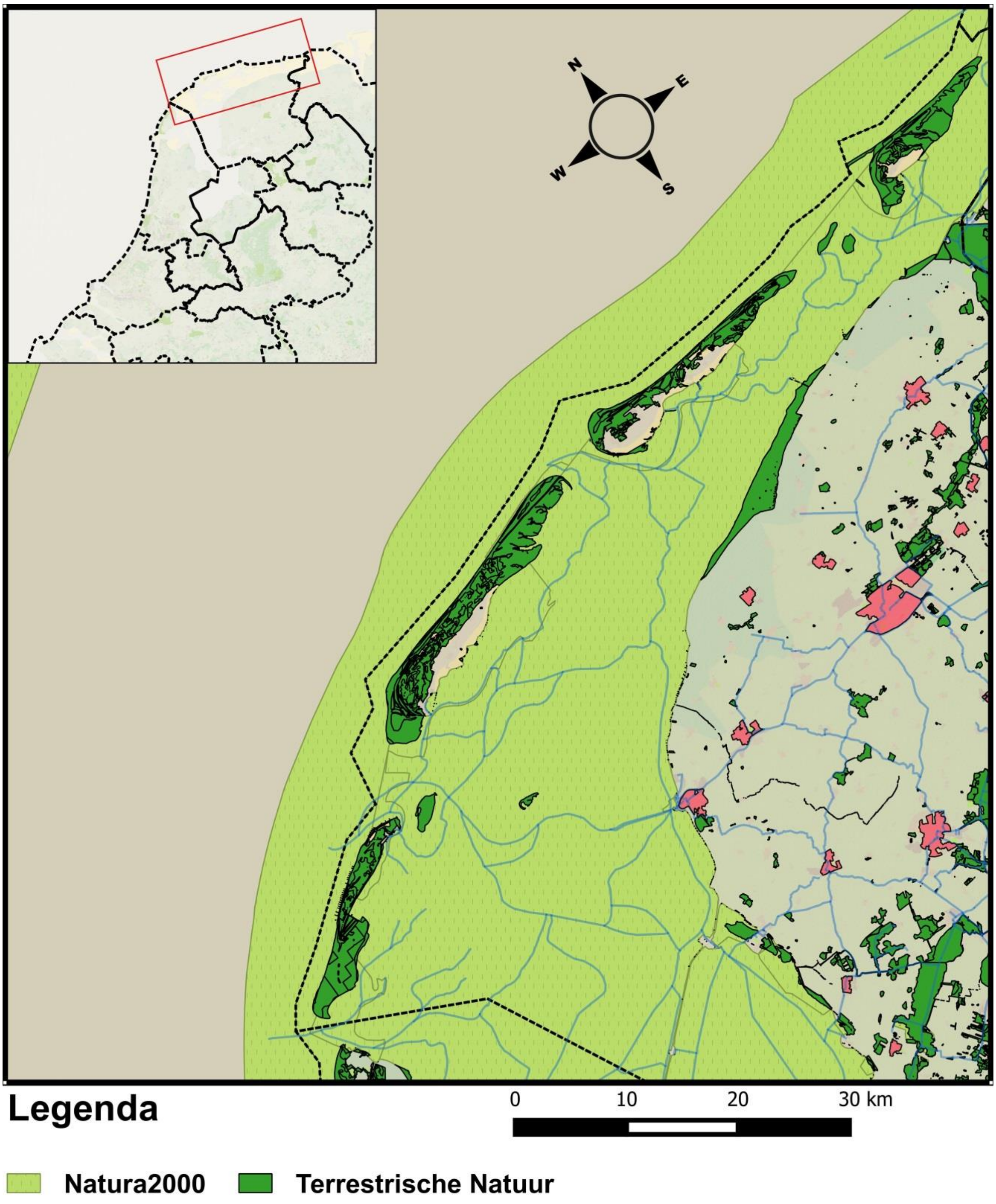


Zeeland Safety



Groningen Nature



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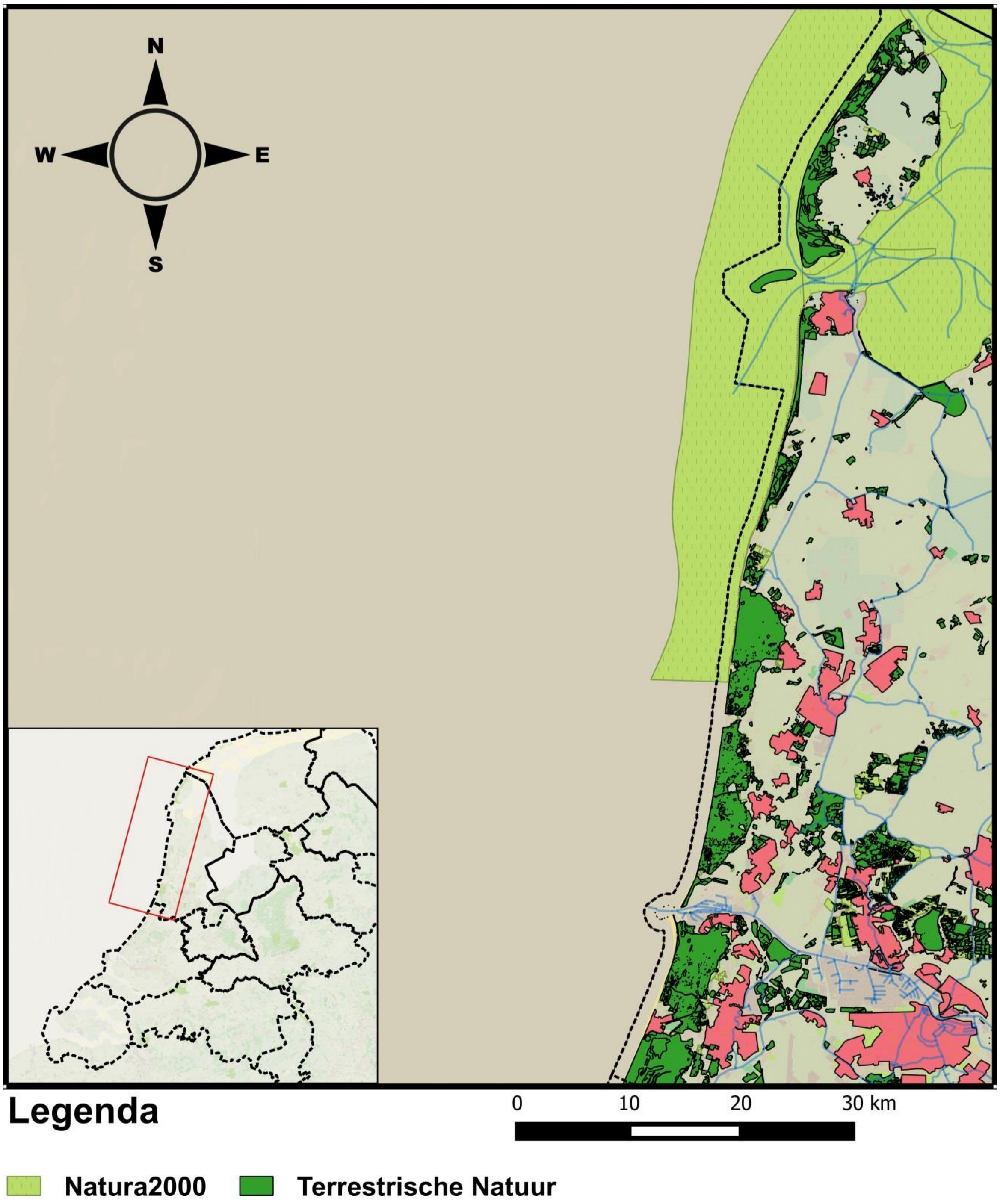

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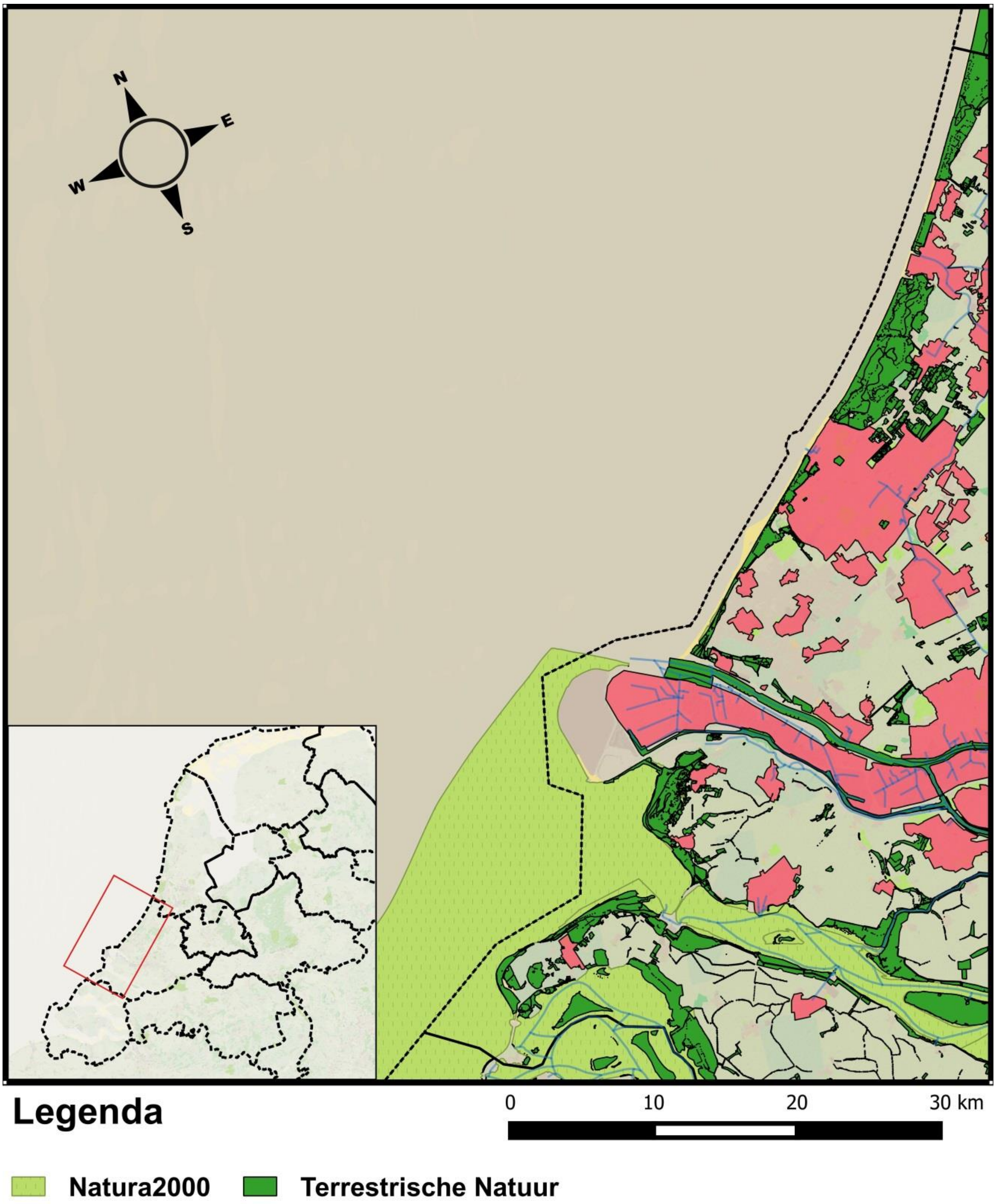

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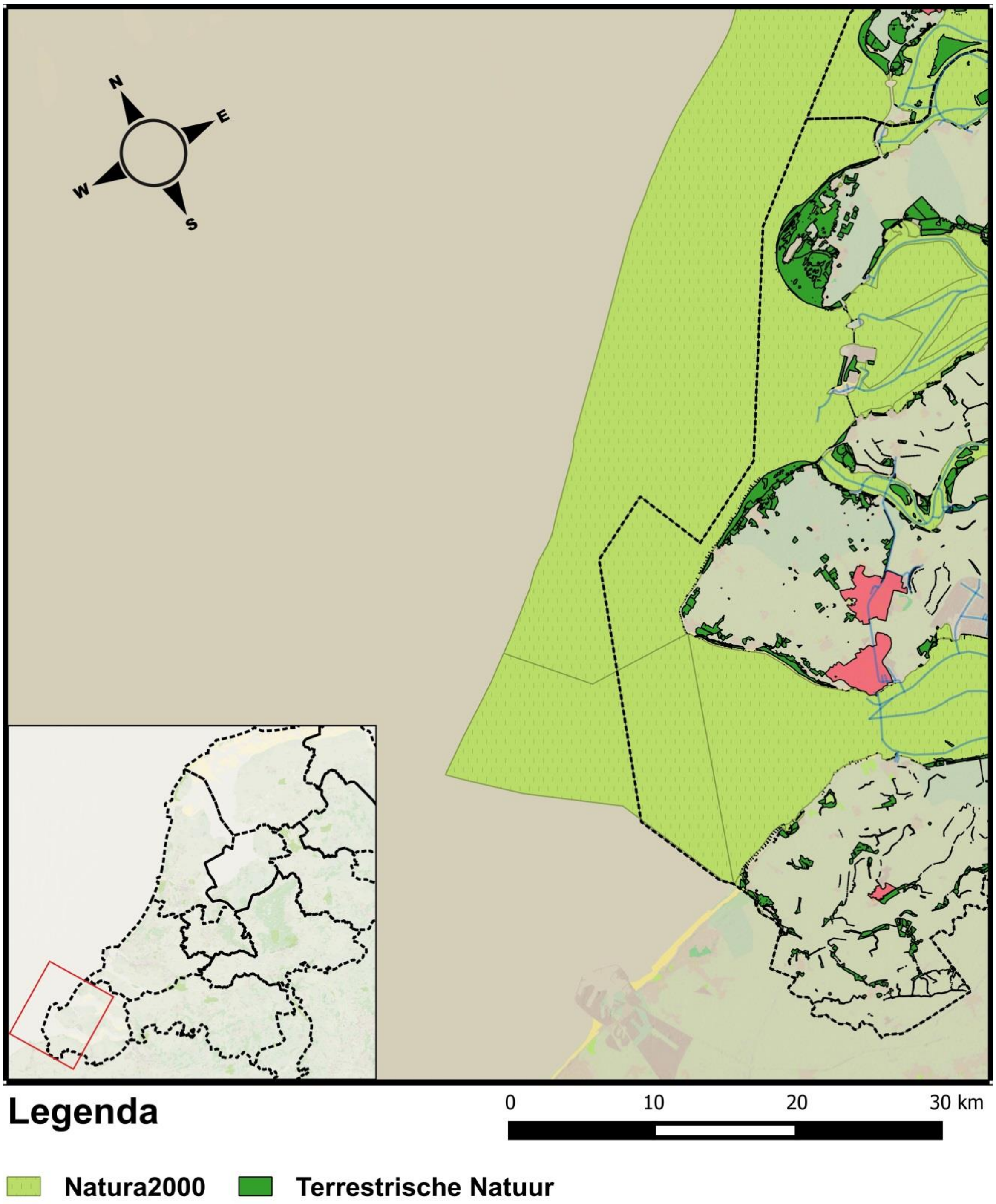
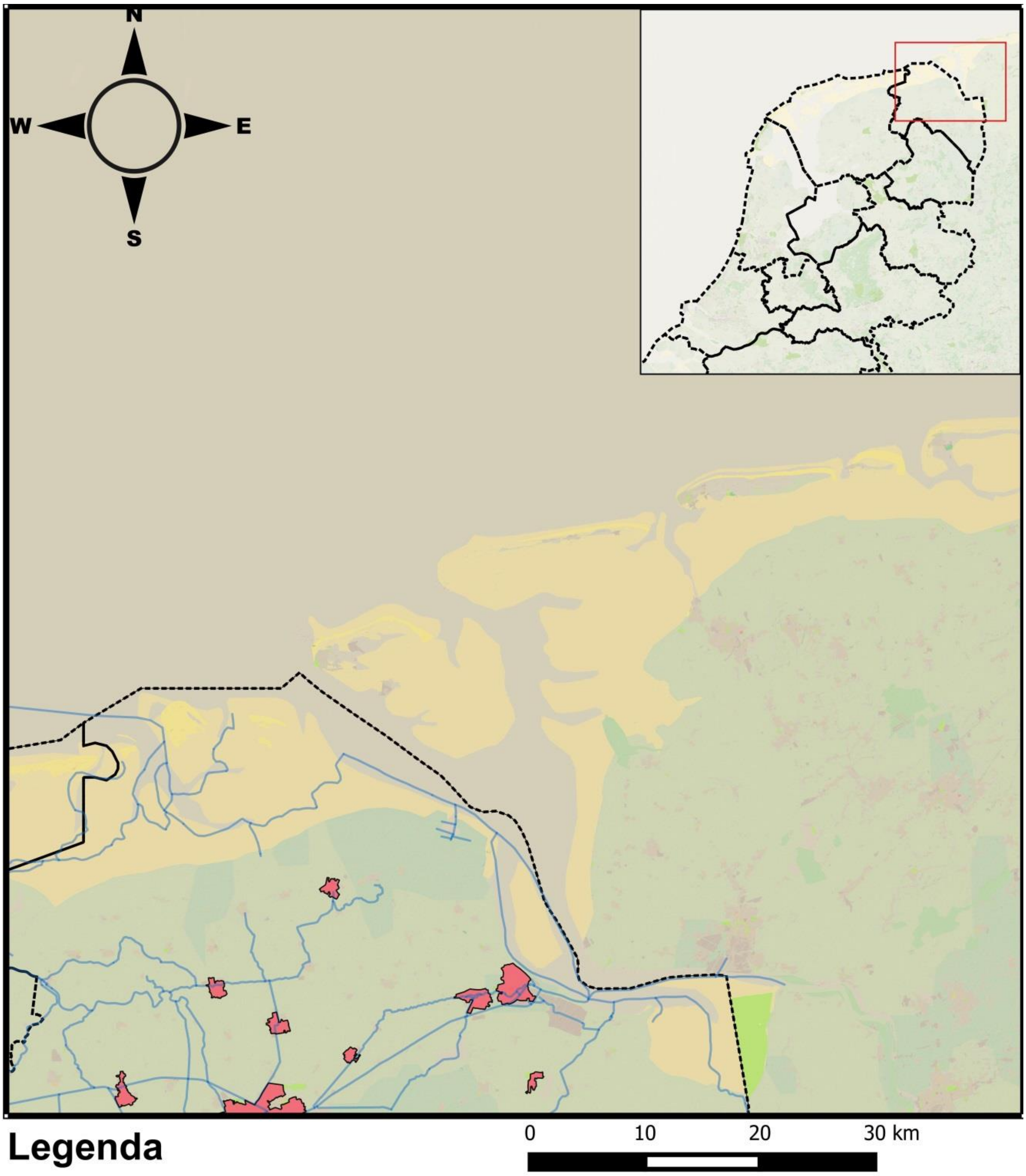


Zeeland Nature



Legenda

Recreatie Druk

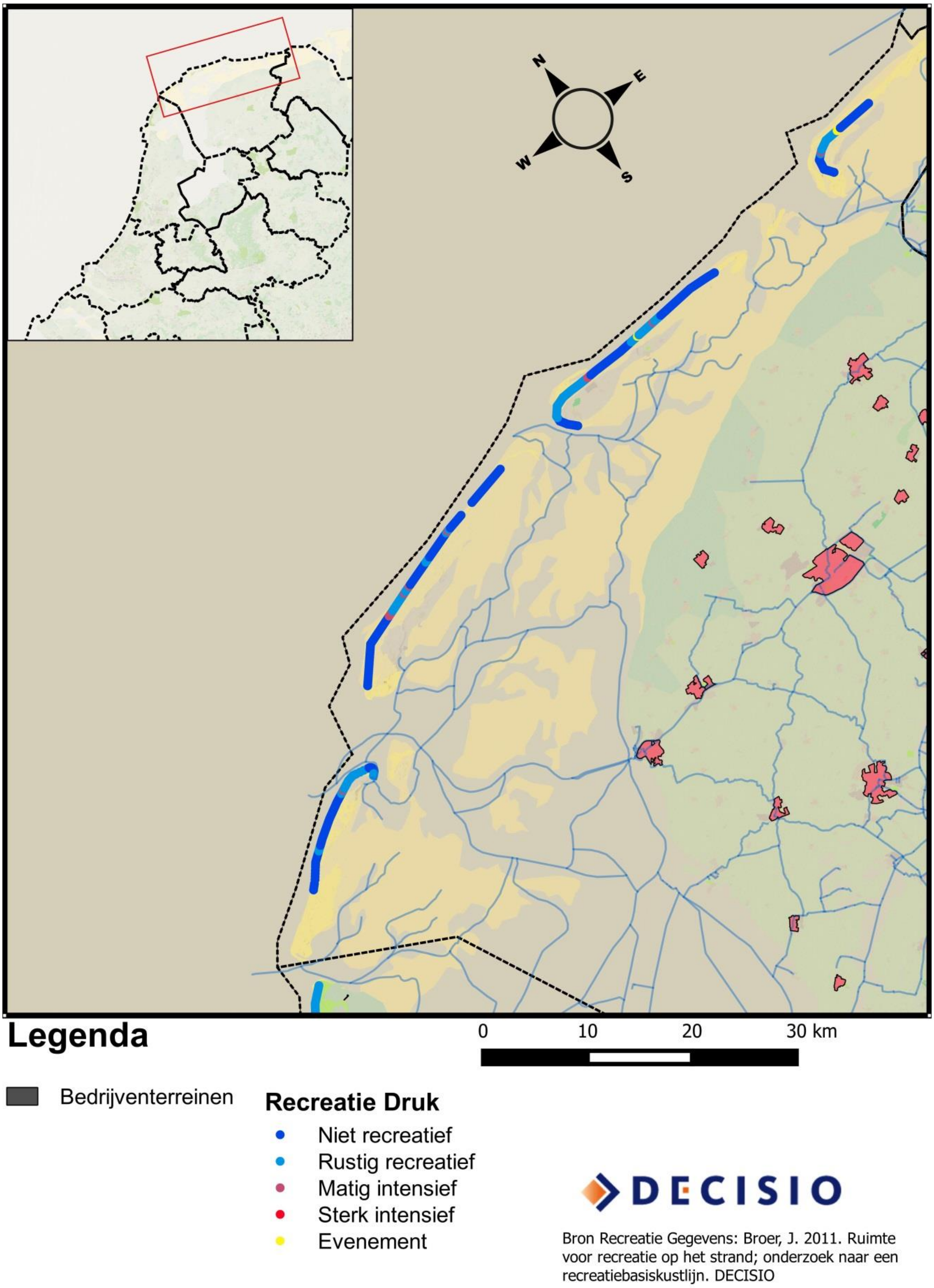
- Niet recreatief
- Rustig recreatief
- Matig intensief
- Sterk intensief
- Evenement

DECISIO

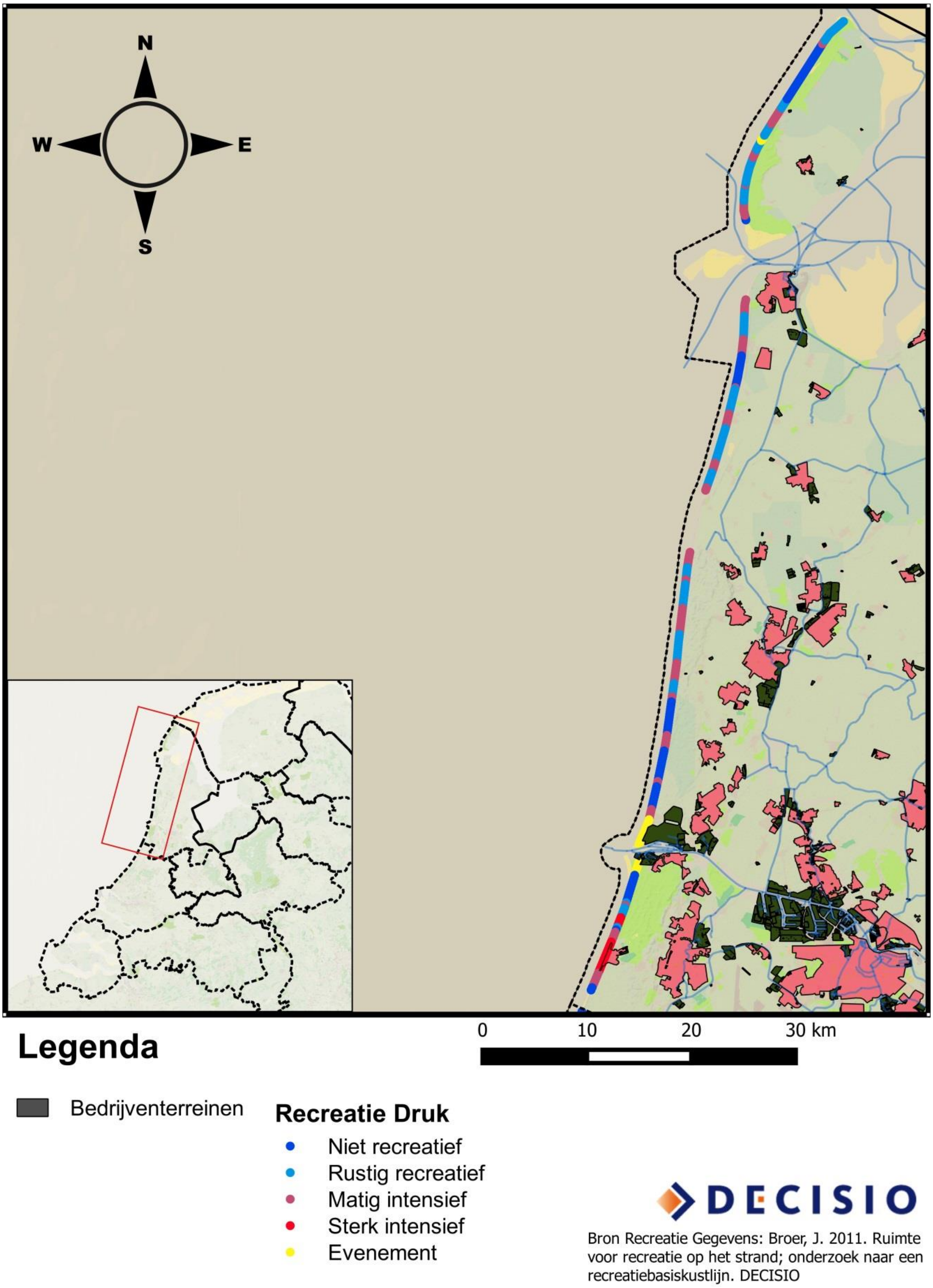
Bron Recreatie Gegevens: Broer, J. 2011. Ruimte voor recreatie op het strand; onderzoek naar een recreatiebasiskustlijn. DECISIO

Geen recreatie data beschikbaar voor Groningen.

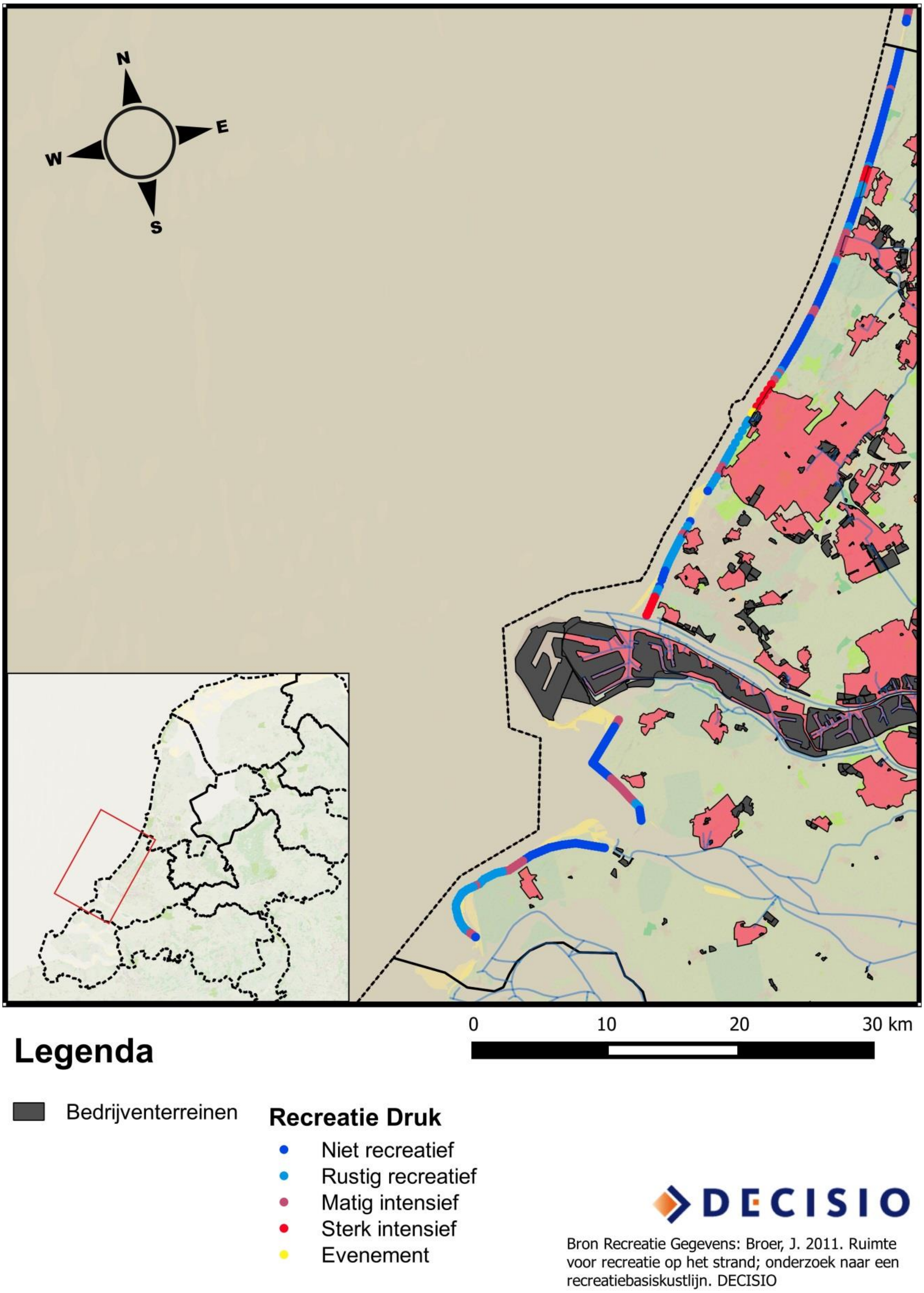
Groningen Recreation



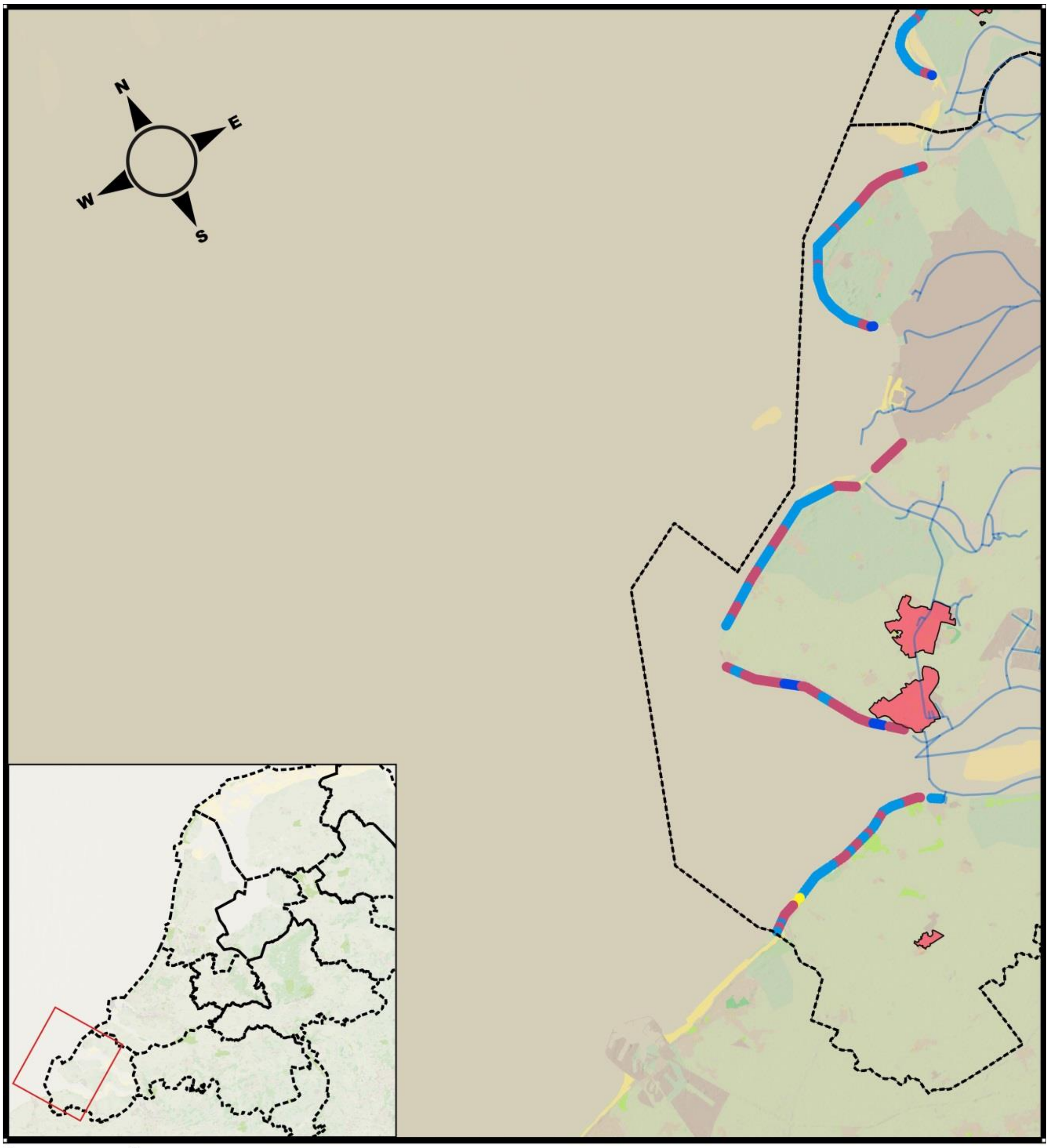
Friesland Recreation



North Holland Recreation



South Holland Recreation



Legenda

0 10 20 30 km

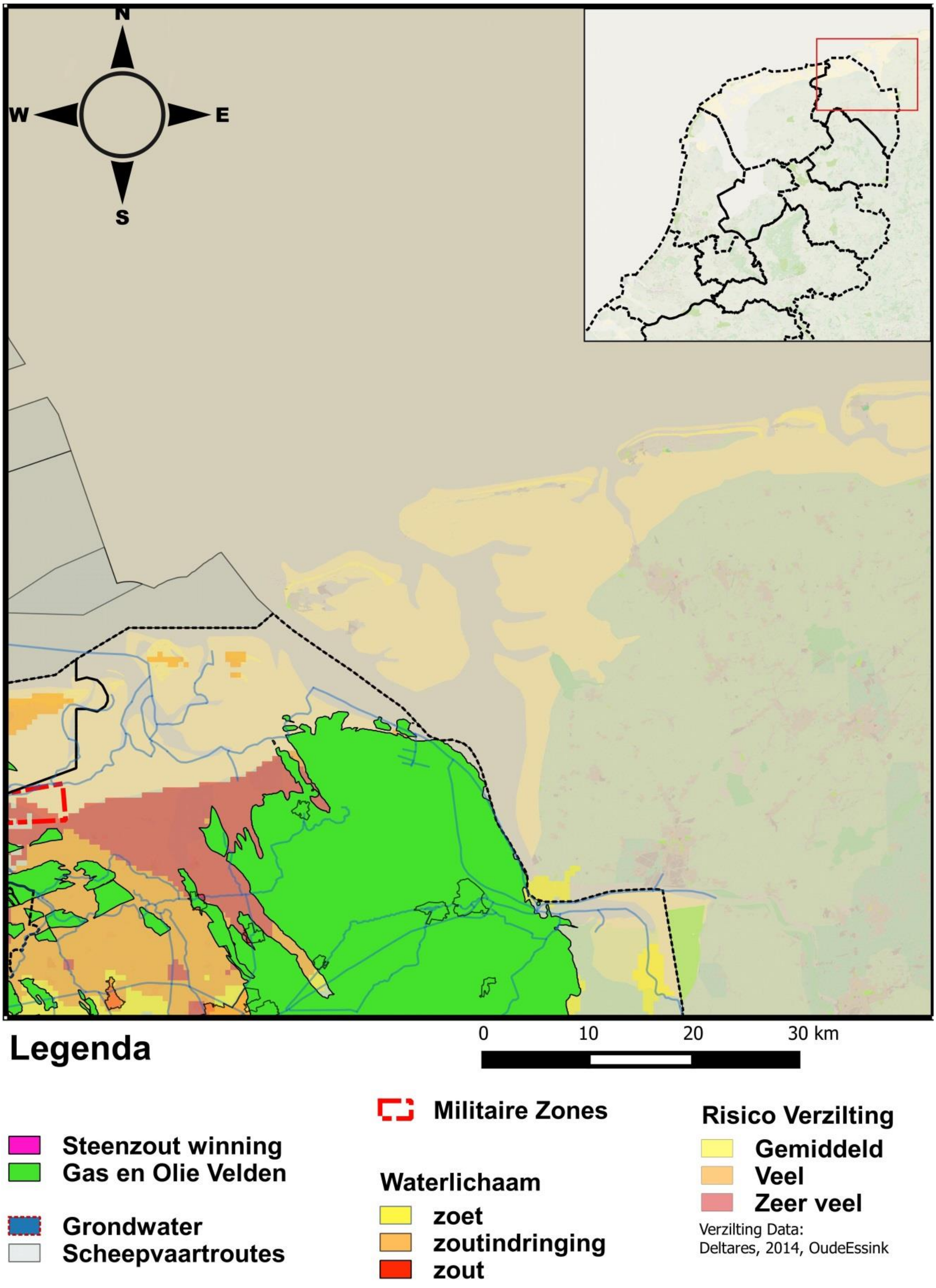
Recreatie Druk

- Niet recreatief
- Rustig recreatief
- Matig intensief
- Sterk intensief
- Evenement

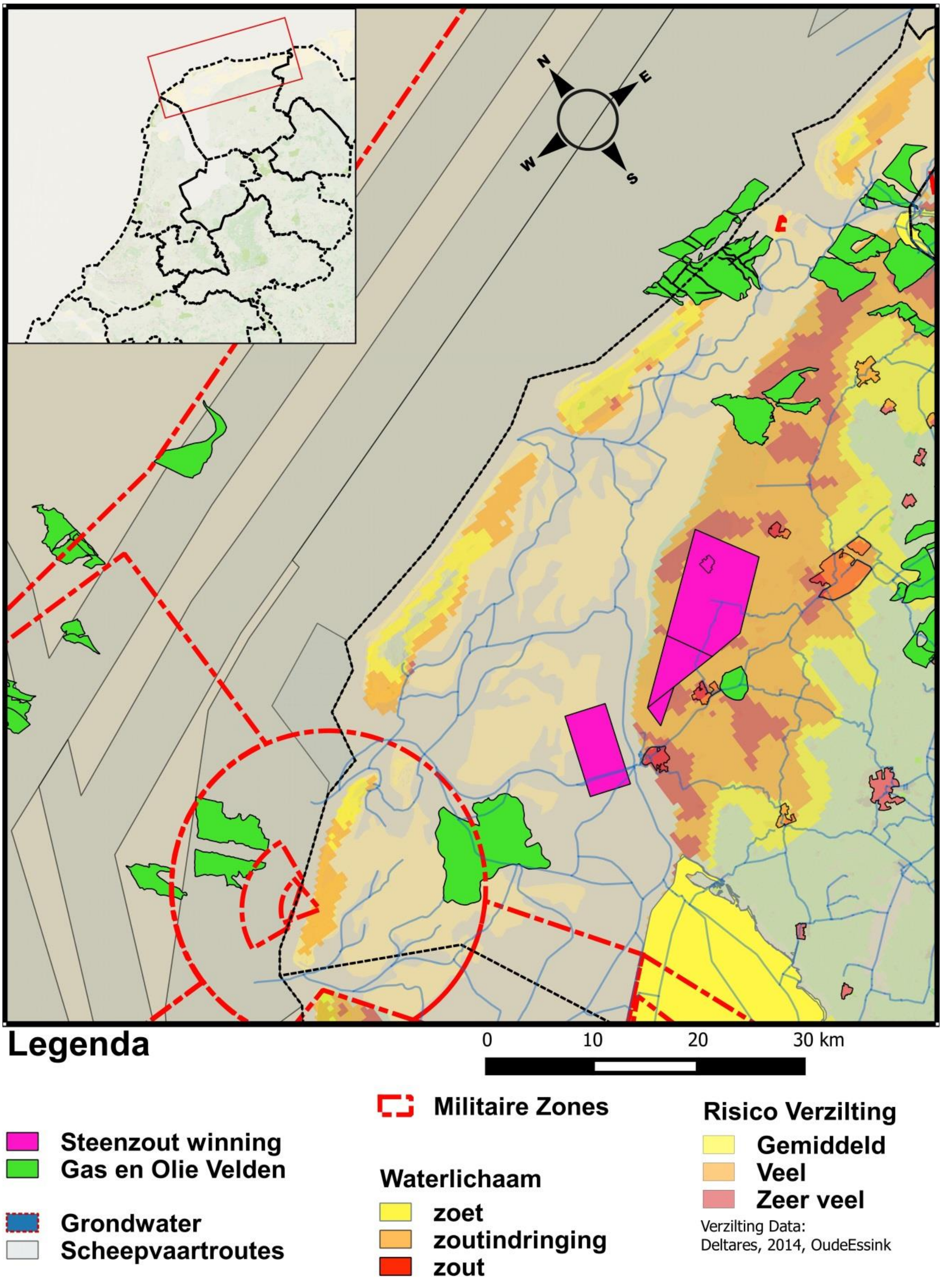
DECISIO

Bron Recreatie Gegevens: Broer, J. 2011. Ruimte voor recreatie op het strand; onderzoek naar een recreatiebasiskustlijn. DECISIO

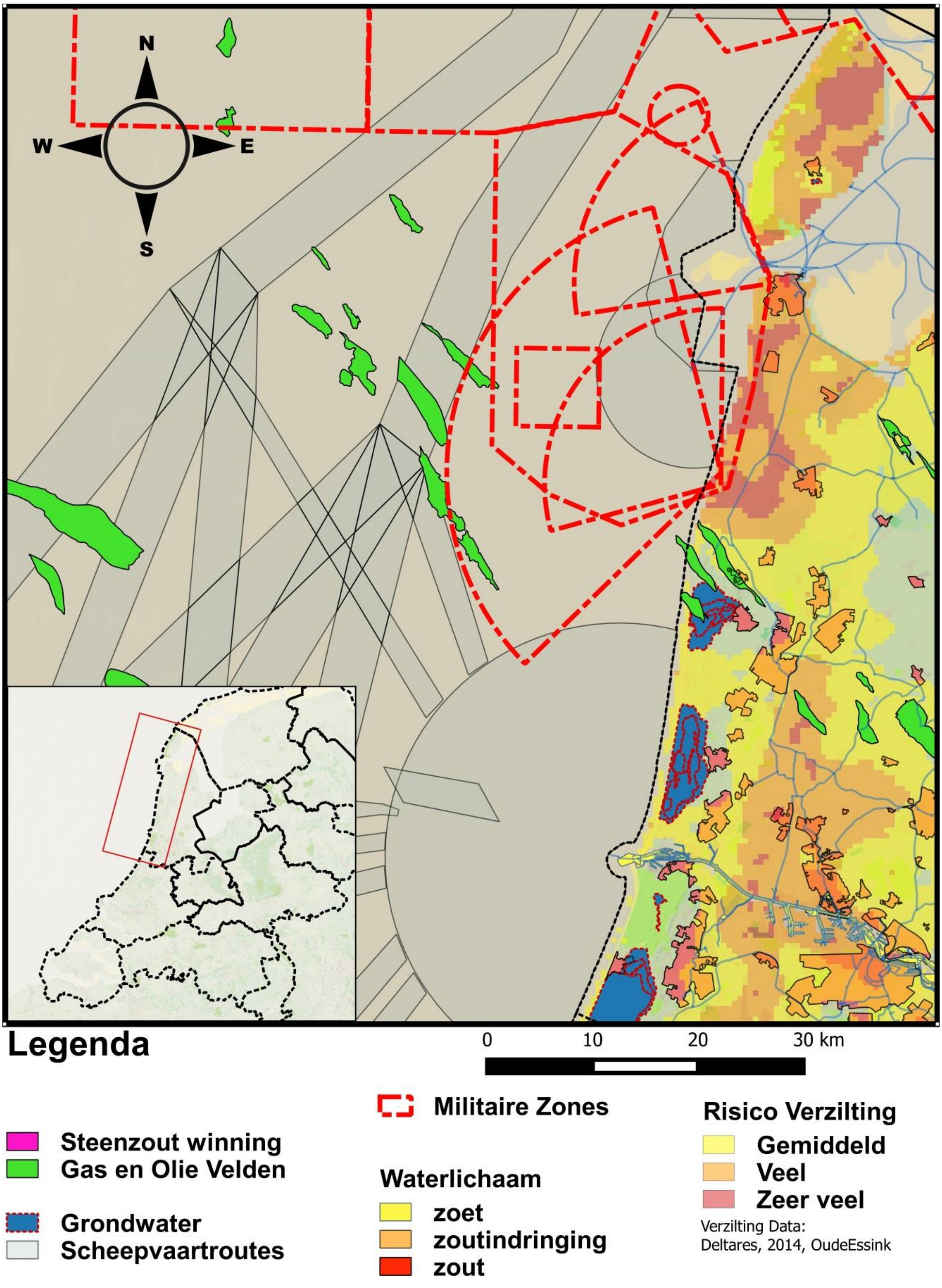
Zeeland Recreation



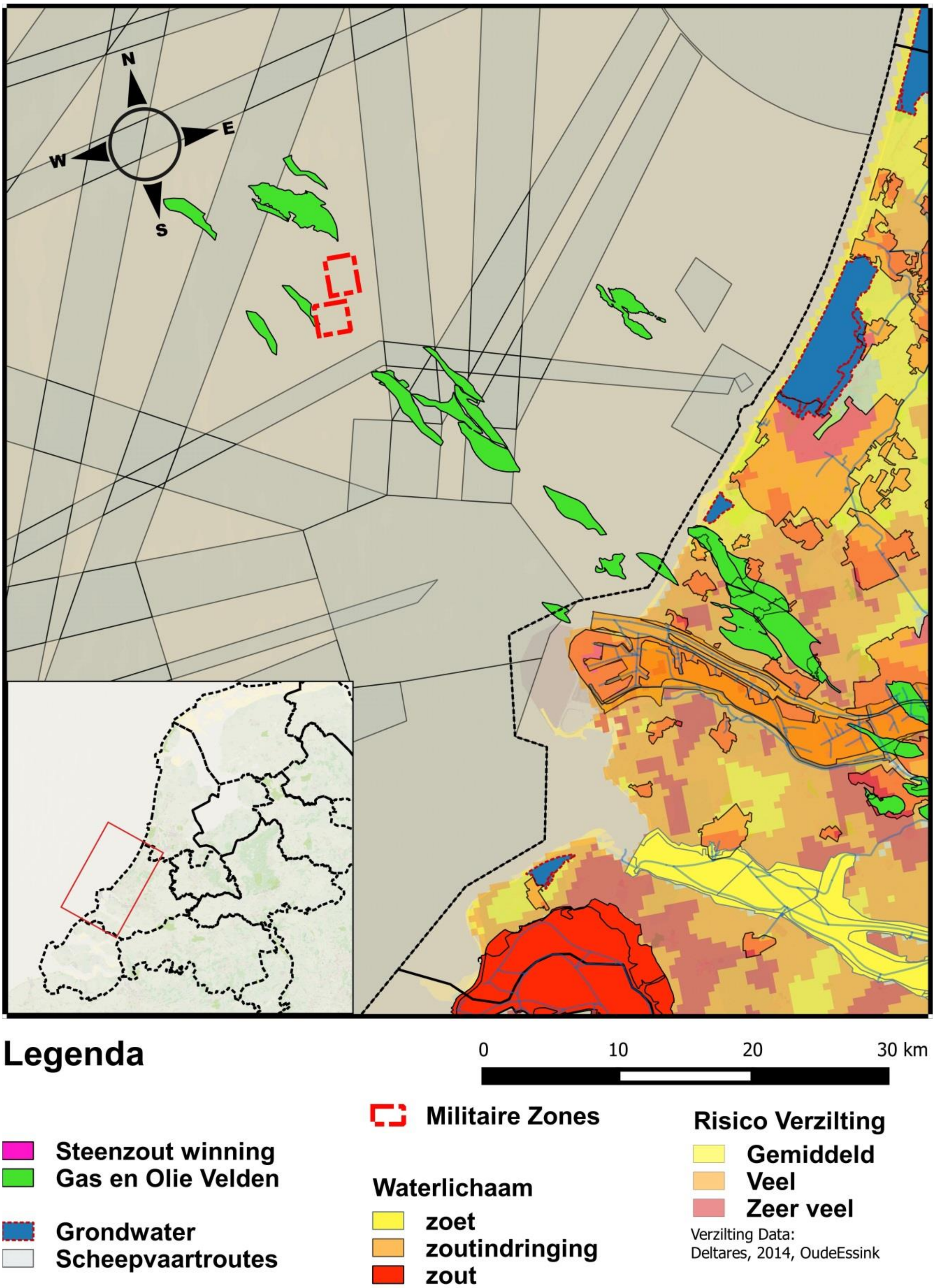
Groningen Other



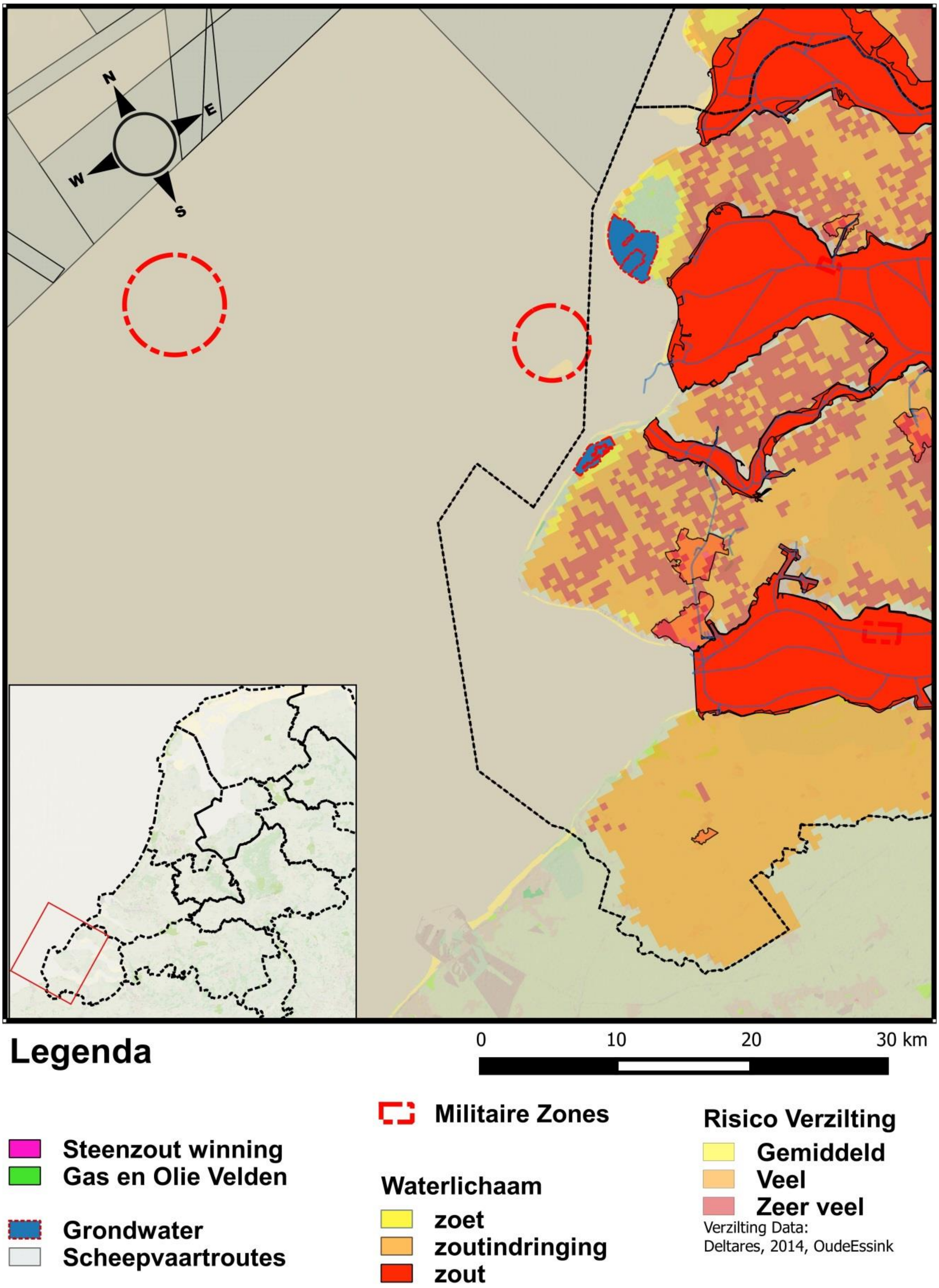
Friesland Other



North Holland Other

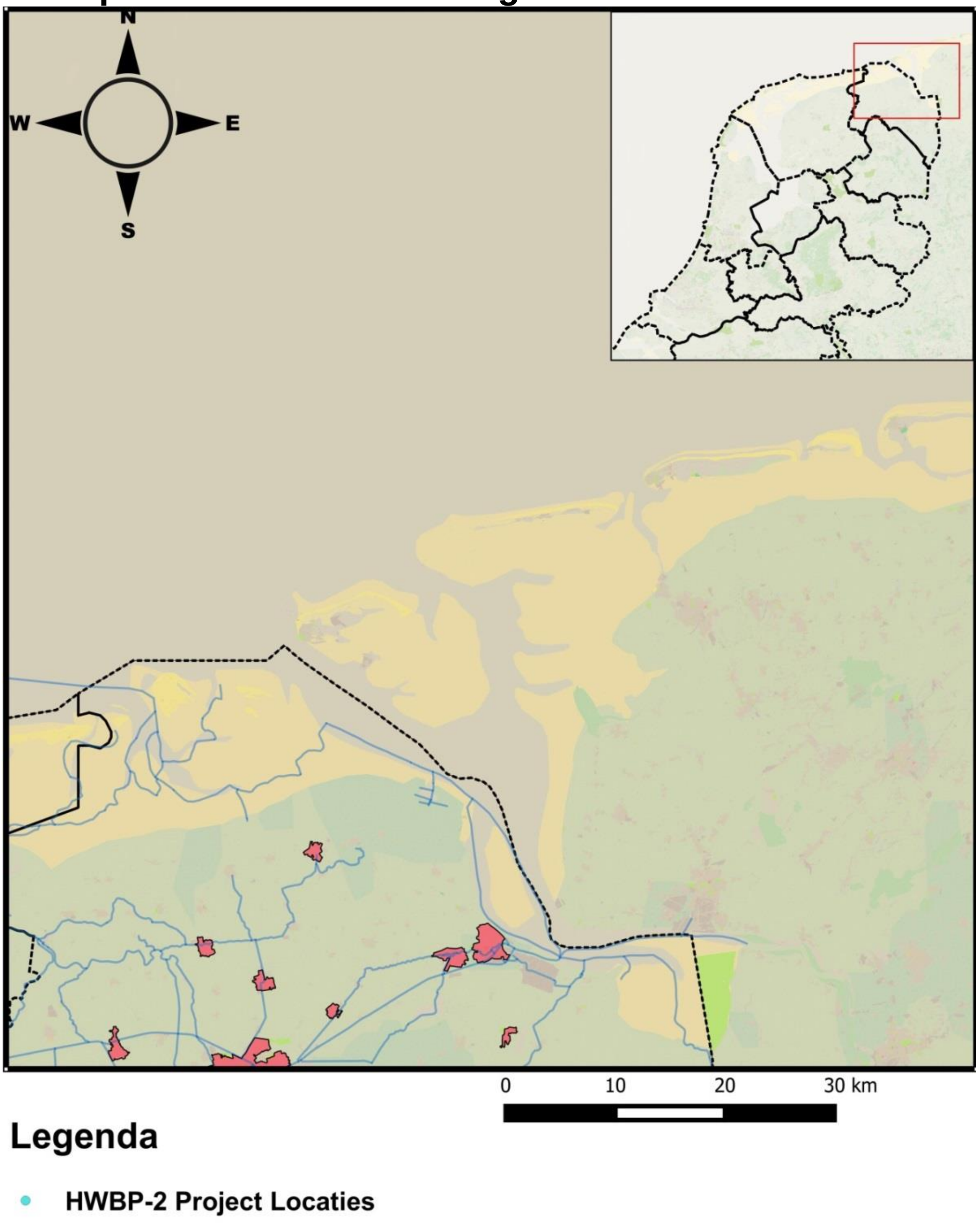


South Holland Other

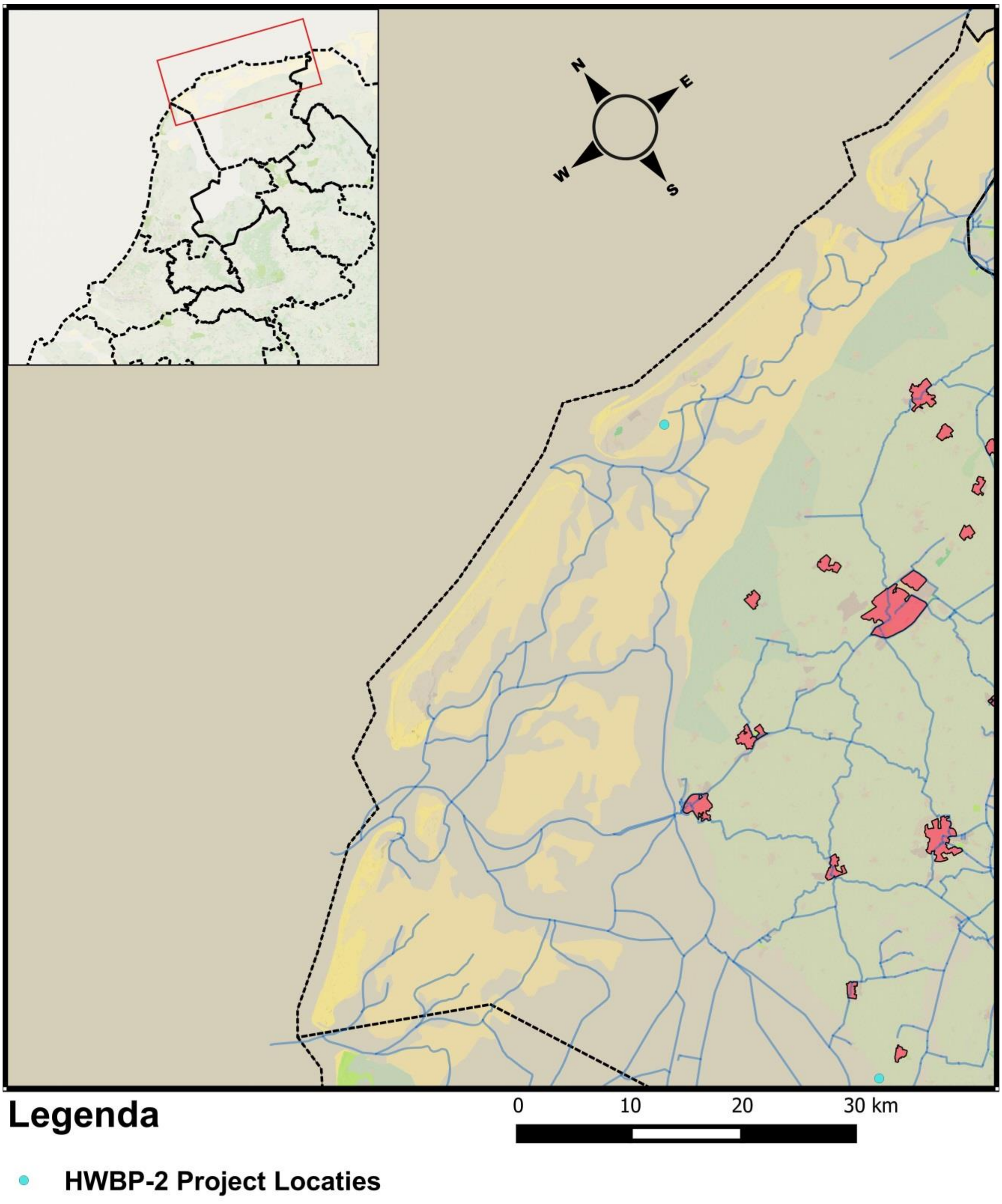


Zeeland Other

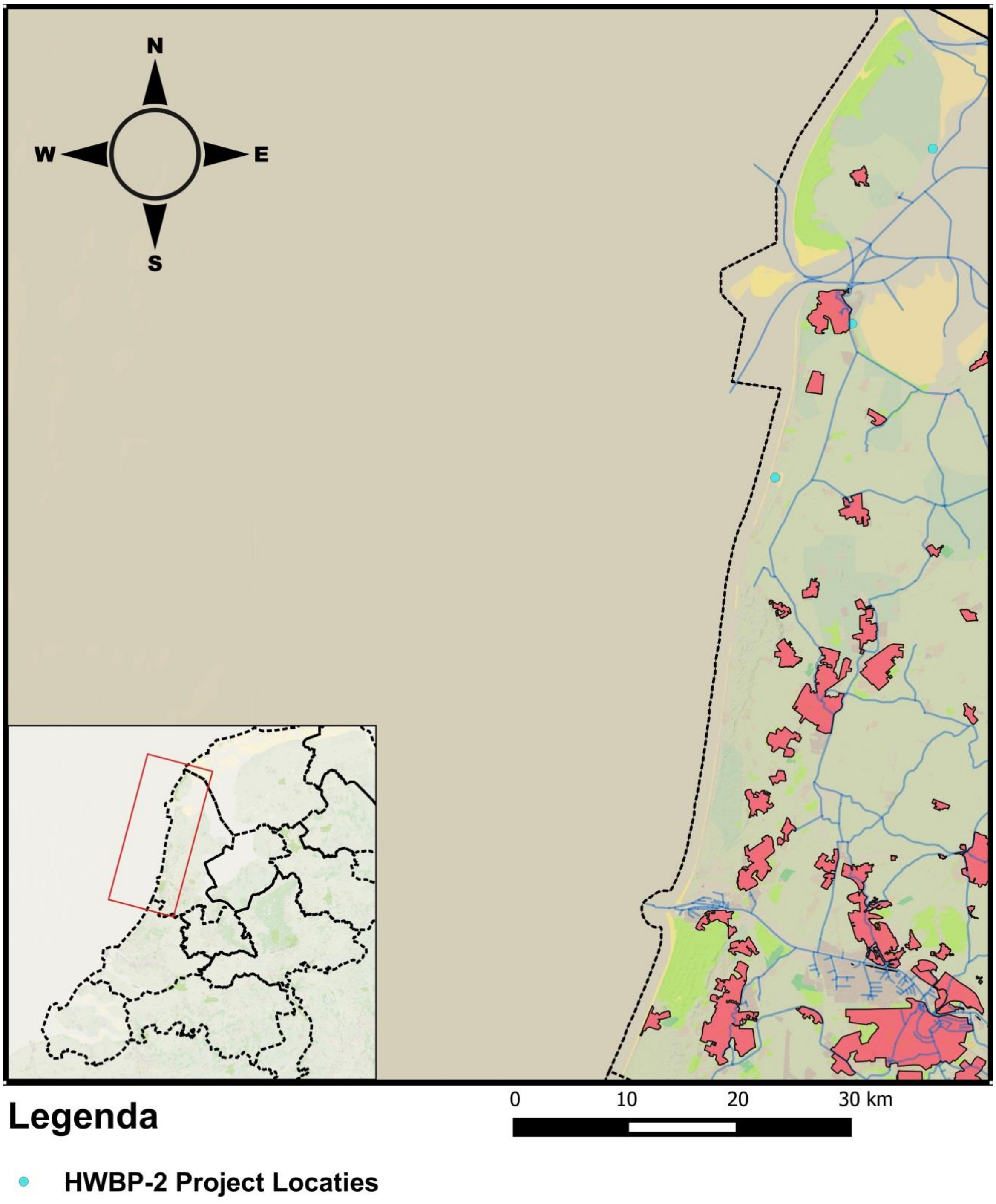
C Requirements wished usage functions



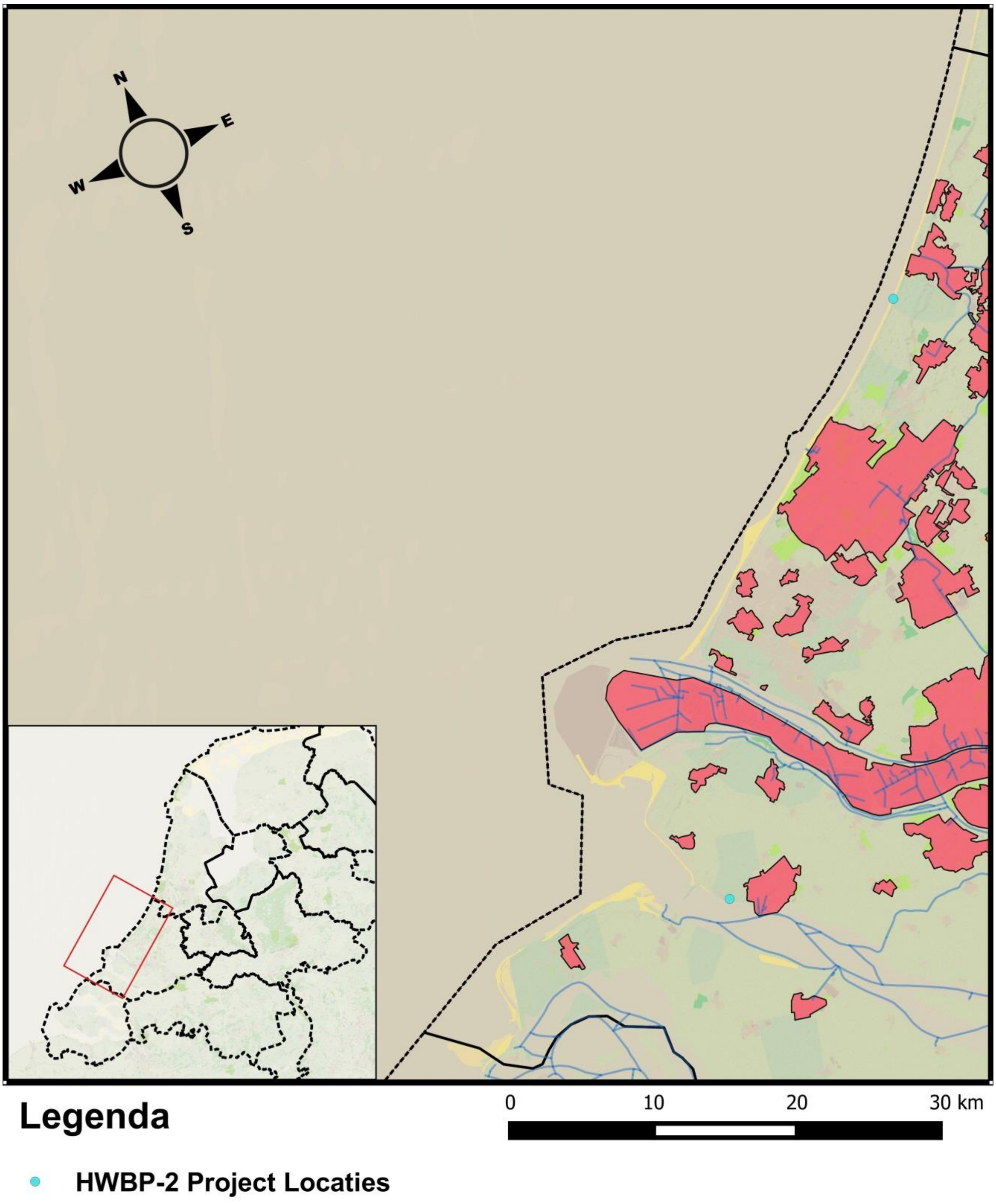
Groningen Wishes Protection



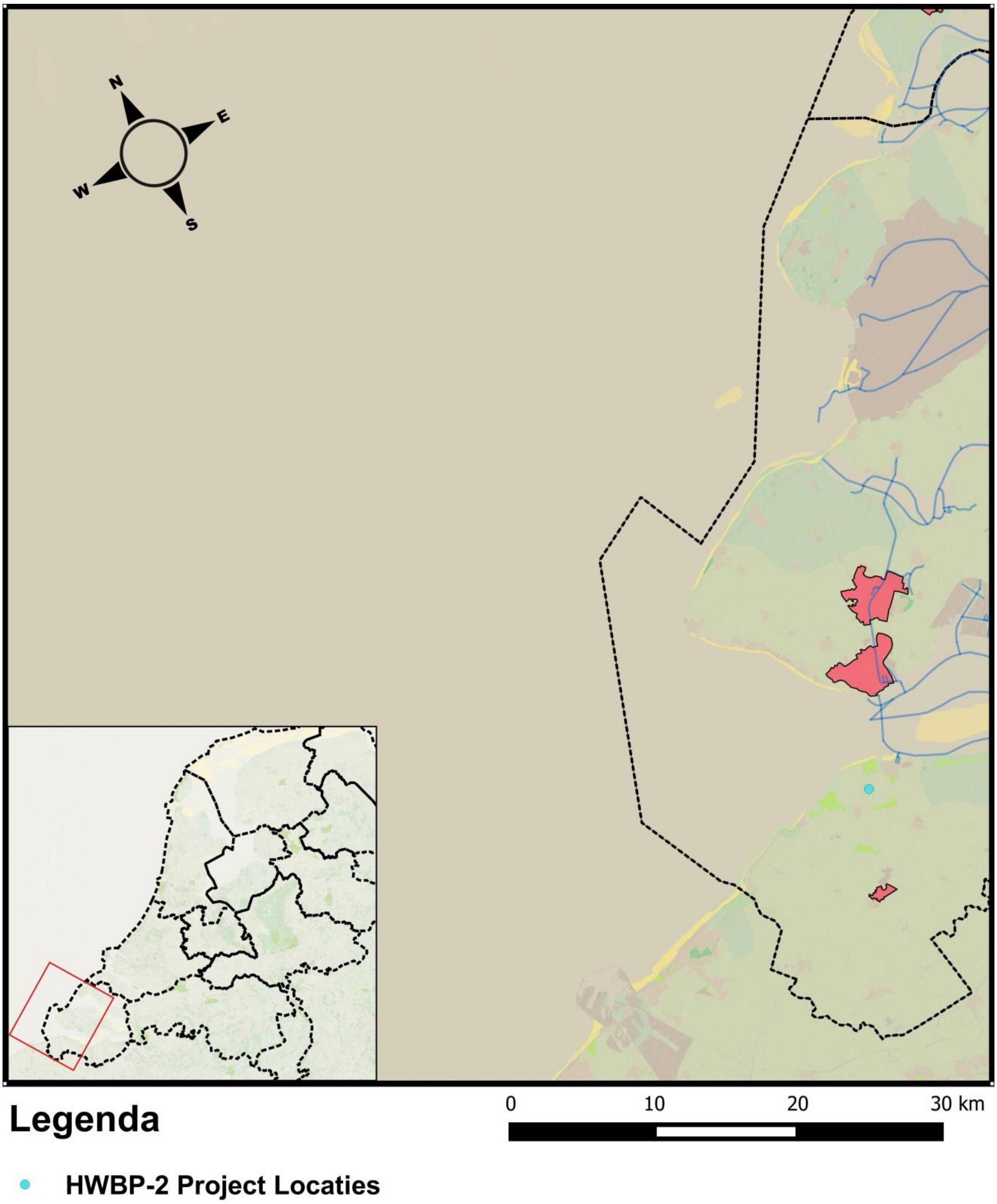
Friesland Wishes Protection



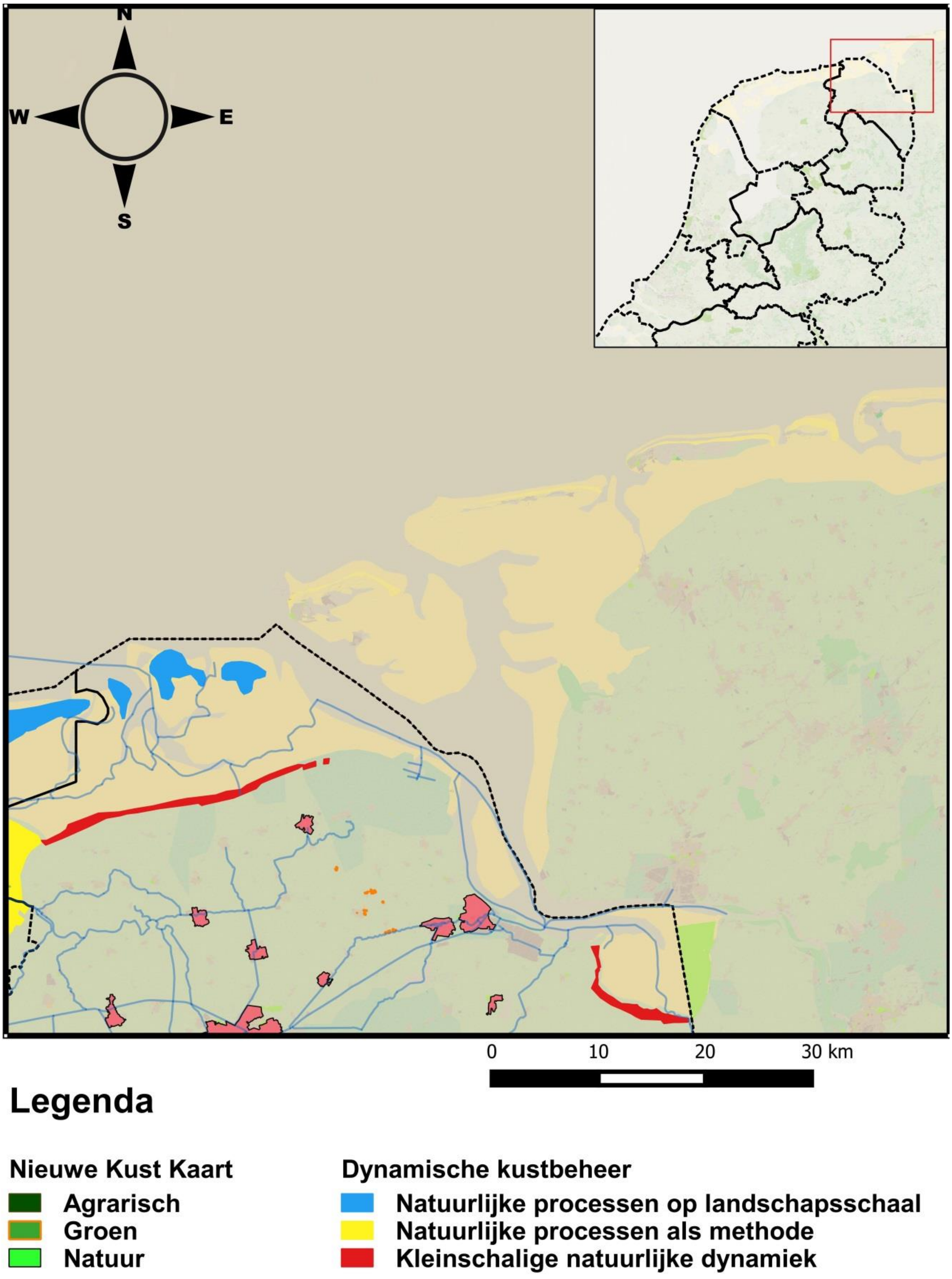
North Holland Wishes Protection



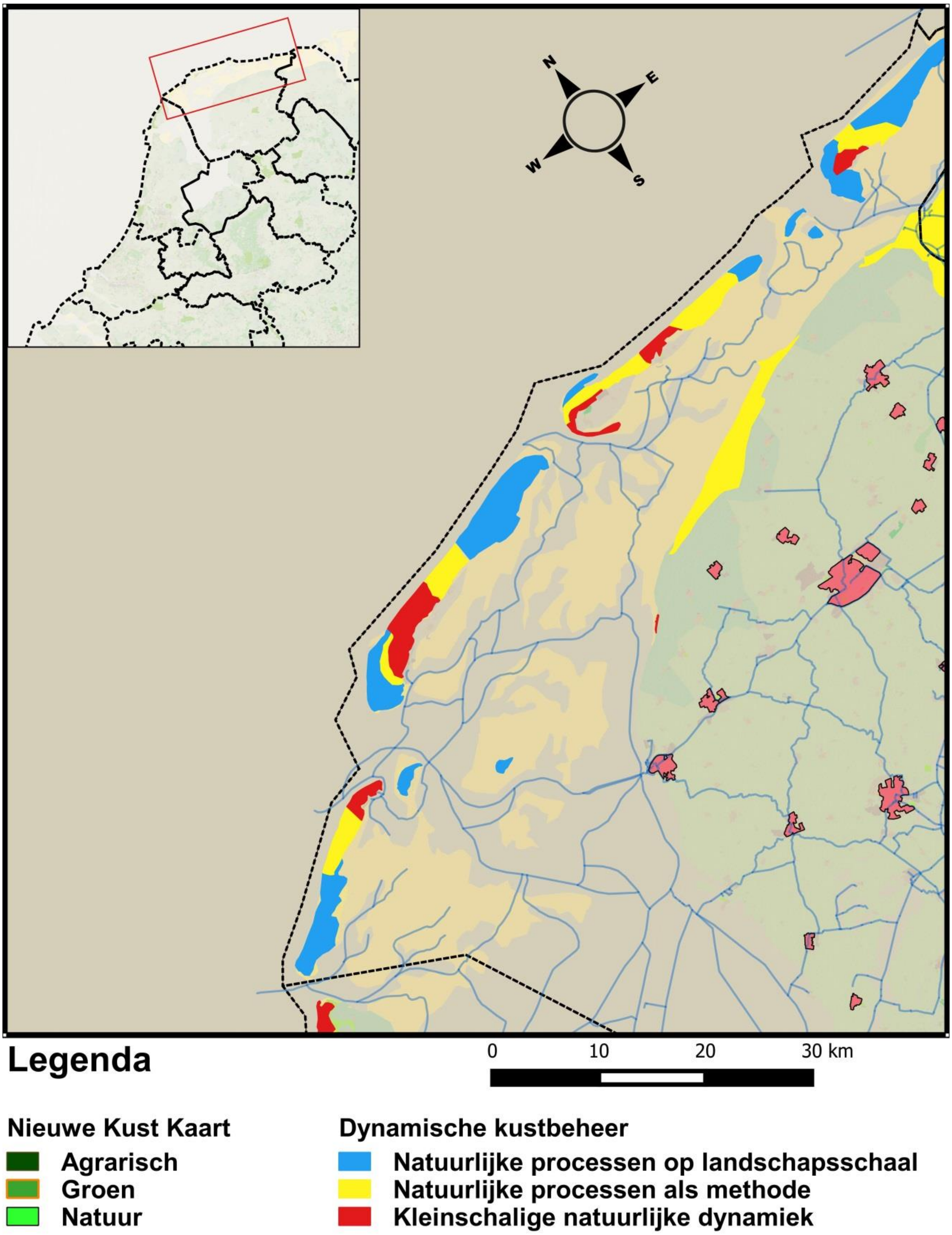
South Holland Wishes Protection



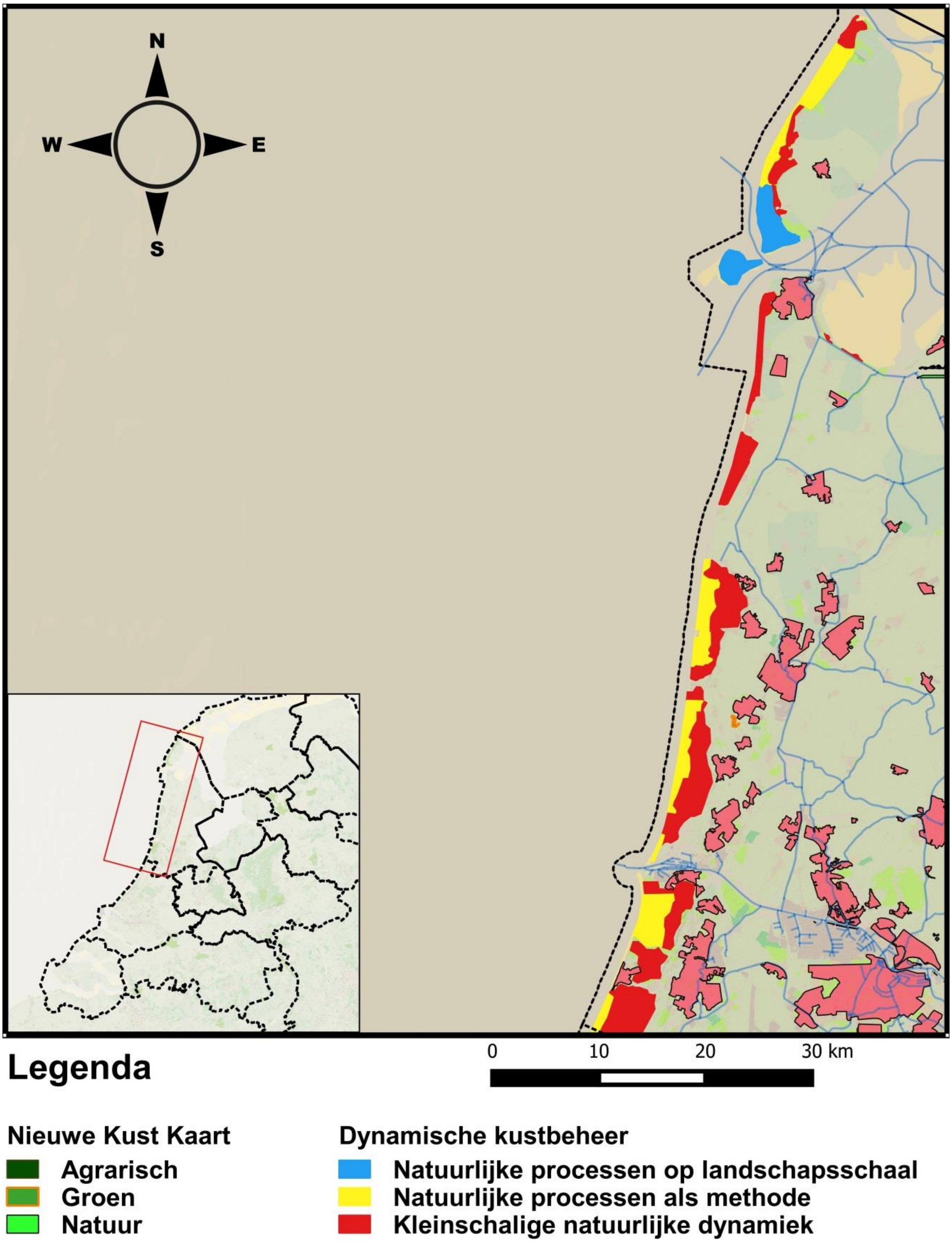
Zeeland Wishes Protection



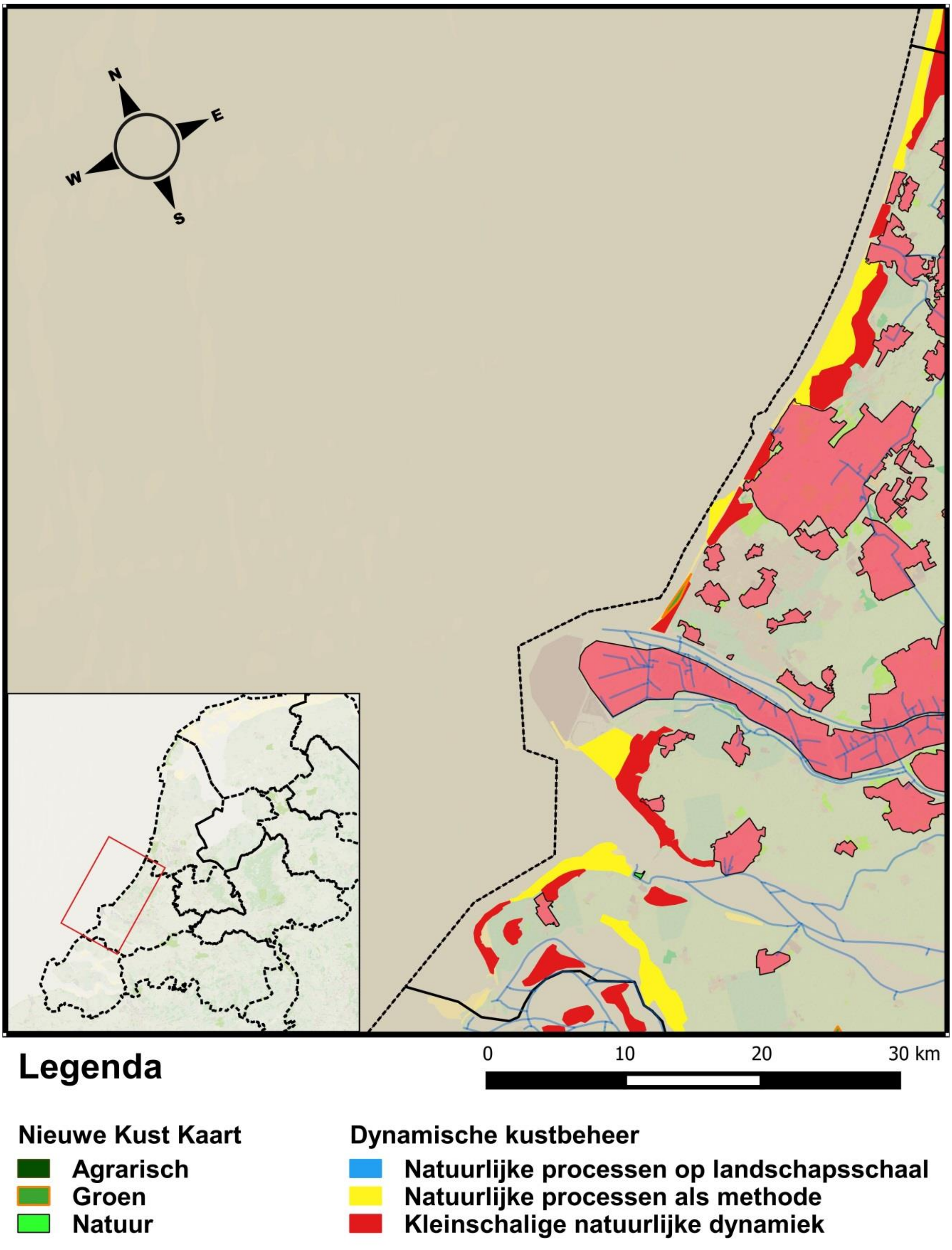
Groningen Wishes Nature



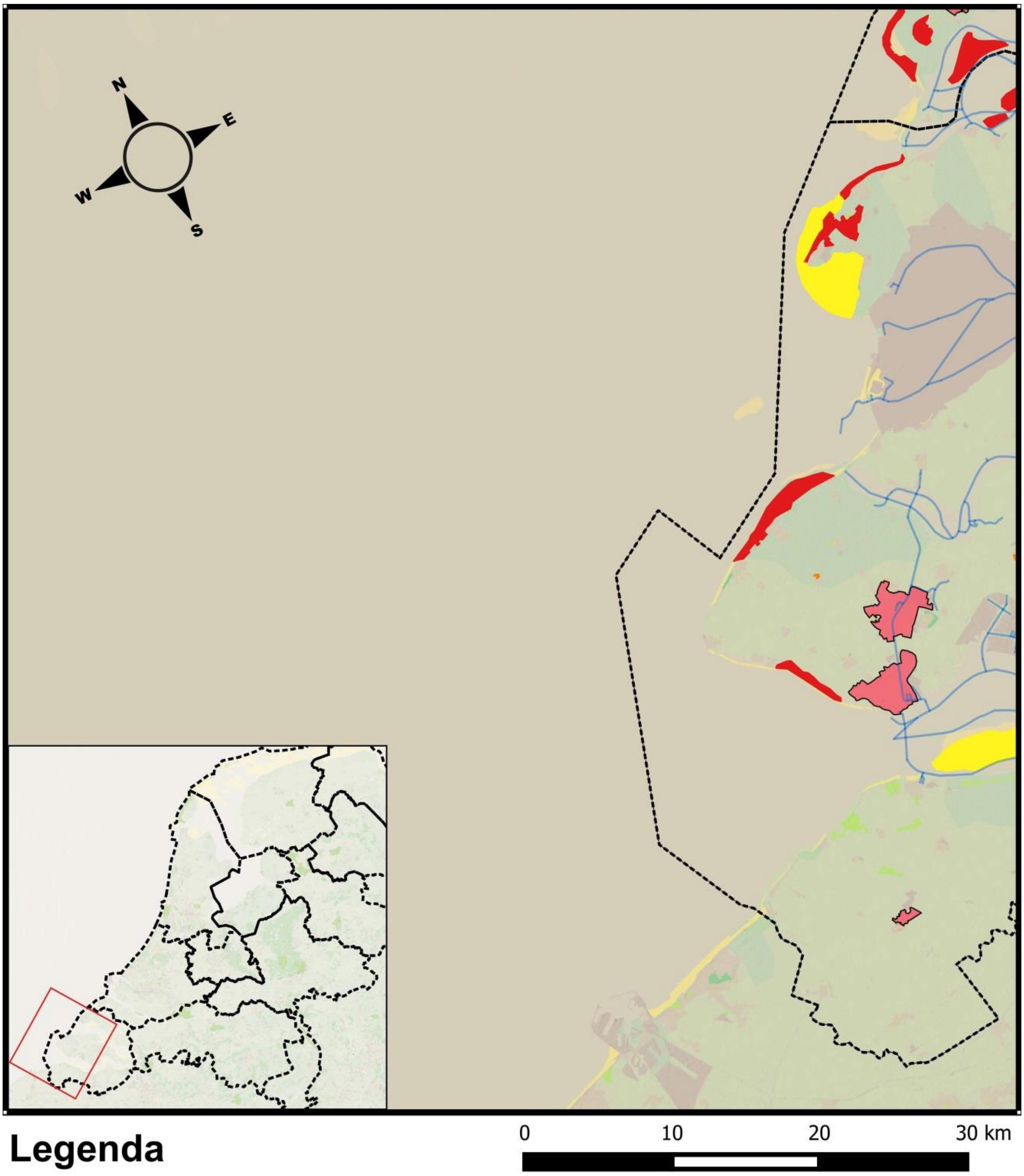
Friesland Wishes Nature



North Holland Wishes Nature



South Holland Wishes Nature



Legenda

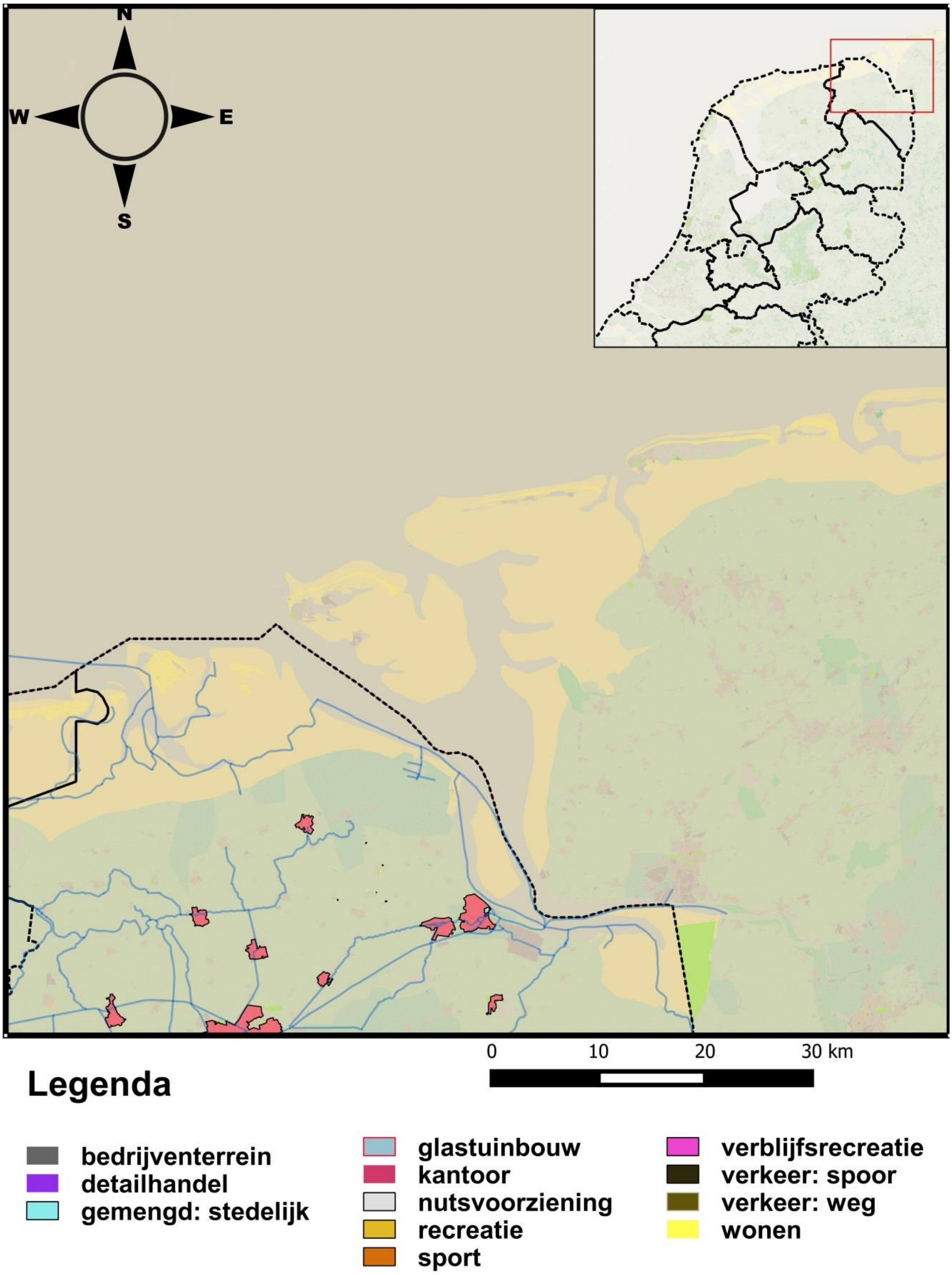
Nieuwe Kust Kaart

- Agrarisch
- Groen
- Natuur

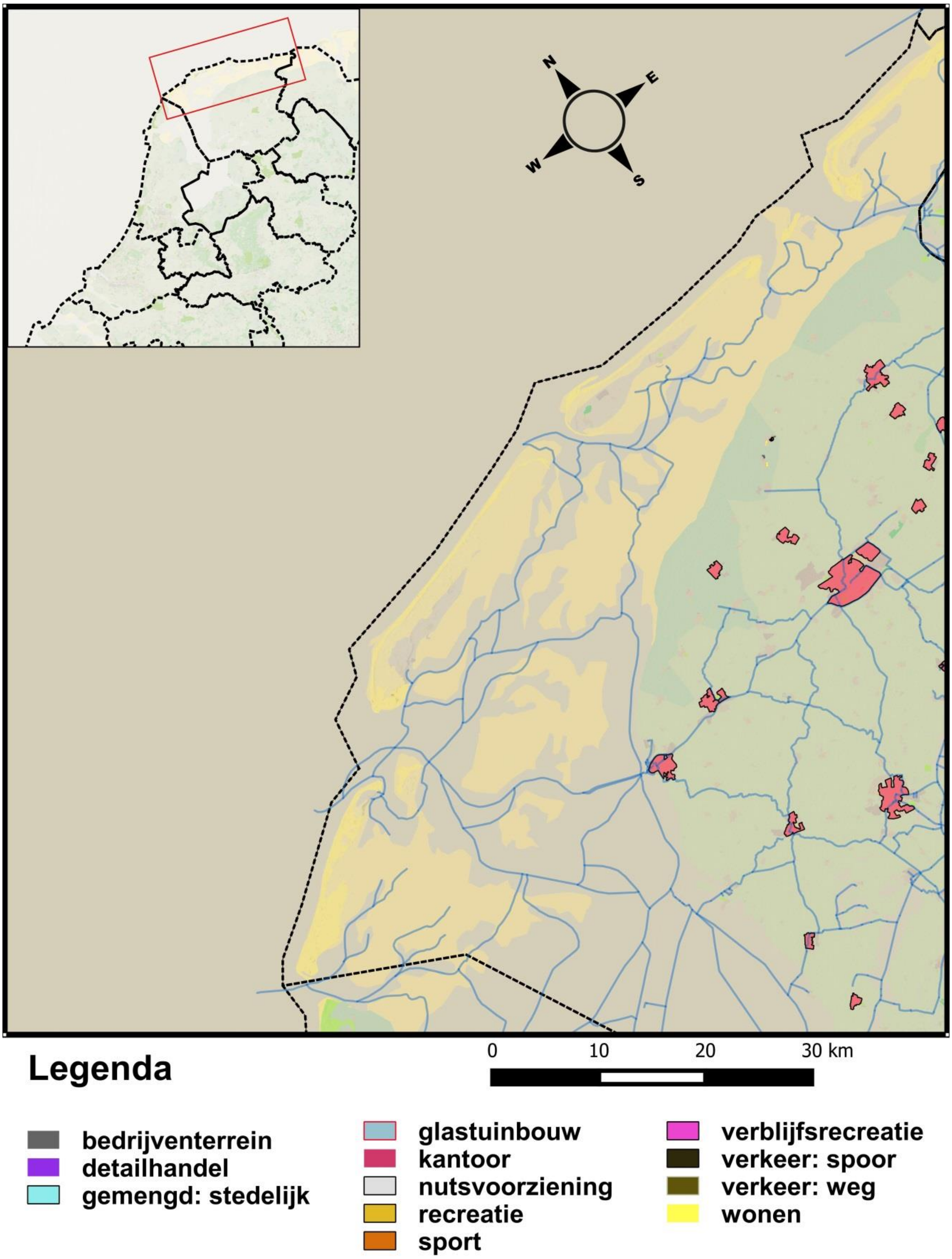
Dynamische kustbeheer

- Natuurlijke processen op landschapsschaal
- Natuurlijke processen als methode
- Kleinschalige natuurlijke dynamiek

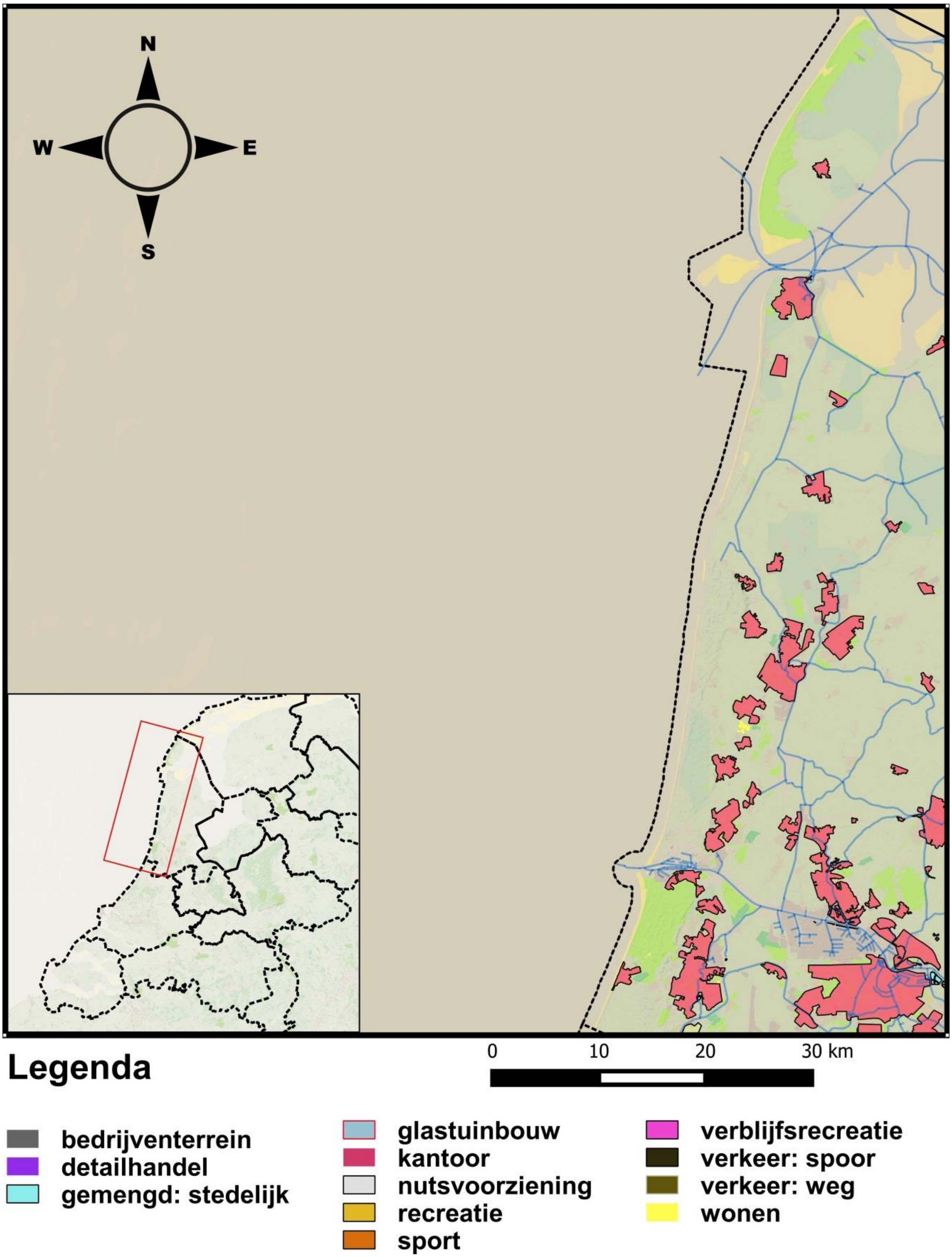
Zeeland Wishes Nature



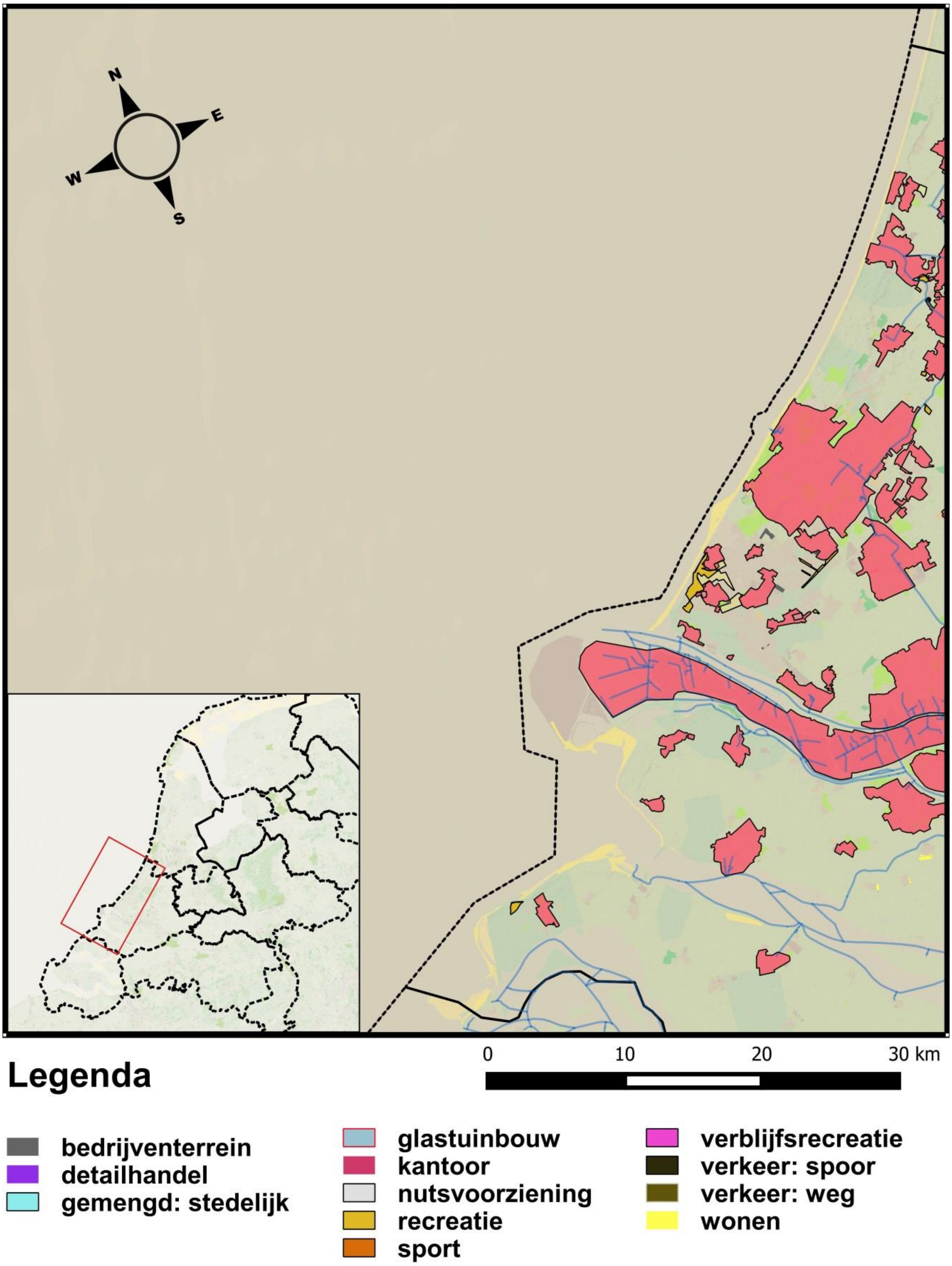
Groningen Wishes Recreation and Layout



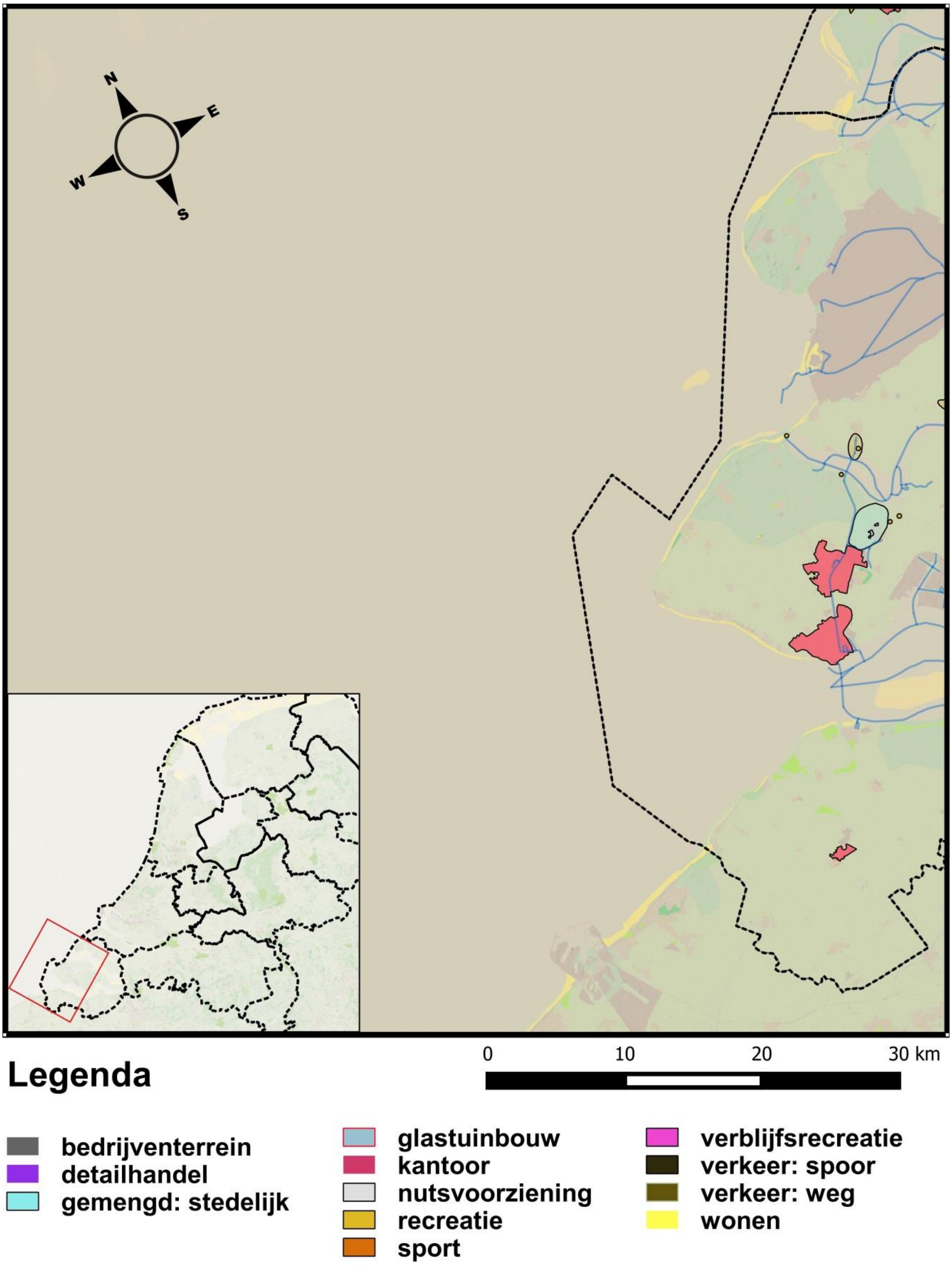
Friesland Wishes Recreation and Layout



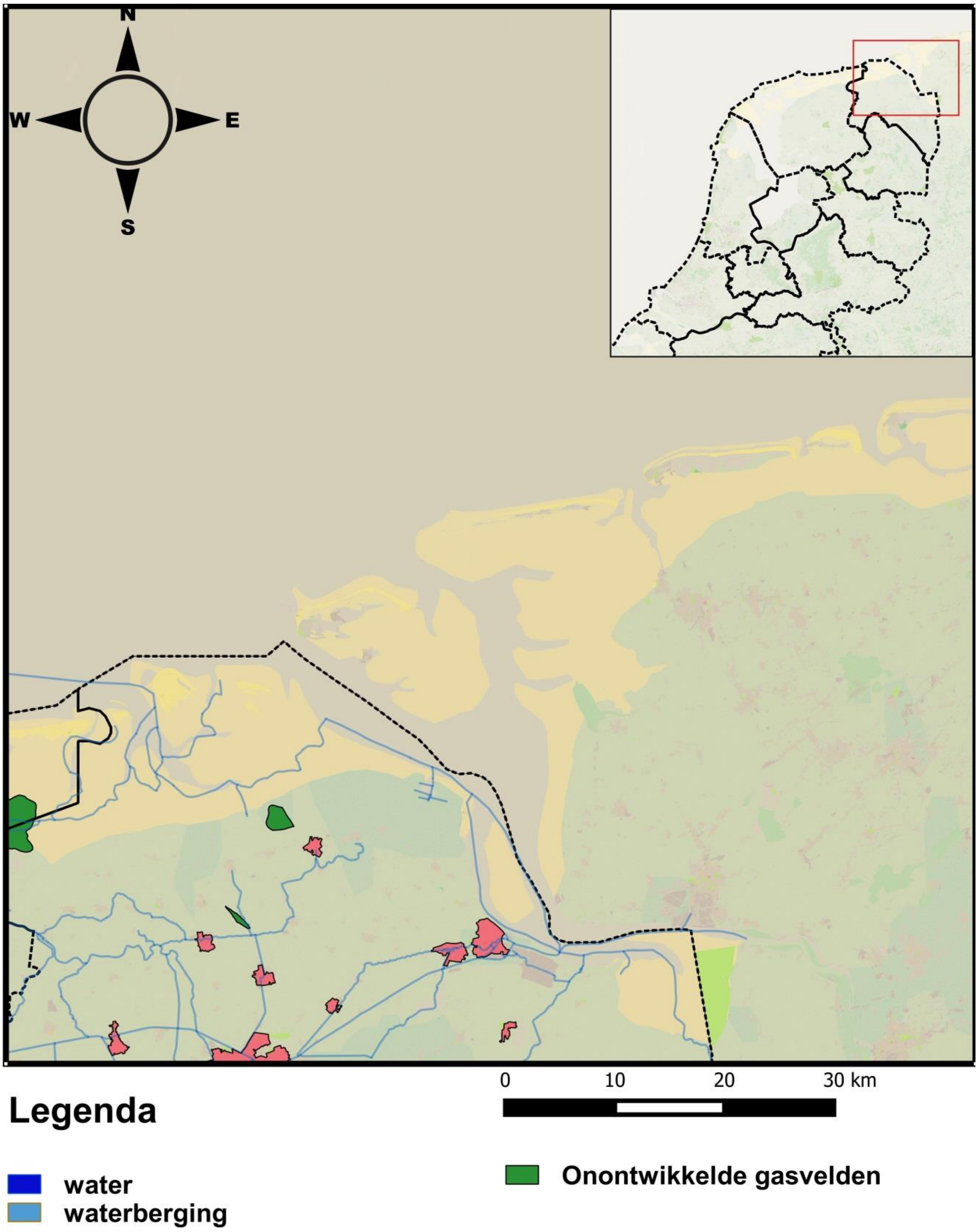
North Holland Wishes Recreation and Layout



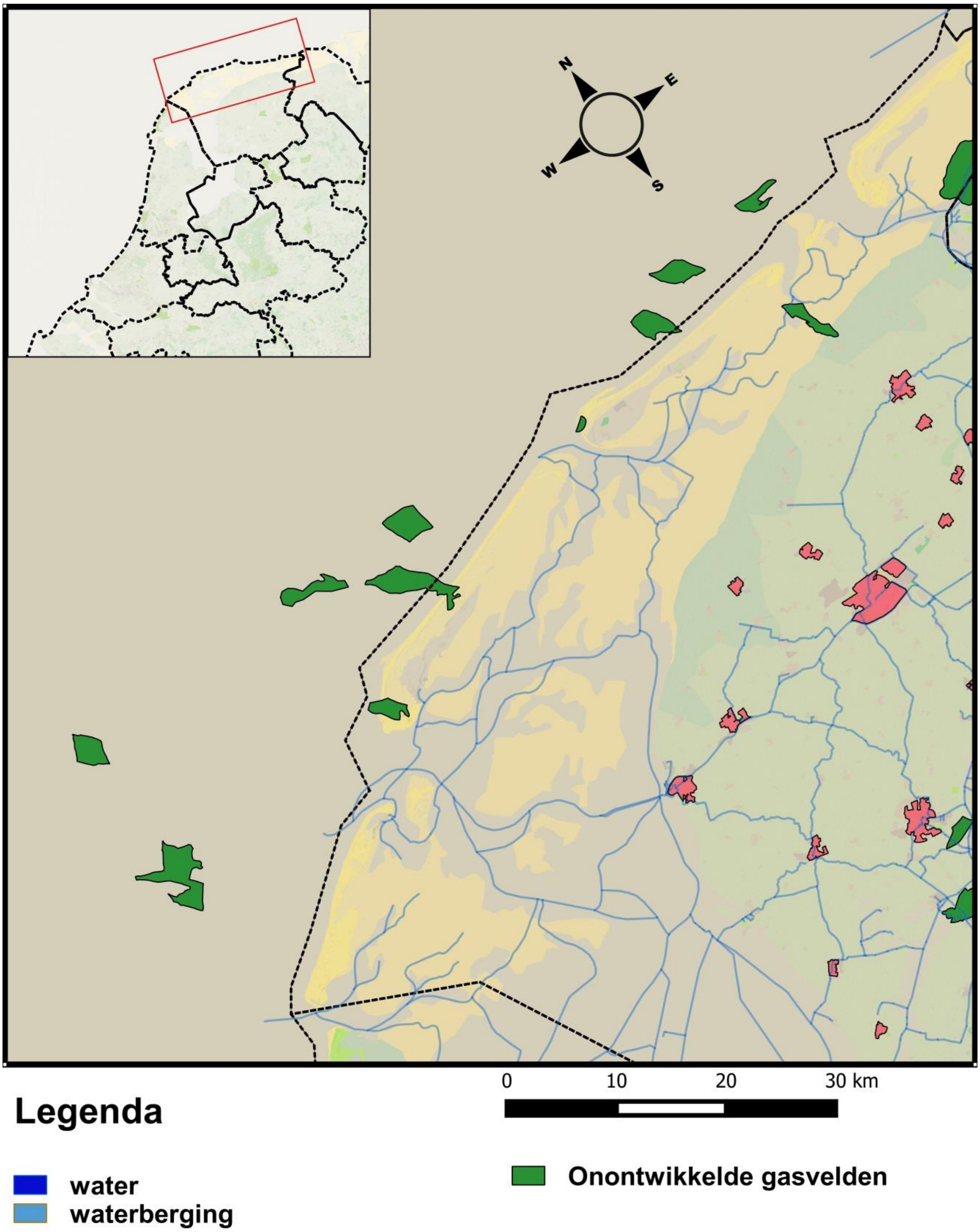
South Holland Wishes Recreation and Layout



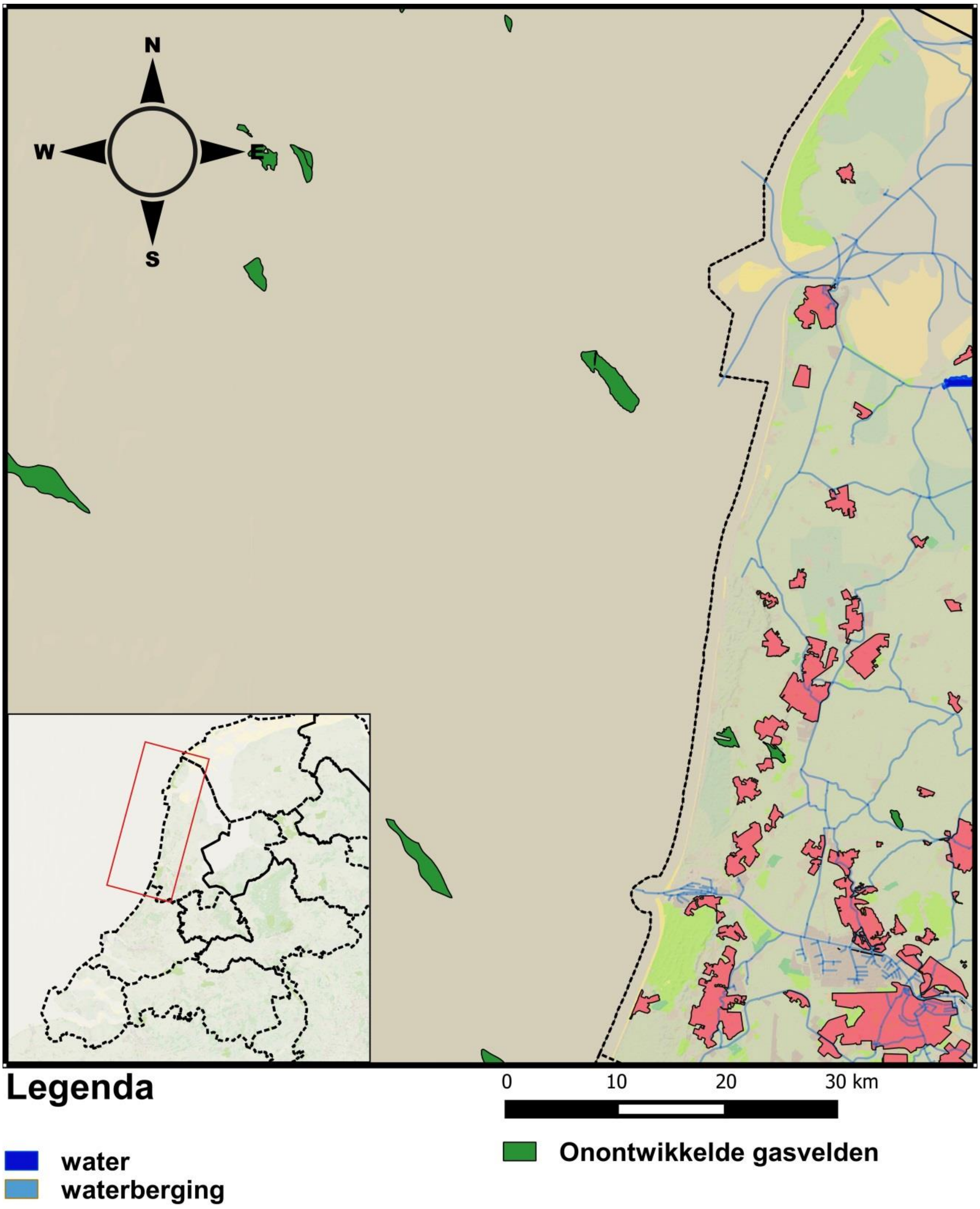
Zeeland Wishes Recreation and Layout



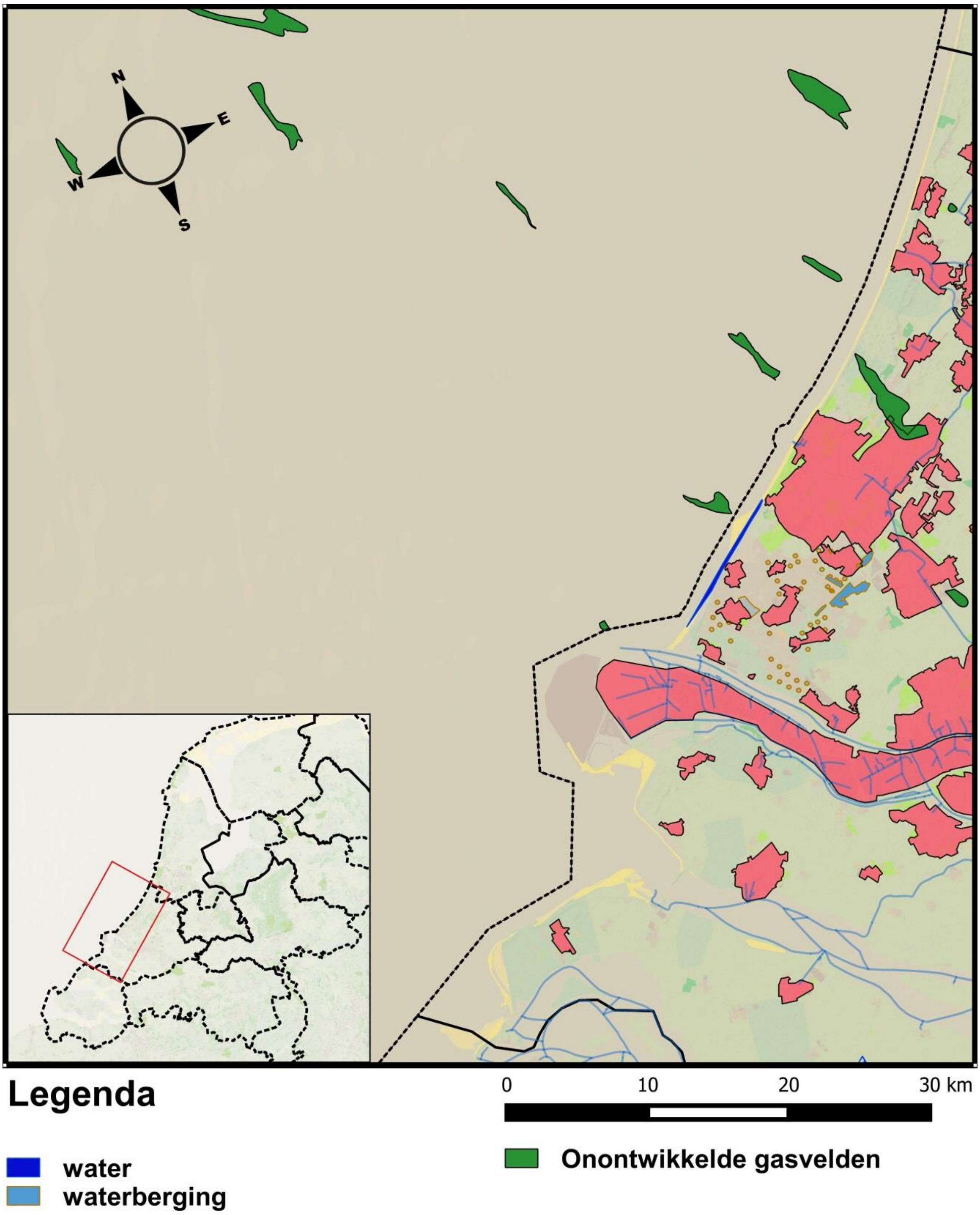
Groningen Wishes Other



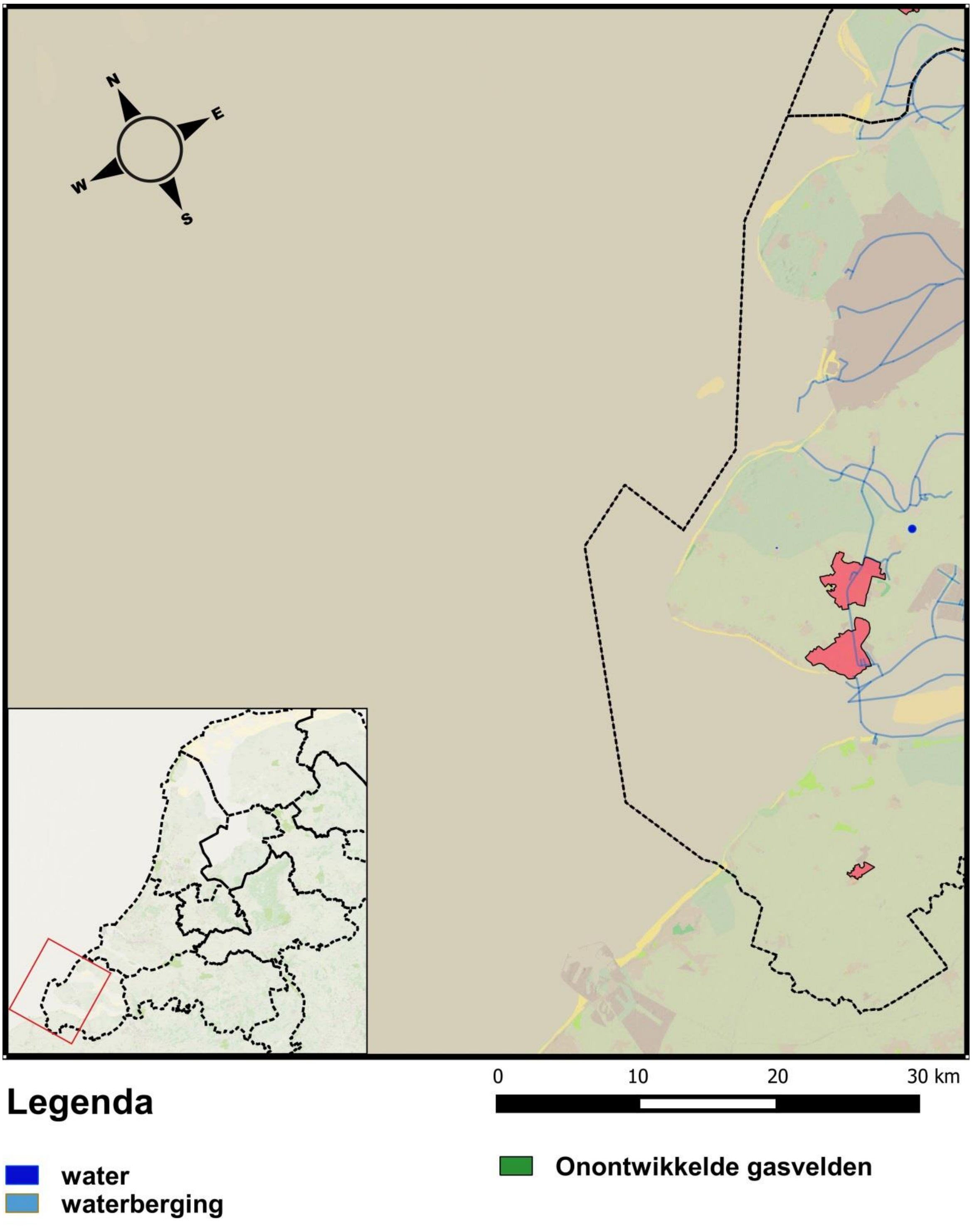
Friesland Wishes Other



North Holland Wishes Other

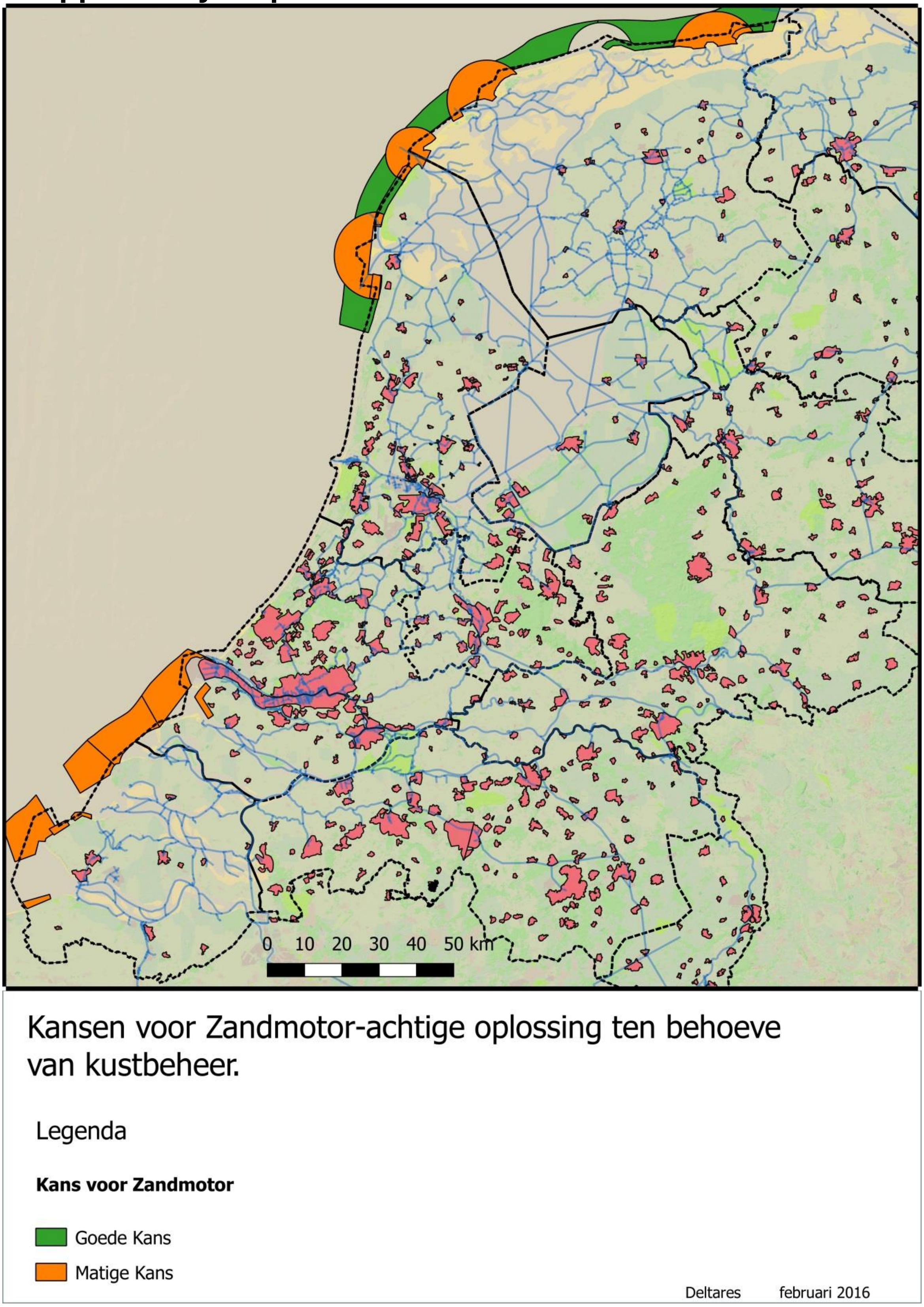


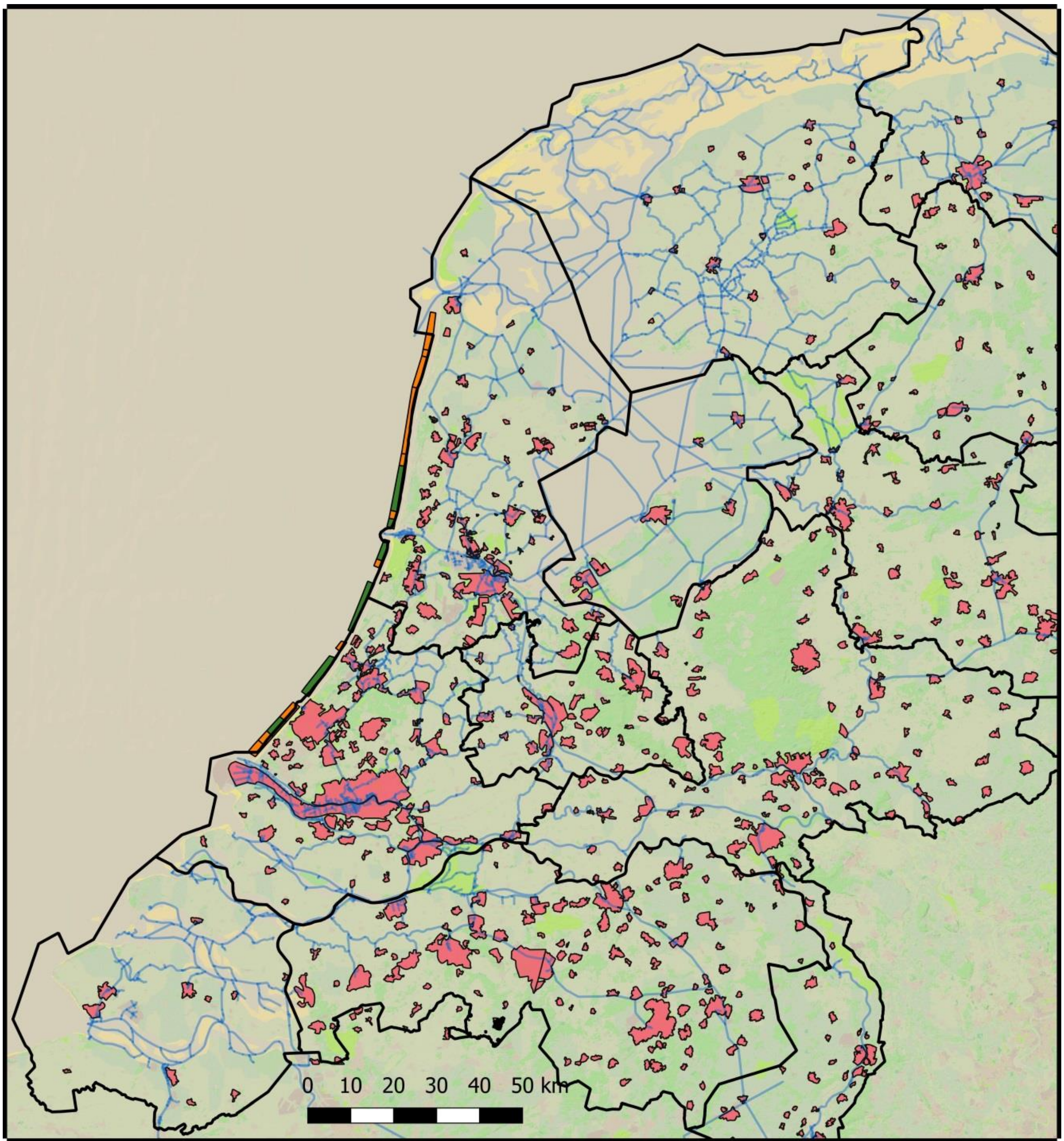
South Holland Wishes Other



Zeeland Wishes Other

D Opportunity maps





Kansen voor Zandmotor-achtige oplossing ten behoeve van natuur

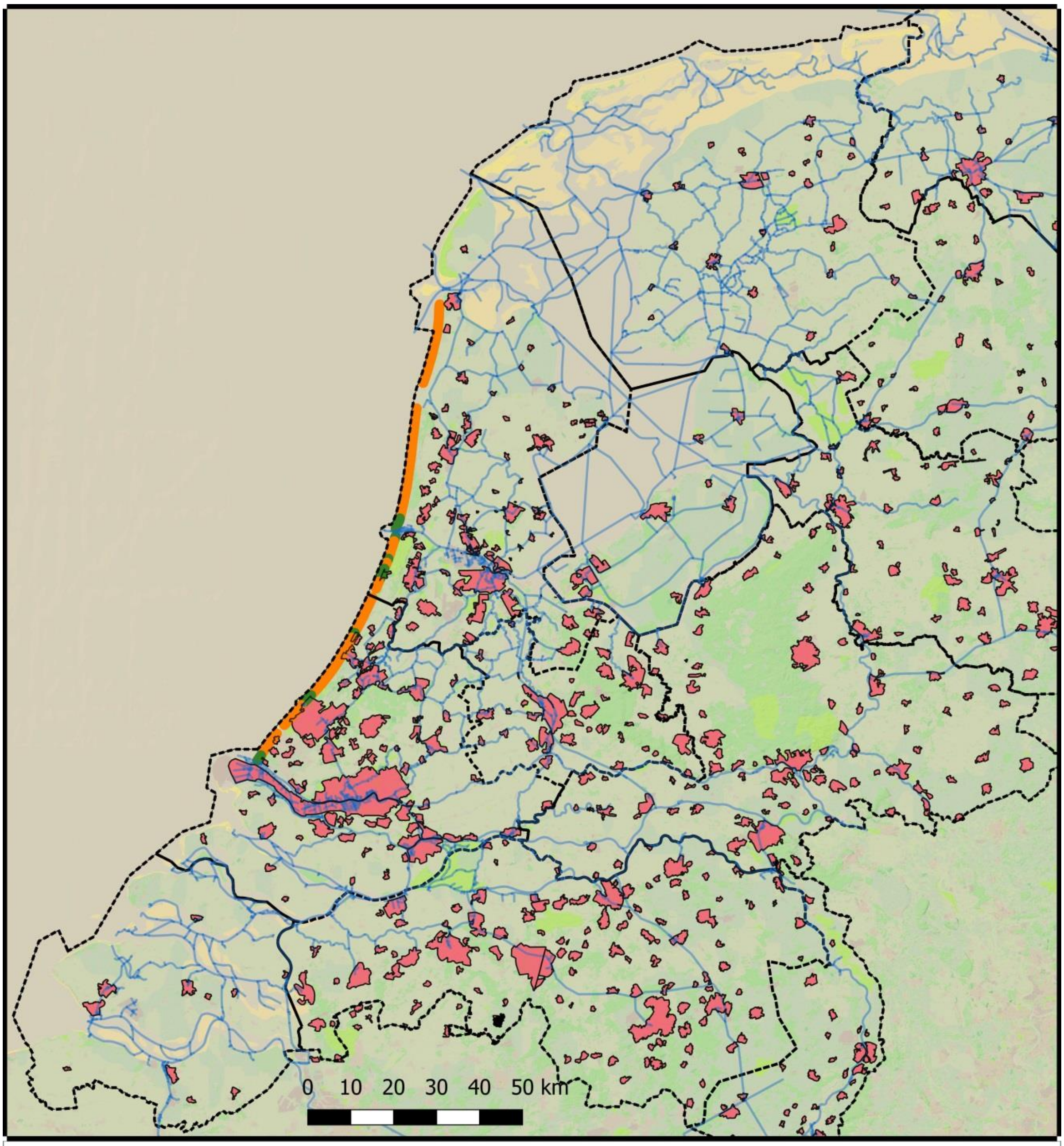
Legenda

Kansen voor Zandmotor

Goede Kans

Matige Kans

Deltares februarie 2016



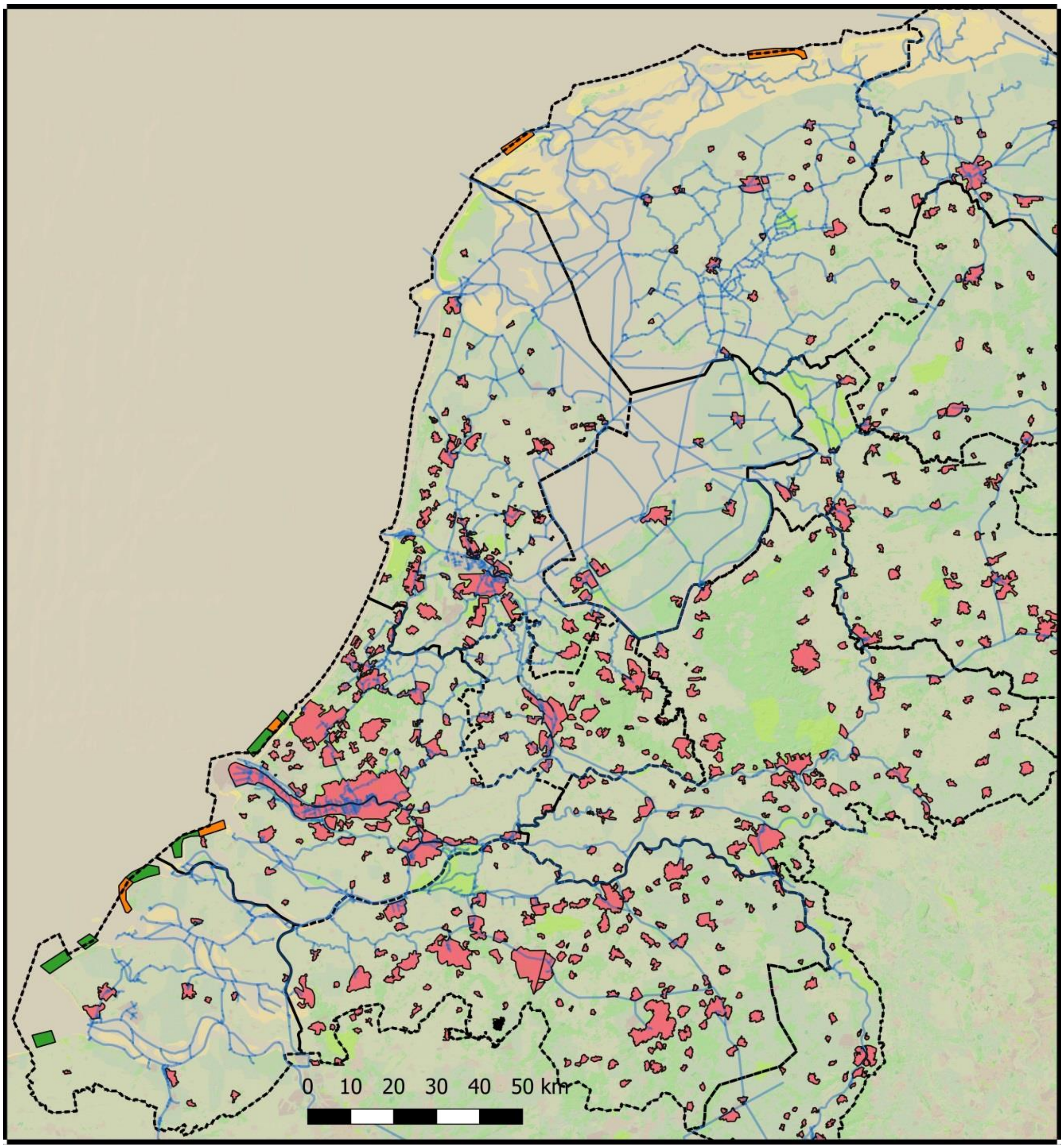
Kansen voor Zandmotor-achtige oplossing ten behoeve van recreatie en inrichting.

Legenda

Kansen voor Zandmotor

- Goede Kans
- Matige Kans

Deltares februari 2016



Kansen voor Zandmotor-achtige oplossing ten behoeve van overige functies en waarden

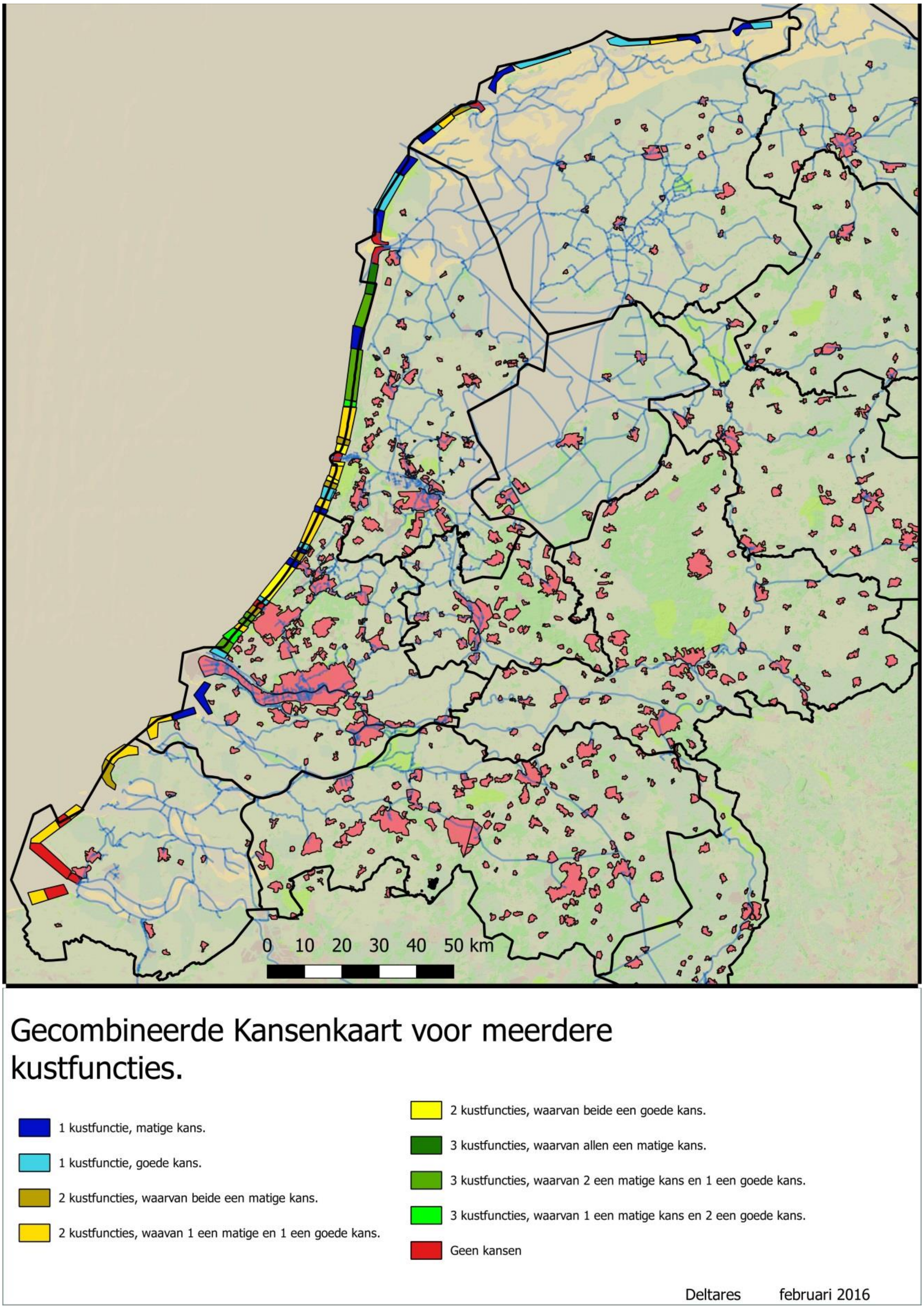
Legenda

Kansen voor Zandmotor

Goede Kans

Matige Kans

Deltares februari 2016


0 10 20 30 40 50 km
Gecombineerde Kansenkaart voor meerdere kustfuncties.
1 kustfunctie, matige kans.
1 kustfunctie, goede kans.
2 kustfuncties, waarvan beide een matige kans.
2 kustfuncties, waavan 1 een matige en 1 een goede kans.
2 kustfuncties, waarvan beide een goede kans.
3 kustfuncties, waarvan allen een matige kans.
3 kustfuncties, waarvan 2 een matige kans en 1 een goede kans.
3 kustfuncties, waarvan 1 een matige kans en 2 een goede kans.
Geen kansen
Deltares februari 2016