Geographical Information Management and Applications

Quantifying the Impact of Coastal Dune Management Policies

a Case Study of Meijendel, Wassenaar, 1975-2020

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Abstract

The Dutch coastal dunes provide a crucial set of services to the Netherlands and its population. In the context of the national park Meijendel, it has intrinsic natural value, it is a source of ecological diversity, provides area for recreation, water filtration, and coastal protection function against the sea. Over the years coastal dune management strategies have ranged from mechanically straightening the dunes, building them up and stabilizing them by planting grasses, to nature based solutions and actively promoting sand connectivity between the beaches and the back dunes. This research posed the following research question: “How have the Dutch coastal management policies influenced the morphological and land cover characteristics of national park Meijendel over the last 44 years?”(1975-2020). The study first created a comprehensive overview of national and local coastal management strategies. Subsequently, morphological and land cover changes were quantified at 5 year intervals using DTM and SVM classification using high resolution false colour infrared imagery. Morphologically the dunes seem to have been relatively stable. Change has primarily occurred in the beach and fore dune sections as a result of stand depletions and vegetation clearing. After the coastal preservation policy came into force the 1990 coastline has been maintained using sand depletions in front of and directly on to the beach. This also grew the foredune in height. The land cover classifications indicate a trend towards increased vegetation cover, increasing from approximately 66% in 1975 to 81% in 2020. It is exactly this trend which many of the management interventions are aiming to address and reverse. The increase in vegetation cover is best observable in the middle and back dune sections of the study area. As a result bare sand land cover is reducing while vegetation cover is increasing. When these results are compared with one another there seems to be a clear correlation between management interventions such as: the clearing of vegetation and top soil, cutting of trees and sand depletions and morphological and land cover change. Outside of these intervention areas there is still a trend towards increased vegetation cover, which cannot be attributed to a single source or management approach.

Contents

1. Problem and its Context

The Dutch coastal dunes provide a crucial set of services to the Netherlands and its population. As a significant part of the Netherlands lies below sea level, the Dutch have always been acutely aware of their need for sea defences (Arens et al., 2012). In the context of the Netherlands, dunes are especially important as they are the main protection of the lowlands behind them from the sea (Waterstaat, 2022). With current anthropogenic climate change and subsequent sea level rise the ability of Dutch coastal dunes to protect the land in the long term is of the utmost importance. Keijsers et al. (2014) and Zang, Douglas & Leatherman (2004) found that the effects of anthropogenic climate change, such as sea level rise and more extreme weather patterns, will have a negative effect on dune building activities in the Netherlands through increased erosional activity.

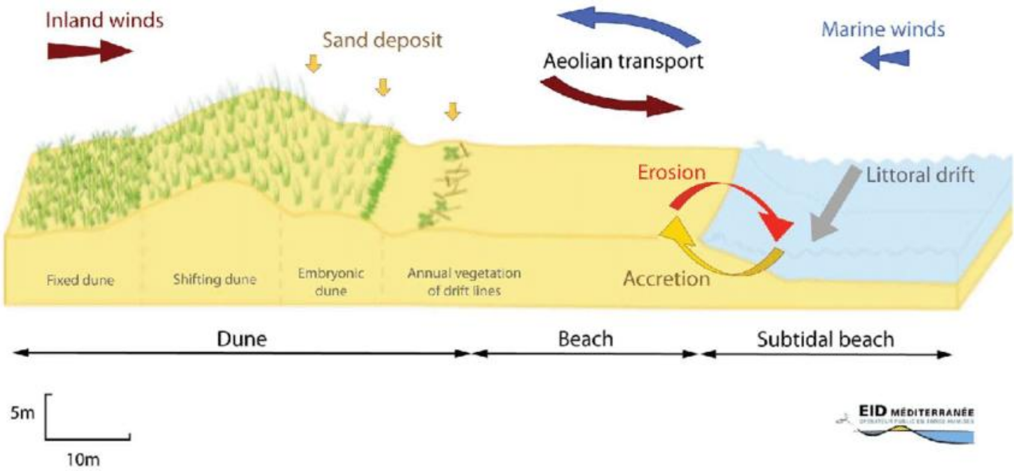

Figure 1 Cross section of a sandy coastal dune (Balzan, El, Hassoun & Aroua, 2020)

A second service the coastal dunes provide is an ecological and biological diversity nature. The Dutch coastal dunes contain a wealth of biological diversity and house up to 66% of the flora found in the Netherlands (van der Hagen, Assendorp, Calame, van der Meulen, Sykora & Schaminee, 2020). Consequently, much of the habitats of coastal sand dunes are protected under the Natura2000 legislation (van der Hagen et al., 2020). The sea protection aspect as well as the biodiversity aspect of the dunes are highly correlated to the coastal dune management strategy, which in the case of the Netherlands has changed drastically between the 1980's and today. The management strategies have ranged from mechanically straightening the dunes, building them up and stabilizing them by planting vast amounts of grasses in the past to nature based solutions and actively cutting slits into the dunes to promote sand connectivity between the beaches and the back dunes (Ruessink et al., 2018).

These measures were taken all along the Dutch coastline. Including at Meijendel, a national park and protected area under the Natura2000. However management strategies were applied on a case by case method depending on the local circumstances and responsible management group. This makes Meijendel an interesting case, as it performs four different functions. First of all, it is widely valued for it intrinsic natural value and ecological diversity (van der Hagen et al., 2020). Second of all, at the same time it is located in the Randstad, one of the most densely populated areas within the Netherlands. Subsequently the area also fills a recreational role to many visitors from the city. Third of all, the park houses water filtration facilities which are crucial in the water supply of the neighbouring cities. Finally, it provides the low

lands behind protection from the sea (Duinwaterbedrijf Zuid-Holland et al., 2000).
All of these different functions are addressed in the management strategy and subsequent management methods. However, the importance or value placed upon each of these different functions in relation to each other has changed over the last decades. Where protection from the sea and water filtration were the dominant factors influencing the management direction until the 1980's nature preservation/restauration and recreation have become the more dominant factors from the 1990's onwards (Duinwaterbedrijf Zuid-Holland et al., 2000).

These three elements, the policy, the morphology and the land cover are closely connected to one another. However the precise impact of policies on dune morphology and land cover are not always clear or documented. By combining both historic and contemporary data a comprehensive understanding of coastal dune development and the impact of management approaches can be investigated. Therefore this study poses the following research question.

2. Research Objectives

Research question:
"How have the Dutch coastal management policies influenced the morphological and land cover characteristics of national park Meijendel over the last 44 years?"

Sub questions:

1. How have the national and local coastal dune management strategies changed over the last 44 years?
2. How to measure/ quantify the impact of management policies?
3. How have the morphological characteristics developed?
4. How has the land cover developed?
5. Is there a correlation between the observed morphological, land cover change and the policy?

Scope:

As previously mentioned this study will analyse the dune park Meijendel, which is part of the national park "Hollandse Duinen". Meijendel is one of the larger dune parks in the Netherlands. Especially the Wassenaar side has had more space and opportunities for restauration activities over the past 40 years. This as a result of less significant water infiltration activities of dunea in this area. Due to hardware limitations it would not be feasible to analyse and consider the whole of Meijendel. Therefore it has been split into two sides, the Hague and Wassenaar. As the later has been the sight of more involved restauration activities it has been chosen as the study area (Figure 2).

The policy analysis will focus specifically on programmes and interventions aimed at the restauration and preservation of the dune environment. Subsequently policies regarding specific water infiltration regulations and or tourism initiatives will not be taken into consideration.

The research is specifically focussed on documenting and subsequently analysing what has occurred over the last 44 (1975-2020) years from both a policy and physical (morphological and land cover) perspective. The two are closely linked together as multiple policies directly and indirectly affected the physical characteristics of the dunes. The GIS analysis will indicate if any physical changes occurred. Combining these results with a thorough policy analysis will allow the two to be correlated to one another. It does not aim to create a model to predict dune dynamics into the future.

The goal and scope of this study have in part been influenced by several consultations with Deltaris, Hoogheemraadschap Hollands Noorderkwartier and Dunea. Dunea in particular proved to be invaluable due to the provision of high quality data in the form of areal imagery and digital terrain models. It is this data which allows the analysis, as described in this document, to be applied on a 44 year temporal scale.

2.1 Study area

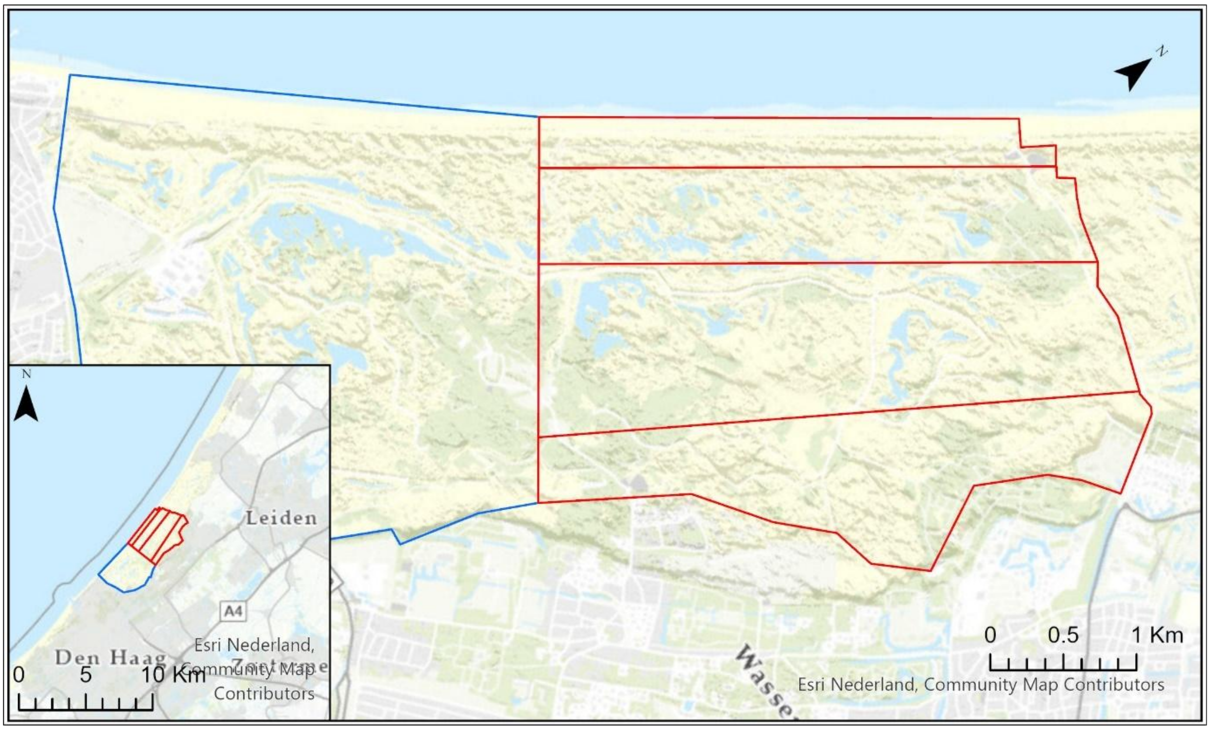

Figure 2 Meijendel in blue, study area in red

The study area is located on the western shore of the Netherlands in the province South-Holland. The study area is located within the national park Meijendel (Figure 2). The study sight covers an area of 10.4 square kilometres. Elevation ranges from 25 metres to sea level. The dominant wind direction throughout the year is from the west/ south west.

3. Methodology

This project aims to analyse the effects of national and local coastal dune policy on the dune park Meijendel. The aim of dune policy has generally been to affect either the morphology and/or landcover of the dunes. As such the study will focus specifically on these two elements.

In order to create a comprehensive overview of the effects of coastal dune policy this study will look back 44 years into the past. The effects of coastal dune policy are not always immediately present or visible. As such the longer time span will allow the effects to become more dominant and thus able to be detected. This will be done by determining the physical state of Meijendel at 9 different points in time: 1975, 1980, 1985, 1990, 1995, 2001, 2009, 2016, 2020, determining what policies are at play and comparing how the morphological and land cover characteristics have developed between on point and another.

The very first step in this process will by identifying what coastal dune management strategies have been implemented nationally and locally over the last four decades. This will be accomplished through a literature review of academic literature, grey government literature and management plans of Dunea. By the end of this step a comprehensive overview of relevant policies and their intended effects pertaining to the study area will be presented. Second, morphological and vegetation cover changes over the last 44 years will be identified. Finally, the research will try to correlate the observed morphological and vegetation cover changes with the relevant policies.

Where possible the locations of specific policy initiatives or interventions will be overlaid with the results. Subsequently, land cover and morphological developments within intervention areas can be compared to developments in areas without interventions. Finally, statistical analysis will determine if differences are significant or not.

3.1 Data

To accomplish the above described analysis of Meijendel the following data sets will be necessary (Table 1). The morphological analysis of the dunes can be accomplished in large part using existing lidar data sets created by the Dutch government. However these only go back until 2001. In order to incorporate the historical perspective orthophoto's and photogrammetrically derived DTM's provided by Dunea will be used. The orthophoto's had been geo-referenced and radiometrically corrected by Dunea. Important to note is that the imagery used for the orthophoto's was collected during the time of the year across the different years, the end of June and the beginning of July.

Tabel 1 Data overview.

Year	**Morphological analysis**	**Resolution**	**Vegetation Cover analysis**	**Scale**
1975	Dunea DTM	2m	False colour infrared orthophoto	1:2500
1980	Dunea DTM	2m	False colour infrared orthophoto	1:2500
1985	Dunea DTM	2m	False colour infrared orthophoto	1:2500
1990	Dunea DTM	2m	False colour infrared orthophoto	1:2500
1995	Dunea DTM	2m	False colour infrared orthophoto	1:2500
2001	Algemeen Hoogtebestand Nederland 1: pointcloud	5m	False colour infrared orthophoto	1:2500
2008	Algemeen Hoogtebestand Nederland 2: pointcloud	0.5m	-	
2009	-		False colour infrared orthophoto	1:2500
2014	Algemeen Hoogtebestand Nederland 3: pointcloud	0.5m		
2016	-		False colour infrared orthophoto	1:2500
2020	Algemeen Hoogtebestand Nederland 4: pointcloud	0.5m	Superview Infrared false colour	50 cm resolution
Build up area	Basisregistratie Adressen Gebouwen (BAG) Standplaats	Polygon		
	BAG pand	Polygon		
	Wegen Kadaster Weggebied (INSPIRE Harmonised)	Polygon		
Water	Hydrografie Waterbody (INSPIRE Harmonised)	Polygon		

3.2 Land Cover Classification and Analysis

Van der Hagen et al (2020) studied the vegetation cover change on a sub set of areas in Meijendel using a supervised classification method. In their analysis they made use of high resolution false colour infrared aerial imagery, classified the imagery and quantified their results into cover percentages of each class, bare sand, grassland and shrubland. This is a method commonly used to analyse and monitor the state of a wide variety of landscapes, including dunes (Jamsran et al., 2019; Xi and Niculescu, 2021).

The vegetation cover will be analysed with a supervised land cover classification method. The land cover classification will be done using ArcGIS pro 3.0. This software provides multiple relevant tools to complete a land cover classification, including the possibility of either object or pixel based classification (esri). Nayaka and byrne (2019) made use of an object based approach to classify high resolution imagery of a beach eco system. Since 2010 supervised object-based classification methods have been essential within the remote sensing research field (Ma et al., 2017). The ersi software ArcGIS pro 3.0 spatial analyst provides the widely used support vector machine (SVM) tool which will also be utilised in this study. Jamsran et al., (2019) used svm and found it to be more accurate, less sensitive to the number of available training samples and better able to differentiate between vegetation classes such as grasslands and trees when compared to the maximum likelihood classifier.

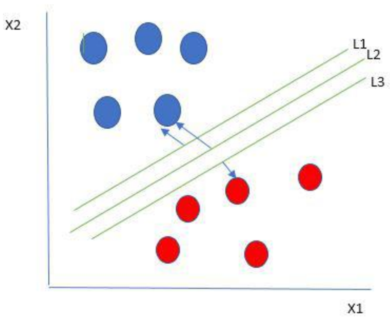

Figure 3 SVM data seperation example (Geeksforgeeks, n.d.)

The support vector machine (SVM) classification is a supervised machine learning algorithm. The aim of this algorithm is to take a data set or input, consider the different classes of the data points and their attributes, and subsequently find a “plane” which separates the different classes from one another (Suthaharan, 2016). Furthermore, it looks for the “plane” which is furthest removed from the data points of each class. In the simplified example on the right correct plane would be L2. In this example the dataset is linearly solvable, meaning that a singular plane, also referred to as hyperplane, can divide the data set. To determine where this plane is located SVM uses the following formula: $y = wx' + \gamma$ (Suthaharan, 2016). However, there are also cases where a dataset, or classes, cannot be divided linearly. In which case it would be classified as a non linear SVM. Unlike a linear SVM a non-linear SVM first transforms the dataset using a kernel function (Suthaharan, 2016). There are several different kernel functions such as: polynomial, radial basis function, and hyperbolic tangent. These transformations move the dataset in a space called “feature space”. Within this space the hyperplane is found using the following equation: $y = w\emptyset(x') + \gamma$. Subsequently the SVM algorithm aims to maximize the margin between the hyperplane and any datapoint. It does so using a “Hinge loss function" and a “regularization parameter”. The function aims to maximize the margin, meanwhile the regularization parameter aims to balance functions accurate and falls predictions.

Land cover classification has been based on both satellite- and aerial imagery and both approaches have been used separately and in conjunction within the literature (Nayak and Byrne, 2019).

This study will make use of two different data sources for the land cover classification depending on the year in question. Those two being satellite imagery and false colour infrared aerial orthophoto's. Although a land cover classification can be run on RGB imagery it is more common within the literature making use of the NDVI to distinguish between vegetated and bare areas (Choi, Seok Keun et al., 2017; Aly et al., 2016). Furthermore, in their specific coastal study area they found that an object based classification run with NDVI obtained the highest accuracy result when compared to RGB and pixel based methods. This study will employ an object based supervised classification method using false colour infrared imagery (Appendix I).

The land cover will be classified into 4 different classes. Those being: Bare sand, sand with scarce vegetation, trees and scrubs, and shade. A similar number of classes used by van der Hagen et al (2020). Subsequently the cover percentage within the study area of each land cover class can be compared over the years. Additionally the development of a pixel from one class to another class the next year can be tracked. This is also known as post-classification change detection (Jamsran et al., 2019). This analysis will also look at changes in specific dune sections, expansion and shrink of clusters and compare area's with management actions to areas without actions.

Assendorp (2010) provides a clear description and visual indication of trees, shrubs and sand. These examples are specific to Dutch coastal dunes and taken from false colour infrared imagery. These descriptions were used as input during the selection of training samples for each of the classes.

A key step in executing an object based image classification is segmentation. During the segmentation process pixels are grouped together into segments. The grouping of pixels is based on their proximity to one another and the similarity of their spectral characteristics (ESRI, n.d. Petropoulus et al., 2012). In addition to the average value per data band statistics such as minimum, maximum and standard deviation are taking into consideration. Furthermore, characteristics such as shape, size, tone, compactness are also considered in the grouping of pixels into segments (Petropoulus et al., 2012).

In Arcgis pro 3.0 this step is completed using the segmentation tool in the image classification wizard. The tool can be adjusted through three parameters: spectral detail, spatial detail and minimum segment size. In the case of the Meijendel dune landscape more weight was placed on the spectral detail parameter (a value of 19 out of 20) when compared to the spatial detail (a value of 10 out of 20). This was found to provide the most representative visualisation of the imagery. Finally minimum segment size was placed at 1.5 square meters. This allows individual trees or shrubs to be grouped into one segment, but stops "pixilation" or splintering of the scarce vegetation found on sand throughout the study area. Subsequently the image is segmented based on a mean shift approach (ESRI, n.d.). This entails the pixels are analysed and grouped together through a moving window. This process includes several iterations to ensure pixels are grouped into the correct segment.

Finally the Support Vector Machine classifier is trained and the image classified. Subsequently the accuracy of the classification has to be determined. This will be done through a confusion matrix. A stratified random strategy distributes points across the study area. Subsequently, the classification can be tested against the ground truth. As there is no ground truth or reference classified dataset available, the points will be checked manually to determine if the classification was accurate or not.

Testing on a smaller subset of the data showed the classifier had significant trouble differentiating between developed area's such as buildings and asphalt, and sand. Subsequently, either significant parts of bare sand were classified as asphalt or vice versa. The addition of training samples and sub-classes did not improve the issue significantly. As the developed/ urban areas only cover a very minor percentage of the study area and are not the main focus of the research question the decision was made to mask them out of the imagery. This will be accomplished using three kadaster datasets (Table 1). The datasets required minor manual adjustment to fit the different years. Subsequent classifications achieved a significantly higher accuracy.

3.3 Morphology Analysis

One of the main elements through which coastal dunes can be characterised is their morphology. Subsequently, there have been policies influencing the morphology both directly and indirectly. In order to analyse the development of the dunes morphology this study will use temporally distributed DEM's to analyse and quantify the changes over time (Figure 3).

DEM or DTM's of difference are a common method used to gain insight into spatiotemporal changes. Hilgendorf et al., (2021), Eamer and Walker (2013), Kaliraj et al (2017) and Carvalho, Kennedy, Niyazi, Leach, Kohnlechner & Ierodiaconou (2020) all made use of Dem of Difference or DoD's to study geomorphic and volumetric change in coastal dune ecosystems. Similarly, Ding et al., (2020) employed DEM differencing to gain insights into the mass balance of dunes near Dunhuang.

The study will make use of DoD's to first identify where a change has occurred by subtracting the DTM of one year from the next. Subsequently it will take a closer look at the volumetric changes in these locations. The Surface volume tool found in ArcGIS pro will be used, in which the reference plane was set to 0 meters NAP, the vertical reference datum. The volumetric analysis will look at both localised changes and larger dune section level changes. Additional metrics will include: average, minimum and maximum elevation. The coastal dunes can typically be separated into three distinct sections or areas of interest: the fore-, middle- and back dune. The Beheerplan Berkheide, Meijendel en Solleveld (2009) describes at what distances from the beach these different sections can be found. Subsequent variations in height and volume can then be analysed.

There are semi-automated methods which identify the dune toe, crest and heel (Wernette et al., 2018; Smith et al., 2020), the transition from beach into fore dune, however these methods are not able to distinguish between fore-middle and middle-back dune. These differentiations will therefore be made using expert opinion from existing management plans.

Finally, this study will also make use of a vector ruggedness measure (VRM) in order to quantify topographic heterogeneity (Sappington et al., 2007). Popit and Verbovsek (2013) utilised surface roughness as a morphometric indicator to quantify the variability of the surface. In order to do so they compared TRI and slope variability, both of which they deemed to be adequate. Like TRI VRM is a measure used to quantify heterogeneity, both use a moving window to quantify variation.

The vector ruggedness measure uses a user specified moving window, often 3x3, to determine the VRM value for the centre cell (Sappington et al., 2007. It decomposes each grid cell into their respective x, y and z components using trigonometry, slope and aspect measures. Subsequently from these measures a resultant vector is calculated. The vector is standardized where 0 indicates a flat surface and 1 most rugged. The equation looks as follows: $|r| = \sqrt{(\Sigma x)^2 + (\Sigma y)^2 + (\Sigma z)^2}$ and $ruggedness = 1 - \frac{|r|}{n}$ where n is the number of neighbouring cells. The resulting index value is subsequently influenced by the spatial resolution of the dem.

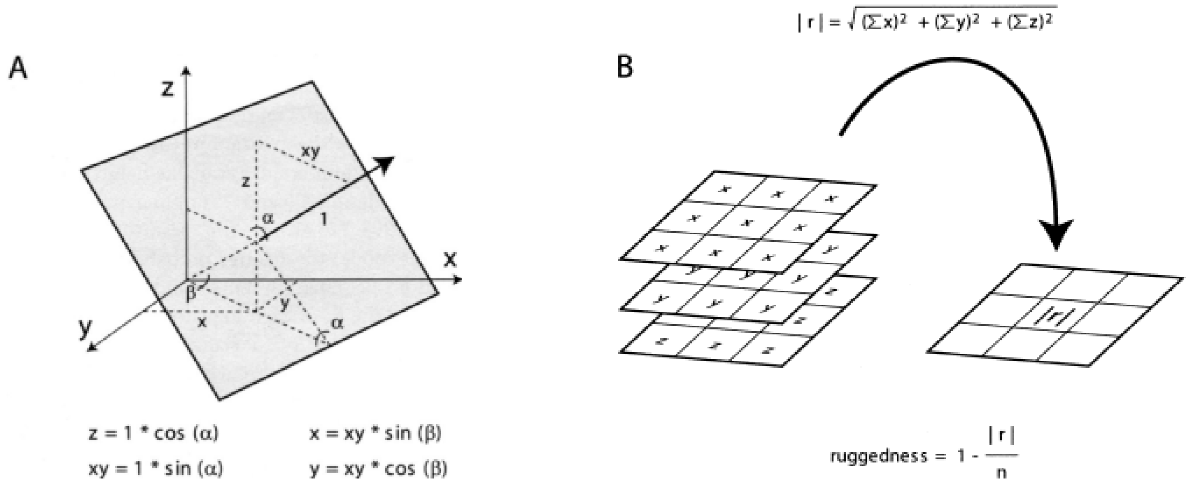

Figure 4 Visualization of VRM by Sappington et al., 2007

Applying the lessons learned above this study will apply calculate the VRM at a 2m resolution. Testing with higher and lower spatial resolutions displayed the same characteristics as found by Popit and Verbovesk (2013). Two meter is the native spatial resolution of the dunea DTM and the AHN DTM will be resampled to match this resolution.

DEM's and raw point clouds of the study area are readily available for the years, 2001, 2008, 2014 and 2020 through pdok. These Lidar derived products are made through a government initiative and updated on a set interval. However this process was only started in 2001 and there are no earlier Lidar products. In order to include these years into the analysis data will have to come from a different source.

Dunea, more specifically the companies it originated from, has flown aerial photographs every 5 years from 1975 onwards over the study area. The imagery in question was flown stereographically and at a very high spatial resolution. Subsequently, the stereographic imagery was used to create digital terrain models at a 2 meter resolution through a photogrammetric process. Historic stereo aerial imagery has been used within the literature to create DEM's. Grottoli et al., (2020) created a historic dem of dundrum bay, North Ireland, from aerial imagery taken in 1963 using structure from motion (sfm).
Once pointclouds for all years have been obtained they will be transformed using Inverse Distance Weighting into DEM. At this stage the data is ready to undergo the previously stated analysis. The analytical steps will be taken in ArcGIS pro 3.0.

3.4 Accuracy

To ascertain the accuracy of the project two different steps will be taken. First of all, the accuracy of the land cover classifications will be verified using a confusion matrix for each year (Appendix I). Within the study area a stratified random sampling strategy will be used to create 150 points. As there is no control data set each of these points will have to be checked manually. Second of all, when comparing the DEM the error margins for each year will be taken into account when discussing any results. The error margins, or measuring error's, of the dem refer to the range around an indicated elevation within which the real elevation can be found.

3.5 Software

In order to process, analyse, visualise and draw conclusions from the data this study will rely on the ESRI software "ArcGIS Pro" version 3.0. This software has all the required tools and abilities to perform the analysis set out above (Figure 3). The image classification will be completed using the classification tools provided in the software. This includes the "segmentation tool" and "training sample manager". Subsequently the image will be classified using the "classification wizard" which is able to perform a supervised object-based image classification using the support vector machine classifier. Furthermore, the accuracy will be attained using a "confusion matrix". Finally, the classified images can be analysed by looking at type change and cover percentages.

The morphological analysis will also be performed in ArcGIS Pro. The software will be able to transform the AHN point clouds to las files using the "convert LAS" tool. Subsequently the point clouds obtained from AHN and Dunea can be converted to rasters using the "LAS Dataset to raster" tool. Subsequent analysis of the rasters, including the TRI, will be completed using the "raster calculator" and/ or in conjunction with the "surface volume" and "extract by mask" tools.

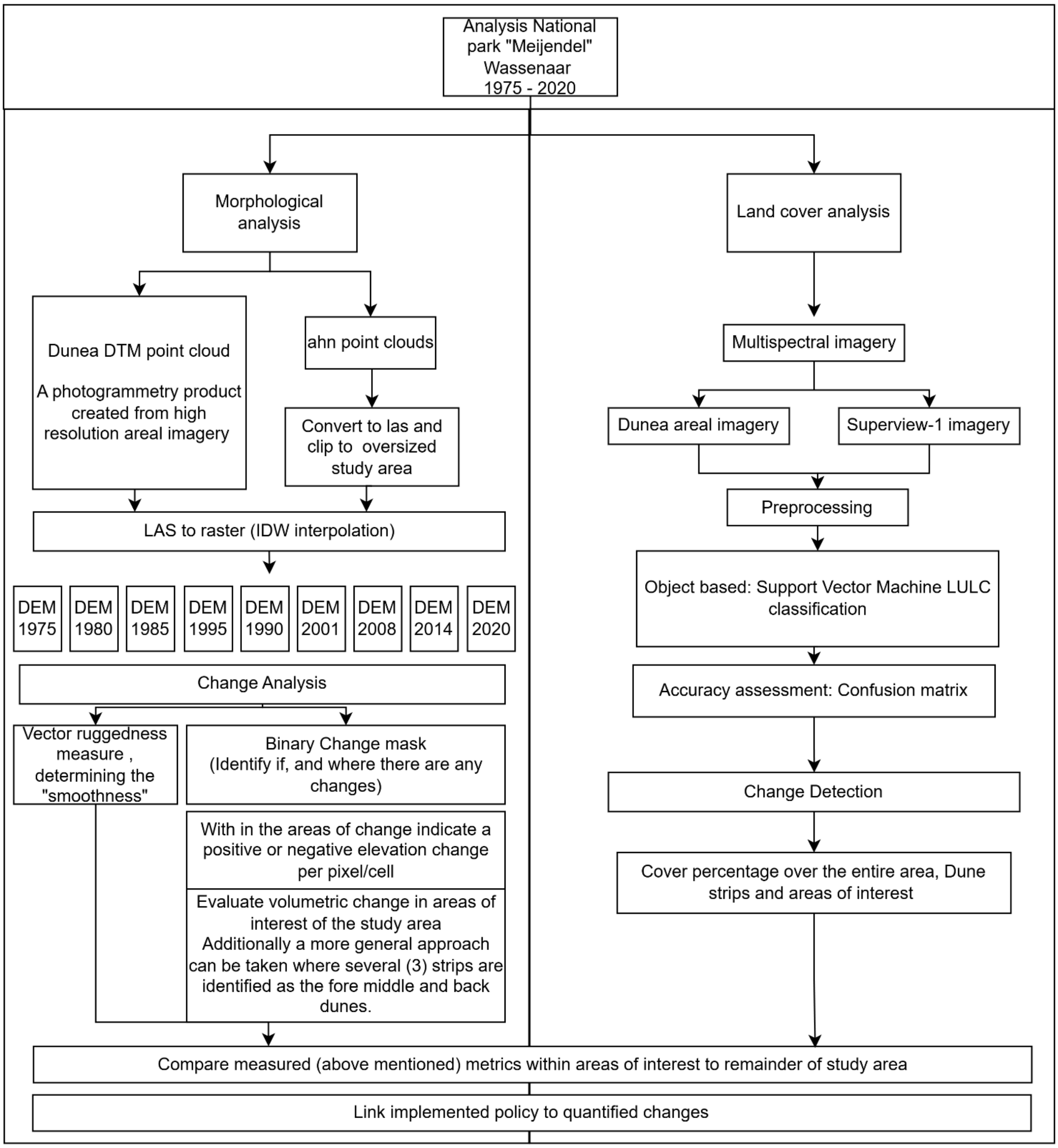

Figure 5 Methods overview

4. Policy Analysis

4.1 Coastal Dune Policy in the Netherlands

When discussing coastal dune policy there are three different levels or entities that should be taken into account. First of all, there is the owner of the land. The owner is usually a national or local government institution or a water company. Second of all, there is the responsible entity. This responsible entity is one of the 21 different waterboards in the Netherlands. These happen to be one of the oldest government institutions in the Netherlands. The first one, hoogheemraadschap van Rijnland, being established in 1255 by “Graaf Willen II van Holland”. Third of all, there is the management entity responsible for the implementation and execution of the management plans. Depending on where along the Dutch coast you are different parties are responsible for these 3 functions.

As a result coastal dune policy is not necessarily straight forward. The multiple involved parties, especially along the coastline, are able to create their own policy and management strategies for the middle and back dunes (specify a number of meters from the coast). Subsequently there is no uniform or national policy in place and instead is being approached on a case by case method. In contrast the beach and foredune are the responsibility of Rijkswaterstaat and as such have been managed and maintained under a national policy piece.

Table 2. Overview of the relevant entities in the management of Meijendel (Beheernota Dunea 2010-2020)

Function	Entity
Ownership	- Staatsbosbeheer - The Hague
Responsibility	- Hoogheemraadschap van Rijnland - Hoogheemraadschap Delfland
Management	- Dunea - Staatsbosbeheer

In the case of Meijendel there are five relevant entities involved in the management of the national park (Table 1). For the extent of the study area this is further reduced, only the frontal dunes are managed by staatsbosbeheer. The middle and backdunes are management and maintained by Dunea (Figure 4).

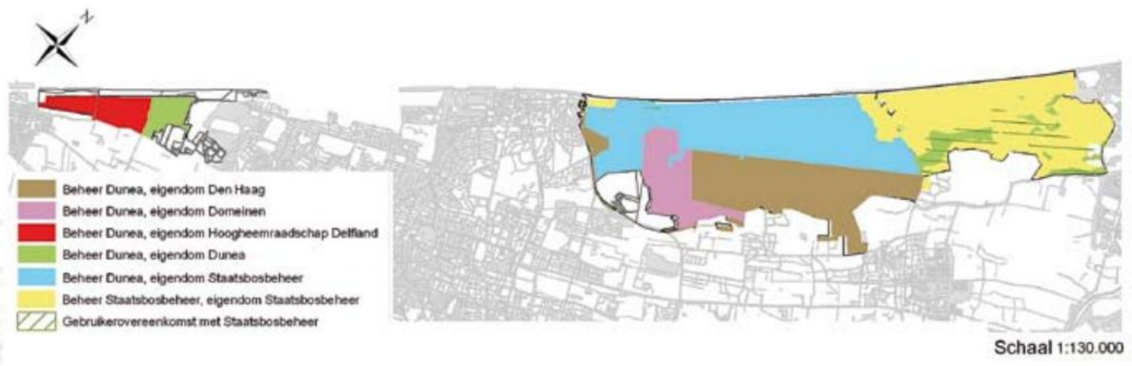

Figure 6 Responsible management entities

This chapter will provide a comprehensive overview of management strategies and policies affecting the coastal dune park Meijendel. The focus will be with policies intended to directly or indirectly affect the landcover or morphological development of the park/dunes. First it will take a closer look at the policies which have been created and implemented on a national level. A comprehensive overview dating from the 1970 until 2020 will be made through a policy analysis. The focus of these policies is expected to lie with the beach and fore dune while the middle and back dune remain out of scope. Second, this chapter will take a closer look at the management strategies and implementation on a local level, these are expected to include more actions within the middle and back dunes. This will mainly concern Dunea policies. Finally, if applicable, measurable features or results will be identified per policy.

4.1.1 National Policy

Until 1989
The Dutch have a long standing relationship with coastal protection measures in their fight against the sea. The Dutch coastline is 350 km long and 254 of those kilometers are made up of dunes (Kosterf and Hillen, 1995). Until the 1990's the coast was characterised by varying levels of accretion and erosion and measures where only taken when the polders behind the dunes or special values in the dunes were at risk (Kosterf and Hillen, 1995). The 1953 floods introduced an era of coastal fortification and saw dunes and dikes being strengthened (van der Meulen, van der Valk and Arens, 2013). During this period many of the Dutch coastal foredunes saw a decrease in both width and volume (Keijsers et al., 2013).

1990 – 2000
The year 1990 became a pivotal moment in the national Dutch coastal defence strategy. This year saw the introduction of the "hold the line policy" or "dynamic preservation policy" as a response to the continued coastal erosion of the last centuries (Rijkswaterstaat, 1990; Kosterf and Hillen, 1995; Keijsers et al., 2013). This policy piece marked the first time the coastline would be maintained in precisely the same position (Kosterf and Hillen, 1995). The policy states the coastline will be preserved in line with the reference coastline, otherwhise known as the basis kust lijn. The basis kust lijn referred to the state of the coastline during 1990.

The preservation of the coastline was to be accomplished with sand nourishment and interference of the sediment transfer process. Each year the current state of the coastline would be compared against the BKL and subsequently sand nourishments would be planned accordingly (Keijsers et al., 2013).

Sand nourishments can be made in several different ways. Sand can be deposited directly on the dune or it can be sprayed onto the beach. Furthermore, it can also be deposited underwater near the coast. In the case of Meijendel four sand nourishments were undertaken directly in front of the area.

Table 3 Sand nourishment in front of Meijendel (Coastal viewer)

Year	Type	Volume
1994	Beach	700000 m3
1997	Beach	552800 m3
2002	Underwater	2508887 m3
2006	Underwater	800400 m3

The method of sand nourishments was deemed to be an effective form of coastline preservation (Roeland and Piet, 1995; de Ruig, 1998). Furthermore, they made the estimate it would take 7 million cubic meters of sand per year to preserve the entire Dutch coastline. However, it is important to note this policy only refers to the preservation of the coastline, not the dunes behind it. The physical impact of this policy can be quantified by quantifying and comparing the beach volume across the different years.

Roeland and Piet (1995) advised that for the full restauration of the coastal dunes a more dynamic approach would also have to be taken in the management of the foredunes. This dynamic management would express itself through blowouts, wash-overs and mobile dunes.

2000 - 2020
This year saw the expansion of the “dynamic preservation” policy introduced in 1990. Where the preservation scope previously only included the BKL it was now expanded to include the entire coastal zone. This meant not only the sand volume of the beach was important but now also the dune system. The management strategy was subsequently renamed from “dynamic preservation” to “maintain the system” (Keijsers et al., 2013).

The new management approach focussed on the functionality or the entire coastal zone. The system approach includes the transportation mechanism of sand from the beach to the dunes (Keijsers et al., 2013). It is this system which allows the dunes to grow and ultimately fulfil their protective role (van der Valk, 2013).

4.1.2 Local Policy

1950 – 1970
During this period the vegetation in Meijendel changed drastically. The area has seen a large increase in grass, bushes and forest area’s (beheersplan 2000-2009, basis document). This can be attributed primarily to human intervention. During this period helm was being planted at a rate of up to 70 hectares per year. Furthermore, mostly native bush species and trees were being planted, at a rate of over 100.000 examples per year (beheersplan 2000-2009, basis document). Finally the decrease in rabbit population and nutrient rich river water, which was pumped into the dunes for drinking water production purposes, aided the increase of forest, shrub and grass landscapes.

In the name of coastal protection (from the sea) the frontal dune had been pulled straight and had been planted full of helm grass. The purpose of the helm grass was to stabilize the fore dune and stop blowouts. As a result its natural character has been completely lost (beheersplan 2000 2009 basis document).

1970 – 1989
The coastline and its dunes continue being stabilised as much as possible. This was being accomplished using a combination of helm grass planting and barriers.

Nature was not only affected for the sake of coastal protection, but also by recreational activities. During the 1970’s nature conservationists and biologists start to worry about the effects of recreational activities on nature. It was subsequently concluded 80 hectares had been severely affected, 33 of which had lost its authentic character entirely (Engeldorp and Kuipers). To counter act this development a new zoning plan was created to keep visitors from certain area’s and straying of the path.

Around the 1980’s large grazers are first suggested as a solution to the stabilised/overgrown dunes (Bakker, 1990). In 1986 a nota provided a comprehensive overview of relevant aspects around the use and implementation of large grazers in the Meijendel dune area. The main points of which were adopted in the 1987 management plan for Meijendel (Bakker, 1990).

1990 – 1999
All of the bare/ open sand in the area had been systematically stabilized through planting in the four prior decades. This had been done in accordance with the hoogheemraadschappen. Consequently Meijendel had been covered in grass, bush and forest. In order to head into a new direction and actively counter this development extensive grazing was introduced into the area during 1990 (Figure 5). This was first done at a ratio of 1 animal per 12 hectares, however in kijkhoef and bierlap this was adjusted to 1 animal per 18 hectares in 1995. The animals in question were horses and Galloway cows. Furthermore, the recommendation was made to leave to grazers out year round. This would ensure the less attractive areas of the dunes were also grazed.

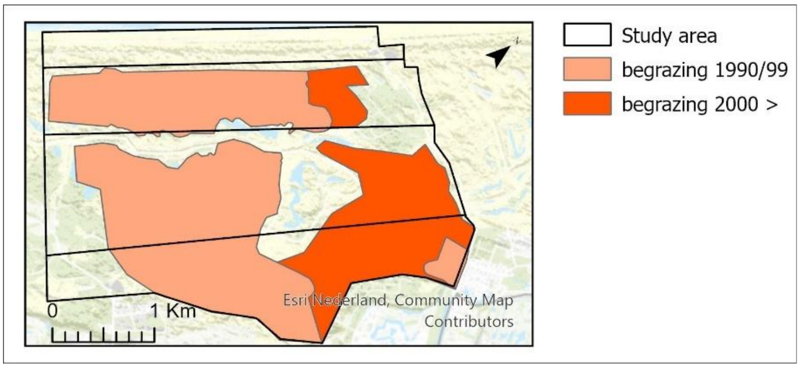

Figure 7 Grazing activities Meijendel 1990 - 2020 (Breedveldt et al., 2016)

During the previous decade tourism was identified as a threat to nature. The subsequent measures were continued into the 1990's. Dunea's main goal was to reduce the presence of cars and phasing out unwanted recreational activities. Furthermore, the walking paths were adjusted and most of the fencing placed during the 1970's was removed.

Finally, a restauration effort of "De klip" was undertaken between 1995 – 2001. The agricultural patch used for tulip bulbs (bottom right of the study area) had been cultivated intensively and fertilized up until that point. Consequently a nutrient rich topsoil had been formed. The restauration efforts to return the agricultural land back to a natural landscape involved the removal of the fertile topsoil and introduction of large grazers (Breedvelt et al., 2016).

2000 – 2009
The main goals during this management cycle revolved around the maintenance, recovery and development of natural values in Meijendel. Natural values are defined the preservation of national and international diversity of species and ecosystems.

To accomplish the goal stated above a number of different measures will be implemented. First, the management strategy of the frontal dunes will be changed to a more dynamic management model. This includes letting dunes drift on both a smaller and lager scale. Surface infiltration in the northern part of Meijendel will be scaled back. Developing natural forests by "doing nothing" and specific change management. Removal of invasive tree species. Thinning of forest areas. Developing a smooth transition between the young and old dunes. Grazing activities will be continued and expanded where possible (Figure 5). The hunting of rabbits is prohibited.

2010-2020
During the previous management cycle many larger projects were undertaken to help stimulate and recover natural processes and moist dune valleys. During this management cycle the goal will be to optimise the previously incorporated projects through many smaller initiatives and optimisation of regular maintenance. These measures can be characterised into two groups.

The first of which is “Maai beheer”. Give the natural processes of verstuiving, natural hydrology, grazing and natural vegetation succession space and opportunity to occur. Furthermore the top soil and vegetation will be removed on five slits or sections of the foredune. The vision of this measure is to actively promote the aeolian transport belt and move sand from the foredune and beach to the middle and back dunes. Furthermore, it is supposed to promote the growth of dune grass lands. Finally a measure called “plaggen” is employed on south facing hills to stimulate dynamic dunes. Similar to chopperen this measure entails the removal of the top soil and vegetation. As a result the sand below is exposed to the elements and able to be affected by the elements.

Second of which is “Bos beheer”. As part of these measures the previously started grazing practices will be maintained, expanded to more area and or intensified. The aim of the grazing activities is to counteract the effects of the significantly reduced rabbit population in the park. The intent is that the large grazers eat vegetation and mull the ground by moving around and by doing so stimulate succession. Furthermore, invasive species removal will be continued. Finally the forested areas will be actively delineated and thinned to prevent the forest from expanding into open dune areas. Similarly the wet dune valleys will continue to be mowed to prevent them from becoming over grown with vegetation.

5. Results

In chapter 4 we have analysed the management strategies, ambitions and intentions for the nature park Meijendel. Several distinct management approaches could be identified within the last 40 years. A major shift in management approach has taken place from stabilization to active stimulation of movement. The interventions employed to bring about these changes in the landscape have either had a direct or indirect impact on the land cover or morphology. As such we will aim to quantify both of these features in this chapter. In chapter 6 we will identify and discus correlations between the interventions, their desired outcomes and the landscape.

5.1 Land cover classification

As discussed in chapter 3 the false colour infrared imagery has been classified using an object based support vector machine classifier. The results of this classification can be seen below. The classified maps reveal many changes have occurred over the years, infiltration ponds have been removed, forested areas have been thinned, grassland has expanded, sand blowouts have been promoted, bare sand has disappeared and replaced grass in other areas. These changes are better quantified in the format of a table.

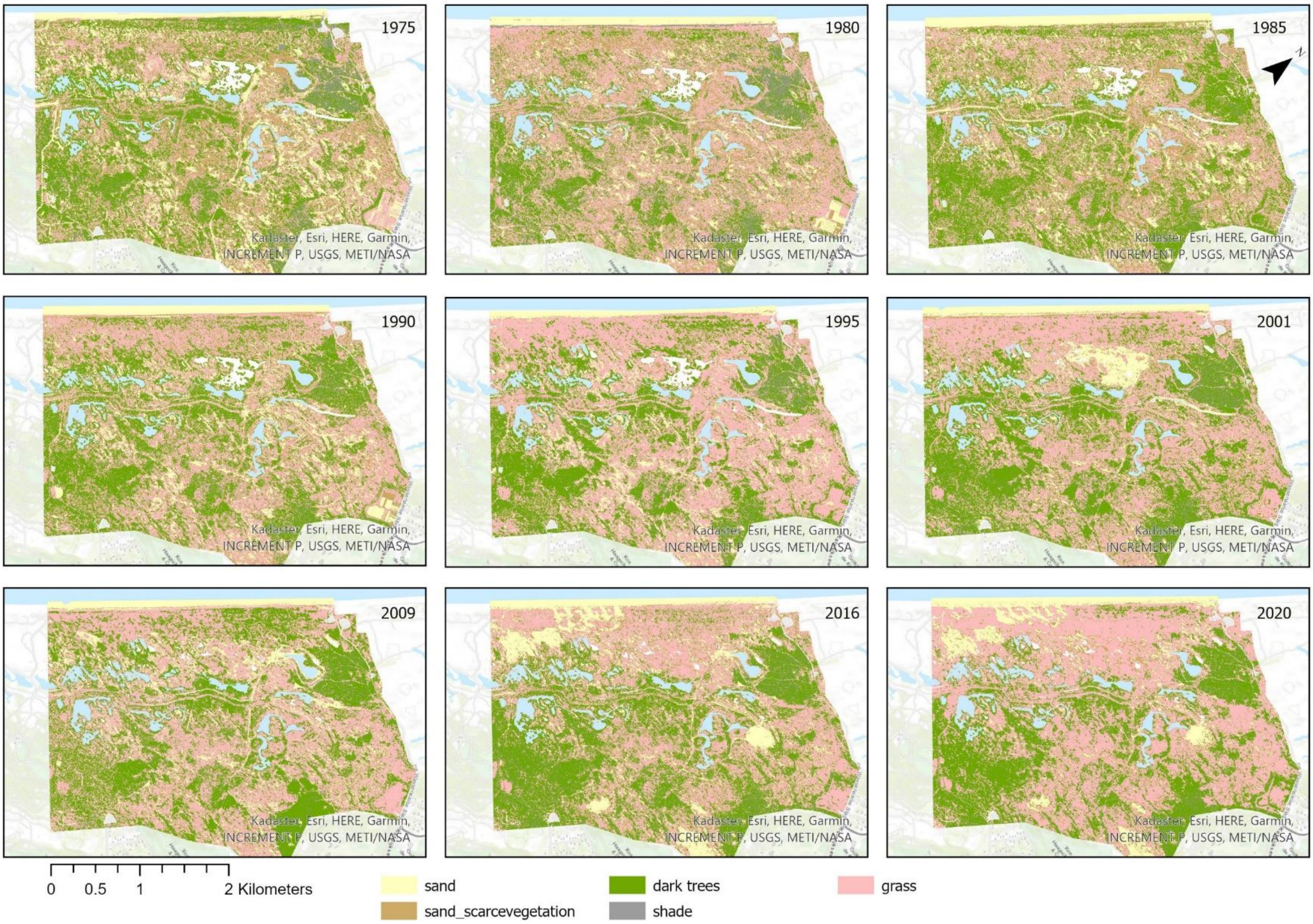

Figure 8 Classified output of the study area Meijendel, Wassenaar, the Netherlands

In table 4 the classified imagery from figure 6 has been compressed to a set of numbers. There are several important points to take away from this table. First of which is the total surface area. As described in chapter 1 the study area comprises 10.4 km2, however the total surface area of the classified landscape does not add up to this number and varies across the years. This is a result of infrastructure and primarily water, the water infiltration ponds, being masked out of the landscape. In 1975 there was more open water within the dunes, as this was cut out of the imagery the total surface area decreased. Over the years some of these ponds were filled in, which caused the total considered surface area to increase as it was no longer being cut out. As the infiltration ponds are located within the fore and middle dunes only these sections experience variation (Appendix III). Second of which is the accuracy, defined by the Kappa score, which varies between 73 and 81%.

Table 4. Surface area per land cover class in km2 per year.

Year	sand	sand & scarce vegetation	grass	trees & Shrubs	shade	total surface area	kappa
1975	1.42	1.18	2.79	3.16	0.46	9.01	0.81
1980	1.00	1.16	4.41	2.57	0.56	9.69	0.79
1985	1.26	1.06	3.56	3.71	0.10	9.69	0.73
1990	1.23	0.75	4.17	3.41	0.15	9.71	0.74
1995	0.96	0.31	4.92	3.04	0.28	9.51	0.79
2001	0.95	0.63	4.42	3.45	0.33	9.77	0.74
2009	1.07	0.38	4.61	3.50	0.18	9.75	0.77
2016	1.30	0.76	3.94	3.42	0.32	9.74	0.81
2020	1.01	0.61	4.91	3.02	0.19	9.74	0.75

As the total surface area varies between the years, the representation of land cover classes is better expressed as a percentage (table 5). Here we can see that between 1975 and 1995 there is a clear trend with bare sand disappearing and vegetation cover increasing. These findings are in line with results from van der Hagen et al., 2017. In the subsequent years this trend seems to stagnate and in some years, 2001 and 2016, even reverse.

Table 5. Land cover class expressed as a percentage of the respective total surface area for that year.

Year	sand	sand & scarce vegetation	grass	trees & Shrubs	shade
1975	15.7	13.1	31.0	35.0	5.1
1980	10.3	12.0	45.5	26.5	5.8
1985	13.0	10.9	36.7	38.3	1.0
1990	12.7	7.7	43.0	35.1	1.6
1995	10.1	3.2	51.8	32.0	2.9
2001	9.7	6.4	45.2	35.3	3.4
2009	11.0	3.9	47.3	35.9	1.9
2016	13.3	7.8	40.4	35.1	3.3
2020	10.4	6.2	50.4	31.0	2.0

Year	Sand + Sand & scarce vegetation	grass + trees & shrubs	shade
1975	28.9	66.0	5.1
1980	22.3	72.0	5.8
1985	23.9	75.0	1.0
1990	20.4	78.0	1.6
1995	13.3	83.8	2.9
2001	16.1	80.5	3.4
2009	14.9	83.2	1.9
2016	21.1	75.6	3.3
2020	16.6	81.4	2.0

When taking a closer look at the results however we find that this trend is not uniform across the different dunes sections (Appendix III). The increase of vegetated land is especially noticeable in the middle and back dune sections. In 1975 around 66% of the middle dune was covered by vegetation. This percentage steadily increases each subsequent time step until 2001 when it hits 86.8 %. In 2009 it remains comparable at 86.5% before dropping in 2016 to 83.5%. This drop in vegetation cover can be attributed to top soil clearing activities within the middle dune section. A similar development trajectory can be observed in the back dune section. A direct consequence of the increased vegetation cover is a lack of sand movement and subsequent halt of the succession process.

A further point of interest is how bare sand is distributed across the study area. In 1975 bare sand seems to be relatively uniformly distributed across the whole study area. There are no obvious large patches of sand, instead there seem to be a myriad of smaller patches. As time passes, and vegetation cover increases, these smaller patches of bare sand seem to disappear. In 2001 and 2016 large patches of bare sand appear where there used to be not as a result of human intervention. Subsequently, these large patches of bare sand seem to reduce again in 2009 and 2020.

5.2 Volume

Next to its cultural and ecological value the dune landscape also provides a fundamental function as protection from the sea. As such policies have aimed at improving and securing this protection factor. Which is why volume is a relevant factor to consider. This metric has been calculated using the "volume" tool in ArcGIS. As this is specifically relevant in relation to flood protection the volume has been calculated between the DTM and 0 meter elevation NAP.

Table 6. Surface volume above 0 meters NAP.

Volume in m3

year	beach	fore	middle	back
1975	11582993	17596210	38910509	36528463
1980	11266013	17606166	38914394	36484014
1985	11376889	17513478	38789970	36452490
1990	11307917	17506032	39058521	36464972
1995	11215582	17454229	38914741	36457079
2001	11851172	17860775	39410715	36593242
2008	12203437	18863417	40286932	36450708
2016	12207704	17503216	38922433	36336495
2020	12371116	17511606	38798317	36258924

Volume as % of 1975 base year

year	beach	fore	middle	back
1975	100	100	100	100
1980	97	100	100	100
1985	98	100	100	100
1990	98	99	100	100
1995	97	99	100	100
2001	102	102	101	100
2008	105	107	104	100
2016	105	99	100	99
2020	107	100	100	99

The base numbers do not immediately show a clear pattern, which is why 1975 has been taken as a base year to which the following years are compared. When looking at Table 6 there are several noteworthy points. Between 1975 and 1995 the middle and back dunes are very stable with the overall volume of these sections not changing. Important to note however is that this does not per definition mean there is no movement. The fore dune similarly seems to be stable, only loosing 1% of volume between 1985 and 1990. The beach section however seems to be experiencing more erosion, losing 3% of its volume. From 1995 forward the sand budget increases across all of the different dune sections. Specifically the beach seems to increase between 1995 and 2008, and later between 2016 and 2020. Similarly the fore dune increases in volume between 1995 and 2008, however in 2016 it sees a significant decrease in volume.

Visualizing these changes within the study area in Figure 7 we can observe the fore dune to be the most dynamic. In figure 7.c we can see that across the frontal dune its height has increased compared to 1975, with the exception of several slits.

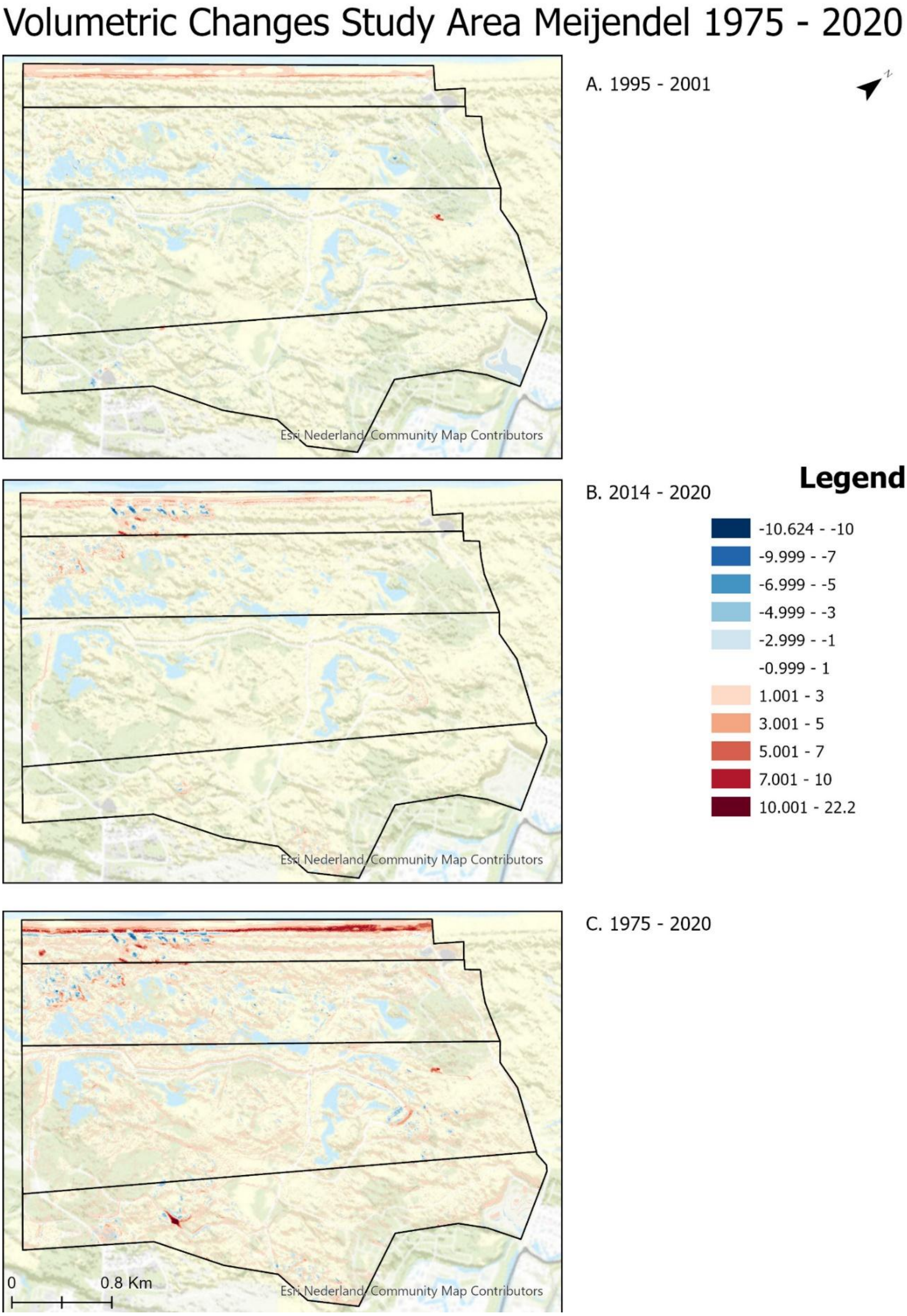

Figure 9 Volumetric changes

5.3 Vector Ruggedness Measure

Table 7. Overview of the minimum and maximum vector ruggedness measure (VRM) per dune section.

	beach		**fore**		**middle**		**back**	
year	max	mean	max	mean	max	mean	max	mean
1975	0.0660	0.0024	0.0804	0.0033	0.2147	0.0030	0.1113	0.0034
1980	0.0665	0.0020	0.0816	0.0029	0.1348	0.0027	0.0939	0.0031
1985	0.0820	0.0022	0.0729	0.0032	0.1211	0.0029	0.0756	0.0033
1990	0.1176	0.0021	0.0784	0.0033	0.0791	0.0030	0.0810	0.0034
1995	0.0582	0.0020	0.0729	0.0032	0.1211	0.0029	0.0756	0.0033
2001	0.0866	0.0047	0.2200	0.0055	0.2755	0.0052	0.2207	0.0061
2009	0.0685	0.0026	0.0909	0.0035	0.0903	0.0031	0.0764	0.0035
2014	0.0978	0.0029	0.0815	0.0034	0.0649	0.0030	0.0765	0.0033
2020	0.1012	0.0050	0.1125	0.0055	0.0886	0.0050	0.0935	0.0054

6. Analysis: Linking Policy and Landscape

6.1 National policy

At a national level there were two main goals guiding the management of Meijendel. The first regards the maintaining of the coastline to 1990 standards and the second regards the general management approach of the dune ecosystem as a dynamic system characterized by the free displacement of sand.

Prior to 1990 the coastline was slowly eroding away. In this analysis this is also visible when looking at the volume of the beach above 0 meters. As can be seen in table 6 the volume reduces every 5 years compared to 1975 levels. To counteract this erosion sand deposits were made both directly on the beach and in the water in front of it. Looking at table 6 there are two specific instances in which the volume increases significantly. The first increase, of 5% compared to 1975 levels, occurs between 1995 and 2001. In 1997 a sand deposit was made directly on the beach, totalling 0.552 million cubic meters of sand. The second increase in volume, of 3% compared to 1975 levels, occurs between 2001 and 2008, similarly two sand deposits were made during this period (2002 and 2006). However, these deposits were made underwater instead of directly onto the beach. Furthermore, they represented a much larger volume of sand, over 2.5 million cubic meters, as can be seen in table 3. The timespan within which the sand depositions were made and the beach volume increased therefore seem to indicate a clear correlation between the two events.

The Meijendel national park has seen an evolution of management practices evolving from a static “hold the line” strategy to a dynamic preservation and eventually a maintain the system management approach. These different management styles affect the landscape both from a land cover and morphological perspective. In the beach and foredunes these management styles primarily affect the morphology, as has been discussed above. In the middle and back dunes however the practices which define these different management strategies are focused on the land cover, which subsequently can affect the morphology.

In figure 8 we can observe the changing amount and location of bare sand in the study area. Table 4 and Appendix III provide further information quantifying these land cover changes. The interventions which brought about these changes however where executed on a local level and will be discussed below.

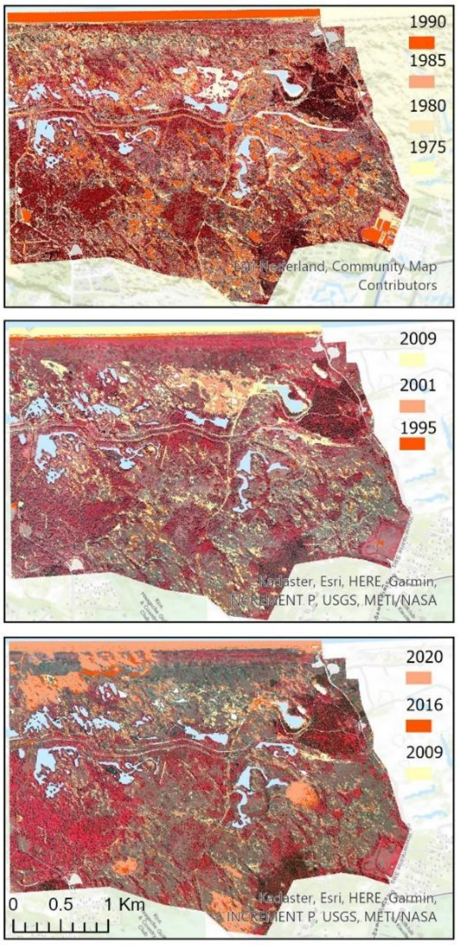

Figure 10 Exposed sand Meijendel

6.2 Local Policy

Up until 1995 “de klip”, a field in the bottom right of the study area, was used as agricultural land for the cultivation of tulip bulbs. It had been levelled and subject to intense cultivation and fertilization for decades when the decision was made to restore it to a natural landscape (Breedvelt et al., 2016). As a result of these activities a fertile layer of topsoil had been developed. As part of the restauration efforts this fertile top soil was removed and large grazers where introduced into the area. Figure 6 and 7 provide an image on how the land has developed since the restauration efforts. The landscape is characterised by vegetation, primarily grass and several patches of shrubs and trees. There is a complete lack of bare sand or blowouts. When looking at the morphological evolution no change is visible. This however is to be expected as the area is covered in vegetation.

Between 1995 and 2001 a body of water in the middle dunes was filled in as can be seen in figures 6 and 7. As a direct result of this intervention the landscape changed to sand. However, this body of bare sand is slowly encroached upon by grass land in the years following the intervention.

During the 2010-2020 management cycle several significant projects were undertaken. In 4 locations throughout the dunes the top soil and vegetation was removed. As indicated in the figure below parcel one was cleared in 2012, the parcels indicated with a 2 in 2013 and parcel 3 in 2014. Parcel 3 was slightly different from the others as it pertained to a section of the frontal dunes. The aim of this project was to stimulate dynamic dunes and the movement of sand.

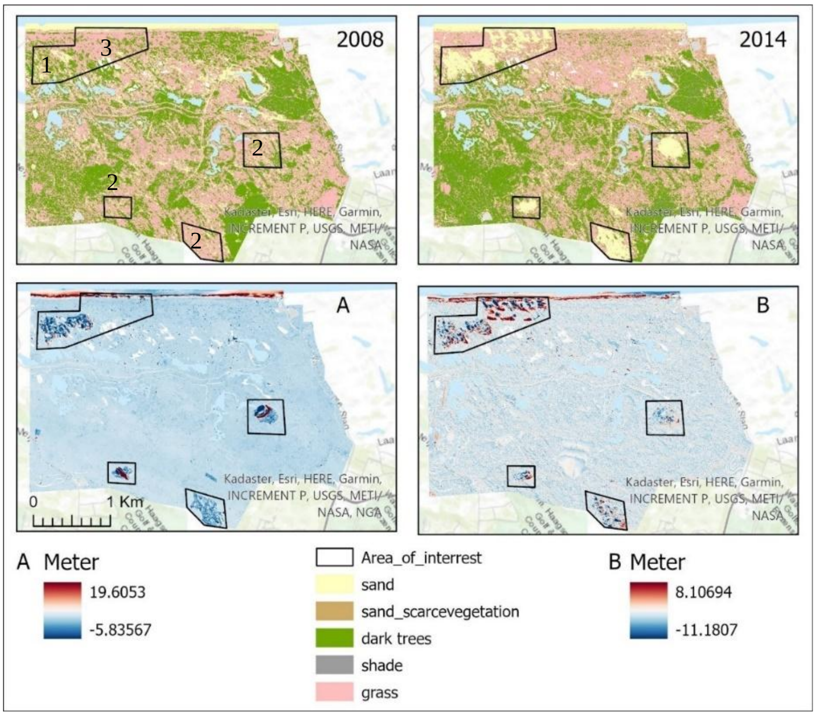

Figure 11 Impact of land cover clearing activities

The impact of this intervention can clearly be identified in figures 7 and 8. The direct impact of this intervention was a change of land cover, from grass to bare sand. A change which is not visible anywhere on this scale throughout the study area. A subsequent effect of this land cover change is that the sand is susceptible to the elements and easily blown away. For parcels 1 and 2 this is clearly visible in figure 9A. Where the sand has been exposed to the elements it is being eroded, as indicated by the dark blue colour. In parcel 1 some of the sand is heaping up near the edge of the cleared patch. The same effect can be seen in the parcels of 2. However, in the left and right patch of two clear depositions of sand are also visible among the erosion. The intended effect of the intervention, mobilizing sand, therefore has been achieved.

Although parcel 3 (Figure 10) was cleared in 2014 no morphological changes are visible in that year as the elements had not yet had enough time to affect any change (Figure 9A). By 2016 however this resulted in the formation of 5 deep gullies in the foredune and sand being transported behind the initial dune where it covered vegetation (Figure 8B). The initial increase in bare sand cover, as seen in 2016, reduces slightly in 2020 as aeolian sand transport reduces and vegetation creeps back in (Figure 8).

Finaly, throughout the 2000 to 2020 management cycle interventions were also undertaken to thin out the forests and shrubbery. Figure 10 provides a clear example of trees and shrubbery being removed and subsequently replaced by grassland.

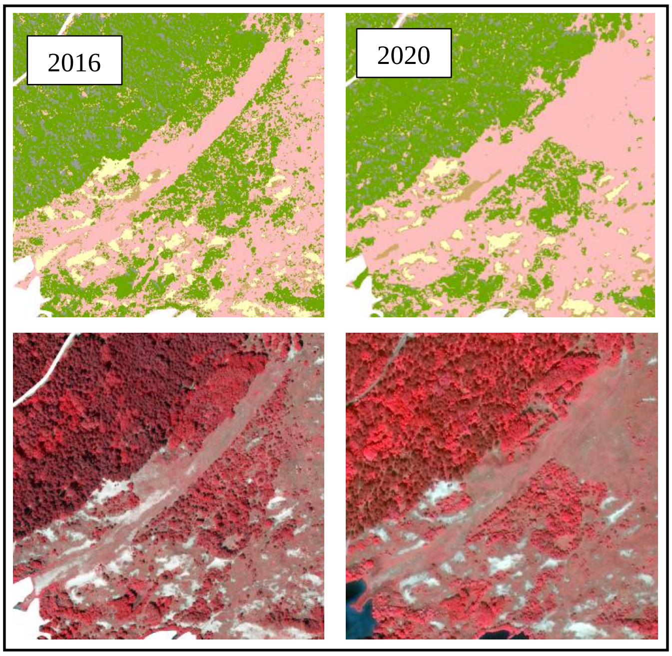

Figure 12 Example of forest thining Meijendel

7. Discussion

Over the course of this study we explored the management of Meijendel, its morphology and its landcover with the aim of identifying a correlation between the three. In order to study this relationship with the data available several compromises had to be made. The first challenge was a result of the older false colour infrared imagery used for the analysis between 1975 and 1995. The imagery was of very high resolution. However, it only contained three data bands, a green , a red, and an infrared band. The absence of a blue band consequently meant that there would be less data to differentiate between the different land cover classes. This turned out to be specifically relevant for the identification of both water and infrastructure (asphalt). As both water and infrastructure were not the main focus of the study the decision was made to mask them out of the data set, which allowed for a better accuracy identifying bare sand, grass, trees and shade. Second of all, as there was not one data set which covered the entire 40 years data had to be taken from two different sources. The year 2020 was not available as aerial photography and thus satellite imagery was used. This imagery however was of a lower resolution. In order to keep the classification process uniform across all of the years the earlier datasets were upscaled to match the resolution of the satellite imagery. Although this was a necessary step it did have a potential effect on the land cover classification process as detail was lost. Lastly, as there was no reference data available with which to confirm the accuracy of the land cover classification this study has had to relied on a manual accuracy assessment. This assessment was undertaken using random samples and a confusion matrix.

This study has provided a clear overview of the different management approaches and subsequent human interventions within the study area. The creation of this overview was complicated by the many different actors and interests involved in the management of Meijendel. The differentiation between national and local policies made better comprehensible. The national policies were clearly stated through government entities, however the local policies were harder to ascertain. This as a result of responsible organizations going through different restructurings and documentation not being available digitally. Furthermore, although the management plans were very specific in their goals and interventions, they rarely indicated specific spatial locations. A fact which is further confirmed by an ongoing internal study into location and duration of grazing practices.

Within the management plans and the policy overview in this study the introduction of large grazers were meant to combat continued stabilization of the dunes. These large grazers were also introduced with the study area defined in this research. However, because of hardware and time constrains the scope of the study area had to be limited to half of Meijendel. Subsequently, the area designated for large grazers covered the vast majority of the study area. Thus without a control area it was not possible to analyse the impact of the large grazers on the landscape within the scope of this study. However, van der Hagen et al (2020) previously a conducted research specifically aimed at this question, within Meijendel, and found the impact of large grazers not to be significant.

The ability to contribute morphological and land cover change to specific management strategies is a great challenge hampered by several key factors. First of which is the sheer number of different variables influencing the dune landscape ranging from planned human interventions such as top soil removal and grazing, to nitrogen deposition from the air and water infiltration, to the weather, temperature, harsh winds, wild animals, decease and the list goes on. Second, not all planned interventions have clear temporal and spatial boundaries or are publicly available, hampering their analysis. Finally, the limited size of the study area influenced the ability to quantify the influence of large grazers on the landscape. However, as the impact and influence of large grazers has already been studied and found to be largely ineffective this does not compromise the comprehensive overview of the Meijendel dune evolution.

This study observed a general trend of increased vegetation cover throughout the different dune section, as has been discussed in section 6. Vegetation cover increased from 66% in 1975 to 81 % in 2020. Bare sand patches seem to have reduced, specifically smaller patches. From the analysis it can be determined that direct physical interventions, such as top soil removal, have had a positive effect on the presence of bare sand cover and sand mobilization. The top soil removal interventions in 2012, 2013 and 2014 opened up large patches of bare sand. The morphological analysis indicated that in subsequent years these areas also saw a decrease in height, indicating sand being transported away. Furthermore, areas east of these patches showed an increase in height, indicating the sand was getting trapped in the vegetation. The direct impact of these interventions seem to deliver the desired effect. However, the effects do not seem to last long term or be a catalyst for a self-sustaining cycle, as vegetation can be seen to encroach onto the bare sand in subsequent years. Therefor topsoil removal interventions would have to be undertaken periodically to promote sand mobilization.

A limiting factor of this research has been caused by data limitations, such as the limited number of data bands in the imagery and only being able to use a digital terrain model. These limitations were caused by the temporal scope of the project, which meant the data availability of the earlier years determined what could be used. Future research should focus on a more recent temporal scope, AHN availability and forward, which would greatly improve data availability. The analysis would be able to make use of additional information bands of spectral imagery, use both DTM and DSM in the classification, and perform the analysis on a higher spatial resolution. This would subsequently increase the accuracy and improve the ability to draw conclusions from the results. Additionally, further research should be conducted to identify and experiment with other methods of stimulating the natural dune succession cycle.

8. Conclusion

To summarize, this research has aimed to expand the understanding of impact on the dune landscape as a result of human interventions. It has done so by looking 44 years into the past up to now, quantifying changes, and linking them with management interventions. To this end the following research question was posed:

How have the Dutch coastal management policies influenced the morphological and land cover characteristics of national park Meijendel over the last 44 years?

As this question has multiple different facets several sub questions were devised to help answer it. First of which, how have the national and local coastal dune management strategies changed over the last 44 years? There is a clear distinction here between national and local policies. The national policy generally focusses on the beach front and the fore dunes in relation to water and flood protection. This was especially the case until the year 2000, after which the Natura2000 status of the nature reserve Meijendel altered this stance to include the protection and restauration of the nature reserve as a whole. The main impact of the national policies have been the sand depletions between 1994 and 2006 which impacted the sand budget and beach line. The local policies where much more focussed on the management of the park as a whole. Over the 44 years three different approaches to the management can be identified. The first was focussed on the stabilization of the dunes as a whole, which lasted until 1990. To achieve this goal helm grass was planted throughout the different dunes sections on a regular basis. The helm grass trapped the sand and stopped it from moving. In 1990's the attitude towards the goal of coastal dune management was beginning to change from a "hold the line policy" to a "dynamic preservation policy. As a result of the previous extensive grass planting and other activities within the park it was losing its natural characteristic and value. The coastal dune ecosystem which relied on succession as a result of sand movement throughout the whole system was no longer functioning. To return this functioning the planting of grass was stopped, human intervention was scaled back and large grazers were introduced within fenced of sections. Finally, starting in the year 2000 a "maintain the system" approach was introduced. The new management approach focussed on the functionality or the entire coastal zone, ranging from coastal protection to ecological functioning.

Having researched and defined the different management strategies throughout the study time period the following sub-question was defined: "*How to measure/ quantify the impact of management policies?".* The purpose of this question was to define how the different management interventions aimed to affect change on the landscape and how they could be detected. At their core the range of interventions aimed to affect change in one of two ways. Either they aimed to alter the landcover or to alter the morphology. The later more specifically referring to coastal protection and beach preservation. The impact of the management policies can be measured by contrasting and comparing land cover change and morphological change. Morphological change has been quantified by making "DEM of Difference" or DoD from digital terrain models. A supervised object based support vector machine was used to classify the false colour infrared imagery into 5 land cover classes, which allowed for subsequent temporal analysis.

Applying the previously identified techniques the following sub-question was answered: "*How have the morphological characteristics developed?*". Morphologically the dunes seem to have been relatively stable. Change has primarily occurred in the beach and fore dune sections as a result of stand depletions and vegetation clearing. After the coastal preservation policy came into force the 1990 coastline has been preserved and maintained using sand depletions in front of and directly on to the beach. This not only maintained the beach, but also grew the foredune in height. The beach section gaining around 1.15 million cubic meters of volume between 1995 and 2020. Furthermore, when the top soil vegetation was cleared on a small section of the foredune the sand was transported into the middle dune, leaving behind clear “cuts” in the foredune. In the middle and back dune sections the change was driven by the filling in of ponds in addition to land cover clearing, which subsequently eroded away. Soil mobility was primarily located around intervention areas. However, as most of the landscape has been covered by vegetation it has also been stabilized. As a result no drastic morphological changes have occurred in areas without direct intervention throughout the study area during the study period.

Using false colour infrared imagery and land cover classification methods the following sub-question could be researched: “*How has the land cover developed?*”. The land cover classifications indicate a trend towards increased vegetation cover, increasing from 66% in 1975 to 81% in 2020. It is exactly this trend which many of the management interventions are aiming to address and reverse. The increase in vegetation cover is best observable in the middle and back dune sections of the study area. As a result bare sand land cover is reducing while vegetation cover is increasing. However, it is also occurring in the fore dune.

Combining the findings of the policy analysis and the landscape quantification the final sub-question was posed: “*Is there a correlation between the observed morphological, land cover change and the policy?*”. When these results are compared with one another there seems to be a clear correlation between some policy interventions, morphological and land cover change. More specifically the clearing of vegetation and top soil, cutting of trees and sand depletions. The latter, as discussed previously, predominantly impacting the beach section by increasing its height. The impacts of top soil removal and tree cutting however are highly localised. Top soil removal has led to the mobilization of sand which causes slight spillover effects outside of the cleared area as the sand is trapped and collected in the vegetation. The removal of trees makes more space for the dune grass landscape. Outside of these intervention areas there is still a trend towards increased vegetation cover, which cannot be attributed to a single source or management approach. However, the observed trends are in line with findings in Meijendel and other dune parks across the Dutch coast. As such the mobilisation of sand will have to be affected through periodic top soil removal. This however relies on human intervention to return natural values in Meijendel and maintain its species diversity and ecosystems.

Future research should focus on more recent temporal scope’s. The more recent scope would allow the analysis to be able to make use of additional information bands of spectral imagery, use both DTM and DSM in the classification, and perform the analysis on a higher spatial resolution. This would subsequently increase the accuracy and improve the ability to draw conclusions from the results.

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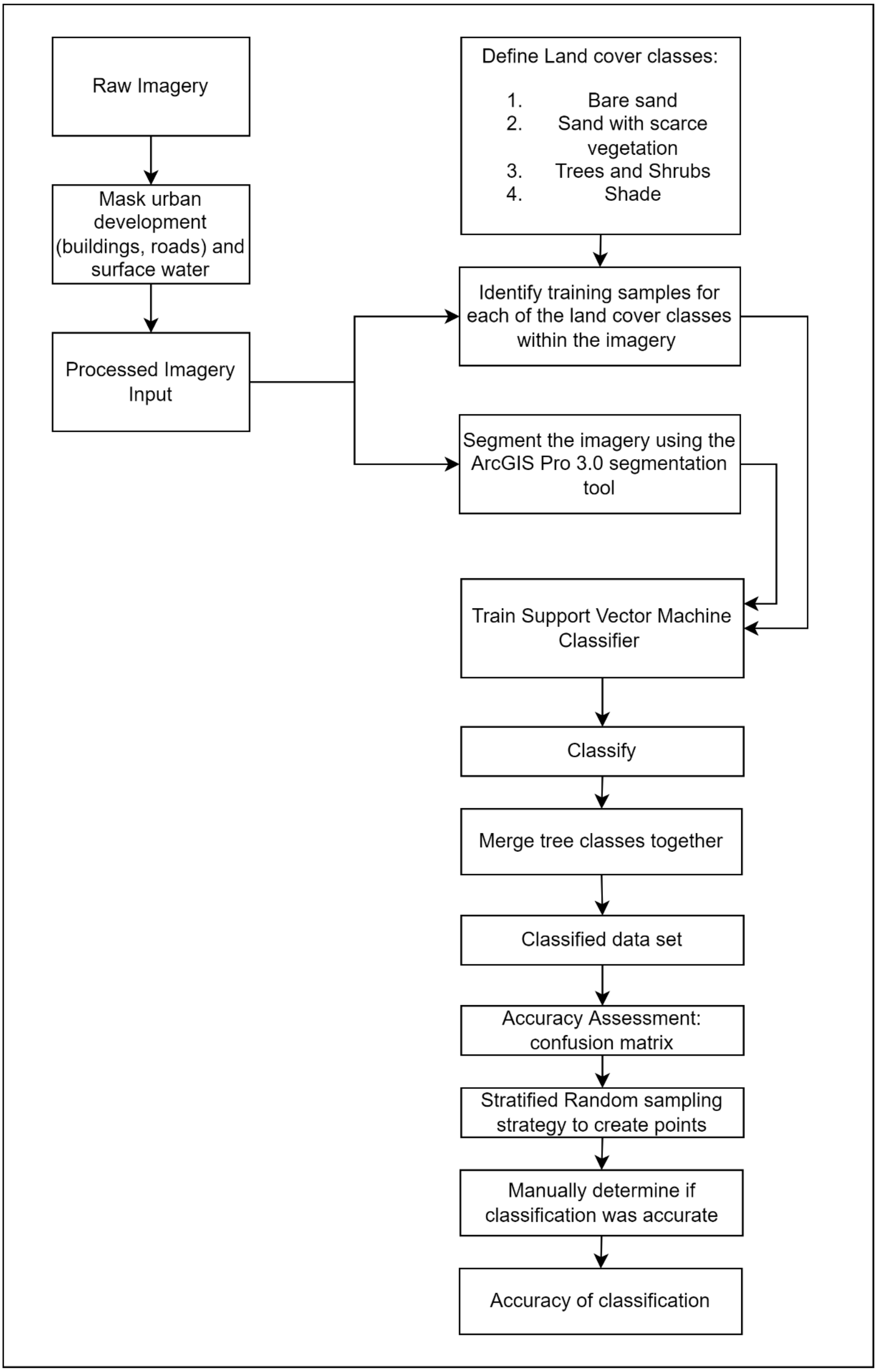
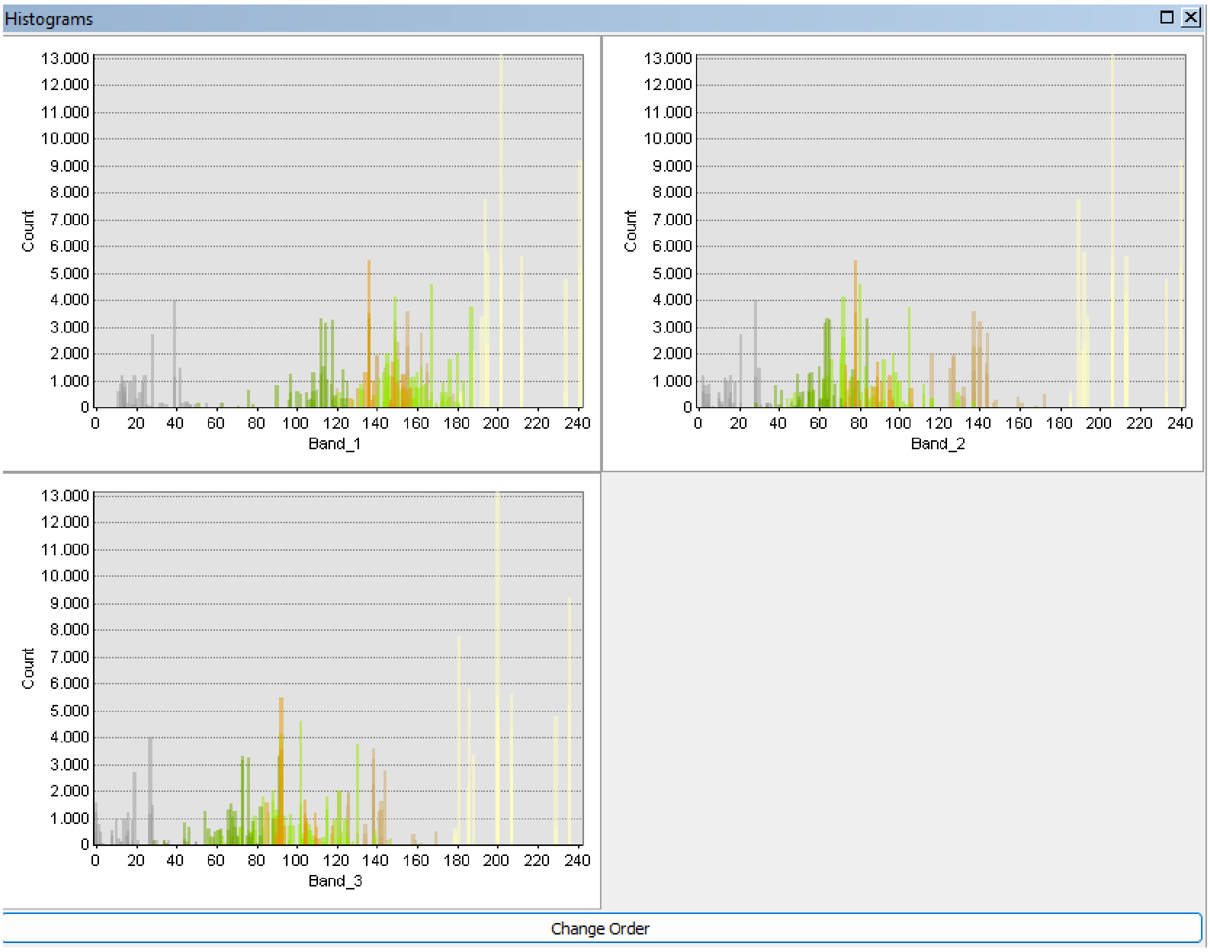
Appendix I



In-depth overview of image classification process undertaken in ArcGIS pro 3.0.

Appendix II

Spectral profile per training sample per class. Colours represent the same classes as in the classified image.



Appendix III Classification Results per year

in km squared

in relative percentage cover

Beach

Year	sand	sand with scarce vegetation	grass and shrubs	trees	shade	Total surface area
1975	0.27	0.07	0.20	0.32	0.05	1.12
1980	0.33	0.15	0.43	0.16	0.04	1.12
1985	0.43	0.08	0.34	0.27	0.00	1.12
1990	0.34	0.11	0.49	0.19	0.00	1.12
1995	0.23	0.02	0.55	0.16	0.00	0.96
2001	0.31	0.07	0.64	0.09	0.00	1.12
2009	0.28	0.02	0.54	0.28	0.00	1.12
2016	0.42	0.11	0.52	0.07	0.00	1.12
2020	0.43	0.05	0.57	0.07	0.00	1.12

Year	sand	sand with scarce vegetation	grass and shrubs	trees	shade
1975	29.7	7.7	22.3	35.0	5.3
1980	29.7	13.0	38.6	14.7	3.9
1985	38.4	7.5	30.3	23.8	0.0
1990	30.3	9.4	43.4	16.8	0.1
1995	23.9	2.4	57.1	16.5	0.1
2001	28.0	6.6	57.1	8.3	0.0
2009	25.0	1.5	48.4	25.1	0.0
2016	37.9	9.4	46.4	6.3	0.0
2020	38.2	4.6	51.1	6.1	0.0

Fore dune

Year	sand	sand with scarce vegetation	grass and shrubs	trees	shade	Total surface area
1975	0.26	0.24	0.71	0.67	0.12	2.00
1980	0.13	0.27	1.05	0.53	0.13	2.11
1985	0.23	0.25	0.88	0.75	0.01	2.12
1990	0.18	0.18	0.92	0.81	0.03	2.12
1995	0.14	0.07	1.15	0.66	0.08	2.09
2001	0.33	0.18	0.99	0.60	0.07	2.16
2009	0.30	0.09	0.95	0.78	0.04	2.16
2016	0.36	0.21	1.01	0.53	0.05	2.16
2020	0.27	0.20	1.26	0.40	0.04	2.16

Year	sand	sand with scarce vegetation	grass and shrubs	trees	shade
1975	13.0	12.1	35.3	33.7	5.9
1980	6.1	12.9	49.7	25.1	6.4
1985	10.6	11.9	41.6	35.4	0.4
1990	8.5	8.5	43.4	38.1	1.5
1995	6.7	3.2	54.9	31.5	3.7
2001	15.1	8.2	45.6	27.9	3.2
2009	14.1	4.0	43.8	36.4	1.7
2016	16.5	9.9	46.9	24.5	2.1
2020	12.3	9.2	58.3	18.6	1.7

Middle dune

Year	sand	sand with scarce vegetation	grass and shrubs	trees	shade	Total surface area
1975	0.46	0.55	1.07	1.31	0.17	3.57
1980	0.29	0.44	1.68	1.15	0.23	3.79
1985	0.38	0.46	1.37	1.54	0.04	3.78
1990	0.42	0.28	1.54	1.51	0.06	3.80
1995	0.35	0.12	1.86	1.35	0.11	3.79
2001	0.18	0.19	1.66	1.66	0.13	3.83
2009	0.30	0.11	1.86	1.44	0.10	3.81
2016	0.25	0.22	1.43	1.74	0.15	3.79
2020	0.16	0.18	1.86	1.52	0.08	3.79

Year	sand	sand with scarce vegetation	grass and shrubs	trees	shade
1975	13.0	15.5	30.0	36.7	4.8
1980	7.6	11.7	44.3	30.3	6.0
1985	10.1	12.1	36.1	40.7	1.0
1990	11.1	7.3	40.4	39.6	1.6
1995	9.3	3.2	49.1	35.6	2.8
2001	4.8	5.0	43.4	43.4	3.5
2009	7.9	2.9	48.8	37.7	2.7
2016	6.7	5.9	37.7	45.9	3.9
2020	4.2	4.7	49.1	40.0	2.0

Back dune

Year	sand	sand with scarce vegetation	grass and shrubs	trees	shade	Total surface area
1975	0.42	0.31	0.81	0.85	0.12	2.53
1980	0.25	0.30	1.25	0.73	0.15	2.67
1985	0.22	0.27	0.97	1.15	0.06	2.67
1990	0.29	0.18	1.23	0.91	0.06	2.67
1995	0.23	0.10	1.37	0.87	0.09	2.67
2001	0.13	0.18	1.13	1.09	0.13	2.66
2009	0.19	0.16	1.27	1.00	0.05	2.66
2016	0.27	0.21	0.98	1.08	0.13	2.66
2020	0.16	0.18	1.21	1.03	0.08	2.66

Year	sand	sand with scarce vegetation	grass and shrubs	trees	shade
1975	16.8	12.5	32.0	33.8	4.9
1980	9.3	11.4	46.6	27.1	5.6
1985	8.4	10.0	36.4	43.2	2.1
1990	10.9	6.9	46.0	34.0	2.2
1995	8.7	3.6	51.4	32.8	3.5
2001	4.7	6.9	42.5	41.1	4.8
2009	7.0	6.1	47.6	37.5	1.7
2016	10.0	8.1	36.7	40.6	4.7
2020	6.0	6.7	45.6	38.7	3.0