Analysis of vegetation changes induced by a European Bison herd in the Kraansvlak area (2003-2009)

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ABSTRACT

Dutch coastal dunes are highly diverse landscapes in terms of biodiversity. 70%of the Dutch flora can be found in this particular landscape and 15% of plant species dwelling in the Dutch coastal dunes can only be found there. Since the 19th Century, human activities have modified the coastal dunes soil chemistry triggering the coastal dunes degradation and threatening the coastal dunes biodiversity.

The process of grass and shrub encroachment promotes the dominance of few tall grass and shrub species at the expense of rare species thus, hampering the coastal dunes species diversity. Large grazers have been reported to counteract this degradation process by removing the soil litter layer and bringing about more open vegetation.

European Bison (Bison bonasus) is the largest living herbivore in Europe. European Bison are considered intermediate grazers which diet is based on: grasses, herbs and woody vegetation. Therefore, the Bison can be expected to counteract dune degradation by grass and shrub encroachment. As part of a pilot reintroduction project, 3 Bison individuals were introduced in the Kraansvlak area in 2007. Currently, there are 16 individuals dwelling in the Kraansvlak.

In this study, the changes in vegetation induced by this Bison herd in a degraded dune coastal area called the Kraansvlak were analyzed. For that purpose, two aerial pictures and GPS data from radio-collared Bison were used. The aerial pictures were classified with the help of DICRANUM extension to Arcview 3.x to obtain an image of the Kraansvlak vegetation structure in 2 different years: 2003 (before the introduction of Bison) and 2009 (two years after the Bison were introduced). With the help of the GPS data, the Kraansvlak herd kernel utilization distribution map was calculated. This map allowed the identification of the most and least utilized areas and three categories were established: high intensity in use, medium intensity in use and low intensity in use.

The relation between intensity in use by Bison and vegetation changes was tested using ANOVA statistical test. According to the study results, Bison caused a significant reduction in the cover of trees and shrubs and it is possible that they caused an increase in short grasses, which is an important habitat for the preservation of the dunes' biodiversity. However, this trend couldn't be statistically proven.

Furthermore, several ANOVA statistical tests were also undertaken to look for significant differences in vegetation development between the Kraansvlak and a control area located around the Kraansvlak. In the Kraansvlak in the period 2003-2009 a significant average increase in short grasses class was found to occur and management measures implemented at the Kraansvlak seemed to slow down the degradation of the dunes by grass and shrub encroachment. This trend can be mainly ascribed to the introduction of the Bison and other grazers in the Kraansvlak between 2003 and 2009.

1. INTRODUCTION

Dune coastal areas are highly dynamic ecosystems characterized by the presence of continuous environmental gradients (Grootjans et al 2002). Dunes dynamic nature and continuous environmental gradients make the dunes highly diverse landscapes in terms of biodiversity. In fact, the recognition of dune coastal areas as part of the Natura 2000 Network speaks for itself about the importance of this particular landscape for the preservation of European biodiversity as a whole (Assendorp 2010). In the particular case of the Dutch coastal dunes, 70% of the Dutch flora can be found in the coastal dunes, including several Red List species (van der Haagen et al 2008). Furthermore, the fact that 15% of the plant species dwelling in the coastal dunes can only be found in that particular ecosystem reinforce the need to preserve it.

Coastal dunes are considered the last semi-natural ecosystem in the Netherlands. Indeed, until the 19th Century, the absence of agricultural activities in the dunes due to their low nutrient availability favored the preservation of this particular landscape (van der Hagen et al. 2008). The beginning of human impact in the dunes started around 1850, when the water stored in the dunes was found to be of excellent quality and water extraction from the dunes started (Bakker et al 1993). The degradation caused by changes in groundwater level is just an historical example of dune degradation. Nowadays the main threats for the preservation of coastal dunes are: dune acidification due to acid rain, grass and shrub encroachment after severe reduction of the local rabbit population by epidemic diseases and enhanced succession by planting of marram grass *Ammophila arenaria* and pines *Pinnus spp.* (Veer & Kooijman 1997, van der Hagen et al 2008).

Particularly important when speaking about biodiversity loss in the dune ecosystem is the process of grass and shrub encroachment. In the coastal dunes grass and shrub encroachment entails the dominance of a few tall grass and shrub species at the expense of rare *Bryophytes*, *Pteridophyta* and *Lichen* species (Kooijman & van der Meulen 1996). As a result, a net biodiversity loss is occurring. The drivers behind grass encroachment remain unclear. The most prevalent explanations for this phenomenon include: increased nutrient availability due to soil acidification, eutrophication due to increased atmospheric N deposition and the decimation of the local rabbit population (Veer 1997, Veer & Kooijman 1997, Kooijman & van de Meulen 1996, van der Hagen et al 2008).

Originally, low nutrient availability in the dunes prevented from the predominance of perennial graminoids, such as, *Ammophila arenaria*, *Calamagrostis epigeos*, *Carex arenaria* or *Elymus athericus* (ten Harkel & van der Meulen 1995). Increased nutrient availability in the dunes due to soil acidification and atmospheric nutrient deposition promoted the development of perennial graminoids at the expense of pioneer species adapted to the dunes extreme environmental conditions (wind blow and dry nutrient poor soils). However, even in dunes with increased nutrient availability grazing by rabbits seems to prevent from the predominance of perennial graminoids (ten Harkel & van der Meulen 1995; Williams et al. 1974; Zeevalking & Fresco 1977), because grazing brings about favorable conditions for pioneer species to out-compete tall grasses (Veer 1997).

The problem with the rabbit population is that once the rabbit population is decimated by epidemic diseases, high nutrient availability drives rapidly a widespread growth of perennial grasses in the dunes (ten Harkel & van der Meulen 1995; Ranwell 1960). Once perennial grasses have become dominant, the area is no longer visited by rabbits for grazing purposes, because non-grazed areas present lower protein content (ten Harkel & van der Meulen 1995; Veer & Kooijman 1997). In the absence of rabbits it is difficult to bring the ecosystem back to its dynamic equilibrium.

However, the dominance of tall grasses can be reverted by the introduction of large herbivores (Williams et al. 1974; Kooijman & van der Meulen 1996). Grazing by large herbivores generate favorable conditions for pioneer species by removing the soil litter layer and bringing about more open vegetation (Veer & Kooijman 1997; Tilman 1993). The improved environmental conditions for pioneer species will result in a reduction of the area covered by problematic perennial graminoids, such as, *Calamagrostis epigeos*, *Carex arenaria* or *Salix repens* (Grootjans et al 2002). The return of the indigenous vegetation will encourage grazing by rabbits and the preservation of the dunes biodiversity in a sustainable way (Veer 1997; Veer & Kooijman 1997).

Bison is the largest living herbivore in Europe (Pucek et al 2004). Despite of the fact that wild Bison population got extinct in 1927, current population in Europe is formed by 18000 individuals. The population is the result of several introduction and reintroduction projects around Europe using surviving Bison individuals from several European zoological gardens (Pucek et al 2004). In 2007 3 individuals of European Bison were introduced in a degraded coastal dune area in the Netherlands called the Kraansvlak.

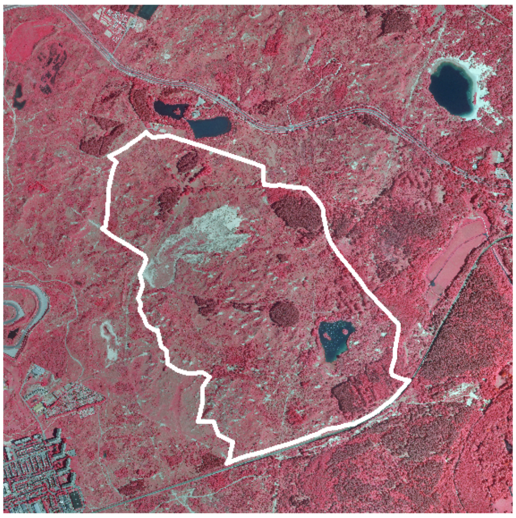


Figure 1. Satellite image showing the study area. The Bison is restricted to an enclosed area of 226 ha, in this picture this area is colored in white (Wisenten in het Kraansvlak 2011).

The Kraansvlak area (52°23'17.03"N; 4°34'13.11"E) i s formed by 226 ha of fenced coastal dunes (Figure 1). This area is part of the Zuid-Kennemerland Natural Park and is currently managed by the North-Holland water supply company (PWN). Twenty years ago, this area was dominated by extensive grassland and open sand. Nowadays, as a result of grass and shrub encroachment the area covered by shrubs and trees has increased and open sandy areas have almost disappeared. A more detailed description of the vegetation structure in 2006 is available on Table 1. The spread of grasses and shrubs was triggered by a severe reduction in the rabbit population caused by RHD disease in 1990. In order to preserve the dunes rich plant community several large herbivores were introduced in the area including, Scottish highland cattle and konik horses (Cromsigt & Kivit 2009) (Appendix 6).

In 2007 as part of a pilot project, European Bison *Bison bonasus* was introduced while Scottish highland cattle and konik horses were removed from the Kraansvlak. The project started with the introduction of 3 European Bison individuals in 2007. 3 more individuals were introduced in 2008. After the birth of 4 individuals in 2009 and 2 more in 2010 the number of individuals in the Kraansvlak herd rose to 12. Currently, the Kraansvlak herd is formed by 16 individuals after 2 more individuals were transferred from Lelystad in 2010 and 2 more calves were born on June 2011 (Wisenten in het Kraansvlak 2011) (Appendix 6).

Vegetation	Hectares	Percentage
Grassland	120.5	53%
High-low shrub	56.7	25%
Deciduous forest	22.1	10%
Pine forest	13.4	6%
Sand	8.5	4%
Water	3.1	1%
Marsh	2.1	1%

Table 1. Vegetation structure of the Kraansvlak area in 2006 as described by Linnaert & Kivit (2006). Note the Kraansvlak area was dominated by grasslands 53%. However, almost the other half of the area was covered by shrubs and trees (41% when categories "high-low shrub", "deciduous forest" and "pine forest" are added).

The aim of the Kraansvlak pilot project is to "evaluate the ecological and technical management aspects of the Bison in natural areas in the Netherlands" (Cromsigt et al. 2007). The knowledge on Bison ecology is limited and most of the existing knowledge comes from the herd of the Bialowieza forest, which is actively managed (Pucek et al 2004). Generating knowledge on the Bison ecology will help to assess the feasibility of future introduction projects in other Dutch and European areas. Along these four years in the Kraansvlak, Bison diet and habitat selection, attitude towards humans and other grazers or seed content in their feces have been monitored. Enhanced knowledge on Bison ecology is crucial for the set up of new re-introduction projects in other areas with favorable environmental conditions. In case the results from the pilot are positive, the project will help to preserve and bring back to the wild the largest living herbivore in Europe.

1.1 Aim

In this study we will analyze the changes in the vegetation structure that occurred in the Kraansvlak area since European Bison was introduced until now. By analyzing the changes in the vegetation structure in the Kraansvlak area 2 years after the herd was introduced, some insight on the changes induced by the Bison herd on the vegetation will be gained. This kind of analysis will test the capacity of Bison to counteract phenomena such as, grass and shrub encroachment and their capacity to promote the formation of sand pits. Thus, the capacity of the Bison to act as a natural manager which contributes to the preservation of biodiversity in the Kraansvlak area will be tested. Furthermore, the findings of this study will contribute to generate knowledge on the Bison ecology and diet.

1.2 Research questions

Question 1

Which are the main changes in vegetation structure at the Kraansvlak area in the period 2003-2009?

-Is there a decrease in the surface covered by tall grasses and shrubs?
-Is there an increase in the surface covered by short grasses and mosses?
-Is there an increase in the surface covered by grey sand?

Question 2

-Can the observed changes in vegetation structure be ascribed to Bison activity?

1.3 Hypothesis

The introduction of Bison *Bison bonasus* in a degraded dune coastal area will bring about a decrease in the area covered by tall grasses and shrubs, favoring the development of indigenous pioneer species and promoting biodiversity.

2. MATERIALS AND METHODS

Following the "DICRANUM classification procedure" (Assendorp 2010), the vegetation of the Kraansvlak area was classified using false color infrared aerial pictures from the years 2003 and 2009 provided by PWN. The classification was carried out with the help of DICRANUM extension to ArcView (Assendorp & Schunik 2005). While the aerial picture of 2003 gave an impression of the situation of the vegetation structure before Bison were introduced in 2007, the picture of 2009 gave an impression of the vegetation structure 2 years after the Bison were introduced in the study area. Afterwards, the classified images were compared and main trends in vegetation development analyzed.

Available GPS fixes from radio-collared Bisons were used to test the impact of the Bison herd on the development of the Kraansvlak vegetation. In order to obtain a map showing habitat utilization by the Kraansvlak Bison herd, the GPS fixes kernel utilization distribution was calculated (Worton 1989). The result was a shapefile showing the Kraansvlak Bison herd utilization distribution. This map was split into 3 categories (high, medium and low). The categorization of this variable, allowed testing significant differences in vegetation development between areas showing different intensity in use using ANOVA statistical tests.

2.1 Interpretation of airborne photographs

2.1.1Available data

The Kraansvlak area vegetation was interpreted with the help of false color infrared aerial pictures from years 2003 and 2009. The picture from 2003 was taken by the company Terra Imaging on June 13th 2003 using a scanner and it had a resolution of 16 cm. The picture from 2009 was taken by the company Eurosense on May 29th using a digital photo camera and it had a resolution of 23 cm, although it was re-sampled to present a resolution of 20 cm. These pictures were then interpreted in order to have an image of the vegetation in the Kraansvlak following Assendorp's methodology (2010).

Apart from the aerial pictures, the used methodology required using ground truth points. The samples used in this study were collected by Cees de Vries in 2005 and 2007. The collected samples have the size of a circle with 1m diameter and their geographical location was recorded with the help of a DGPS.

2.1.2 DICRANUM Classification process

The interpretation of false color infrared aerial pictures was carried out with the help of DICRANUM extension (Assendorp & Schunik 2005). DICRANUM (Assendorp & Schunik 2005) allowed identifying different interpretation classes based on their red and near infrared reflection values. The classification procedure is based on the Serial Landscape Model (SLM) and can be divided into 3 different phases: definition of image interpretation classes, class function construction and image interpretation map construction.

2.1.2.A Definition of image interpretation classes according to SLM

Coastal dunes are quickly changing environments characterized by complex spatial patterns and prominent spatial gradients (Assendorp 2010). Serial landscape model perceives the landscape as “a continuous series of states that can be perceived in spatial and temporal sequences” (Assendorp 2010). According to the SLM, landscape can be represented by a continuum with two extremes (van Leeuwen 1966) (Figure 2).

On the one side, there will be the climax communities. On the opposite side, there will be communities at the very early stages of vegetation development such as, bare soil. Both communities give rise to homogeneous landscapes geographically limited by crisp boundaries (crisp classes in Figure 2). Thorough the gradient, all the gradual stages taking place along the development of a plant community will be represented (fuzzy classes in Figure 2). Unlike the so-called crisp classes, fuzzy classes represent heterogeneous landscapes characterized by the presence of prominent spatial gradients.

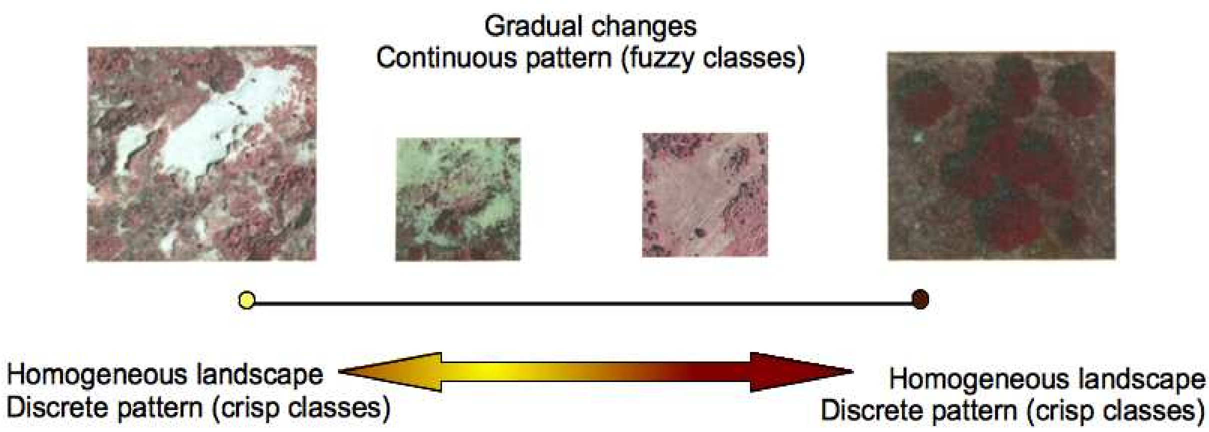


Figure 2. Diagram showing the logic of the Serial Landscape Model. The location of the different classes used in the classification procedure is shown as well (crisp and fuzzy). Pictures from Assendorp 2010.

Droesen (1999) applied this concept to remote sensing images. According to him, those objects with a spatial resolution similar or larger than the image resolution can be considered to be part of the crisp classes (on both extremes of the continuum in Figure 2). When speaking about dune coastal areas, crisp classes were made up by shrubs, trees and bare sand (cc1 and cc7 in Table 2).

On the contrary, plant communities made up by individuals having a smaller resolution than that of the image were considered to be part of the fuzzy classes (all along the continuum in Figure 2). These are the typical plant communities occurring at heterogeneous landscapes, where the existence of continuous gradients makes it difficult to determine when a plant community gives way to another. A good example of this kind of landscape would be dune grasslands.

Dune grasslands are made up by herbaceous species. When using aerial pictures with a resolution of 20-25 cm, there will be a mixture of individuals and plant species within one single pixel. The pixels containing a mixture of individuals were classified with the help of fuzzy classes (fc2 to fc6 in Table 2) and membership values ("MV" in Figures 3 and 7) (Assendorp 2010). Fuzzy classes are established according to the continuous transitions observed in the field (fc2 to fc6 in Table 2), whilst membership values will represent the probability of one single pixel to be part of a certain fuzzy class (Figure 3). Only when the probability of a certain pixel to be part of a fuzzy class is larger than 50% that pixel will be classified under that fuzzy class (Figures 3 & 4). When speaking about dry coastal dunes, all the fuzzy classes represent dune grasslands in different stages of development.

In the process of defining the image interpretation classes, Assendorp (2010) mentions three factors to be considered: the image characteristics, the field characteristics and the manager demands. In this study, the same image interpretation classes as those defined by Assendorp were used. The choice will be motivated in the following paragraphs.

In his study, Assendorp used false color infrared aerial pictures with a resolution of 25 cm. In this case, the same kind of images were used with the only difference that the images available present a finer resolution than those used by Assendorp (16 and 20 cm instead of 25 cm). Yet, this difference in the image resolution won't pose a problem, taking into consideration that the methodology used requires images with a resolution equal or smaller than 25 cm.

In regards to field characteristics, the Kraansvlak is formed by degraded coastal dunes and located on the South of the Zuid-Kennemerland Natural Park. In 2010 Assendorp defined the image interpretation classes for the Dutch coastal dune areas and applied this classification to the Meijendel dunes. The Meijendel dunes are located only 13 km away from the Kraansvlak area. The study about the Meijendel dunes yielded successful results and it was assumed the field characteristics of the Kraansvlak are similar to those from the Meijendel dunes.

The last factor to consider when defining image interpretation classes is the manager demands. As it was mentioned in a previous section, the Kraansvlak dunes have suffered a degradation process leading to grass and shrub encroachment and the introduction of grazers attempts to counteract this phenomena. The aim of the study is to "test the capacity of Bison to counteract phenomena such as, grass and shrub encroachment or their capacity to promote the formation of sand pits”. Thus, image interpretation classes should allow the identification of grass and shrub encroachment processes, as well as, those habitat types relevant for the conservation of biodiversity. Both requirements are met by the image interpretation classes established by Assendorp (2010) as it can be seen in Table 2.

Image interpretation class	Vegetation cover	Implications for nature conservation
Bare sand (cc1)	-No vegetation cover at all	
Thin grass/herb cover with blond sand (fc2)	-Dominated by blond sand. -Few pioneer species	
Intermediate herb/moss cover with grey sand (fc3)	-Dominated by mosses. -Some herbaceous and woody plants	-Habitat type with priority when applying conservation measures “Grey dunes”
High grass cover with litter (fc4)	-Dominated by grasses and herbs	-Undesirable habitat -Entails degradation of “grey dunes” (grass encroachment)
High moss cover (fc5)	-Soil totally covered by mosses and lichens -No/few grasses	-Undesirable habitat -Entails destruction of “grey dunes” (grass encroachment)
High moss cover and low grass cover (fc6)	-Soil totally covered by mosses and low herbs	-Habitat type with priority when applying conservation measures “Grey dunes”
Shrubs and woods (cc7)	100% coverage of woody plants	

Table 2. Table showing the classification used by Assendorp (2010) for the Meijendel dunes, formed by 2 crisp classes and 5 fuzzy classes (Assendorp 2010).

2.1.2.B Class function construction

The aim of class function construction is to identify which combination of red and near infrared is reflected by each of the image interpretation classes previously established. Class function construction was carried out in a GIS environment with the help of DICRANUM extension (Assendorp 2010) and resulted in a feature space (Figure 3). The result of the feature space operation is a graph that shows the range of red and near infrared reflected by the different crisp and fuzzy classes in the study area (Figure 3). Each crisp class will present a specific combination of red and near infrared (polygons in Figure 4). However, the fuzzy classes will be determined according to membership values, i.e. the probability of belonging to that specific fuzzy class (spatial gradients observed in Figure 3).

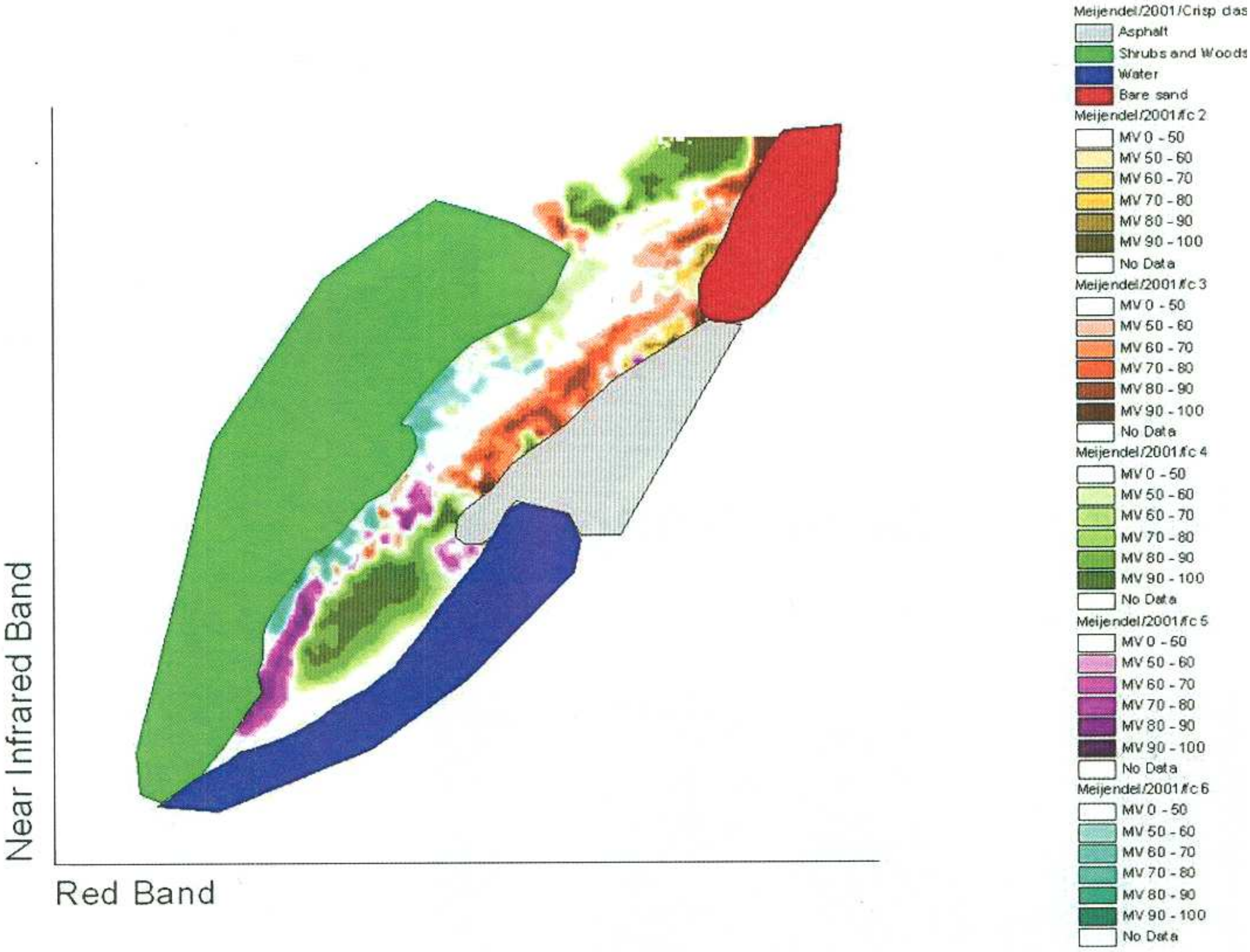


Figure 3. Feature space of the Meijendel area (Assendorp 2010). Note crisp classes (Asphalt, Shrubs and woods, Water and Bare sand) lack of the membership values. X axis = red radiation reflected; Y axis = near infrared radiation reflected.

The whole process of class function construction was repeated for each of the available airborne pictures. Repeating the process is necessary, because the pictures were taken in different years, by different companies and using different devices. Despite of the fact that both pictures were taken in Spring and no bias coming from seasonal vegetation changes can be expected, image characteristics vary under different atmospheric conditions. Besides, pictures taken with different devices pose also different visual characteristics leading to different radiometric characteristics of the image interpretation classes. Thus, making it necessary constructing new class functions for each of the available pictures. The process of class function construction can be divided into two main stages: crisp class function construction and fuzzy class functions construction.

Crisp class function construction

Crisp class function construction was undertaken through an iterative process of: class function construction, classification of the image, controlling the image classification and adjusting class function construction. Once reliable crisp class functions were defined a map with the distribution of the crisp classes in study area was obtained (Appendix 1).

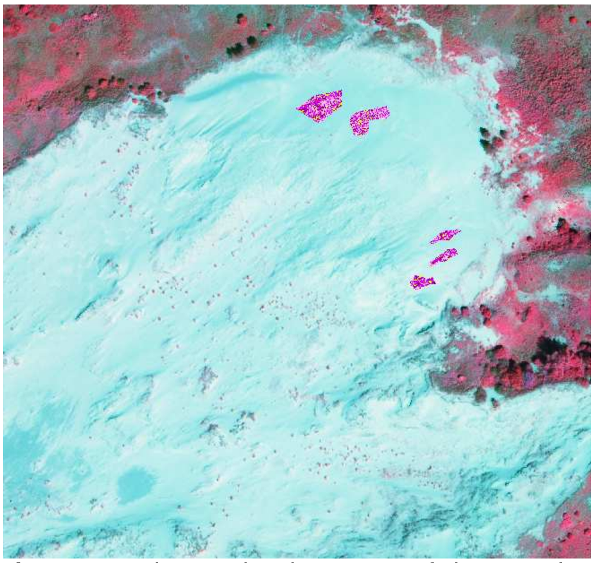


Figure 4. Picture showing some of the samples gathered in the determination of bare sand (cc1) radiometric properties (dotted blue polygons on the sand pit upper right part).

The whole process was based on “on screen training” of the image. First, the radiometric characteristics of the defined crisp classes were examined. For that purpose, a limited amount of samples of the defined crisp classes were selected from the image (Figure 4). Then, these samples distribution in the feature space diagram was analyzed. Figure 5a shows the distribution of crisp classes forest/shrub (green) and bare sand (red) in the feature space. If samples have been taken correctly, the resulting point clouds (Figure 5b) should allow the construction of polygons as those observed in Figure 5c (crisp classes represented by the red and green polygons).

Once satisfactory crisp class polygons have been defined, the obtained polygons were used for the classification of the airborne photographs. The result was a classified airborne image showing the geographical distribution of the crisp classes. After classifying the image, it was necessary to check the classification performance. For that purpose, wrongly assigned pixels were identified and sampled. These samples were added to those selected at the beginning of the process and the whole class function construction process was started again until satisfactory crisp classification was reached. Figure 5d shows the definitive crisp class polygons for the 2003 Kraansvlak image.

In figure 6, an example of the classification performance and the vegetation development in the Kraansvlak during the period 2003-2009 can be observed. The main vegetation trends that can be observed in the pictures are: a decrease in the area covered by bare sand and an increase in the area covered by shrubs. The same trends can be noted when looking at the crisp classification (the pictures at the bottom).

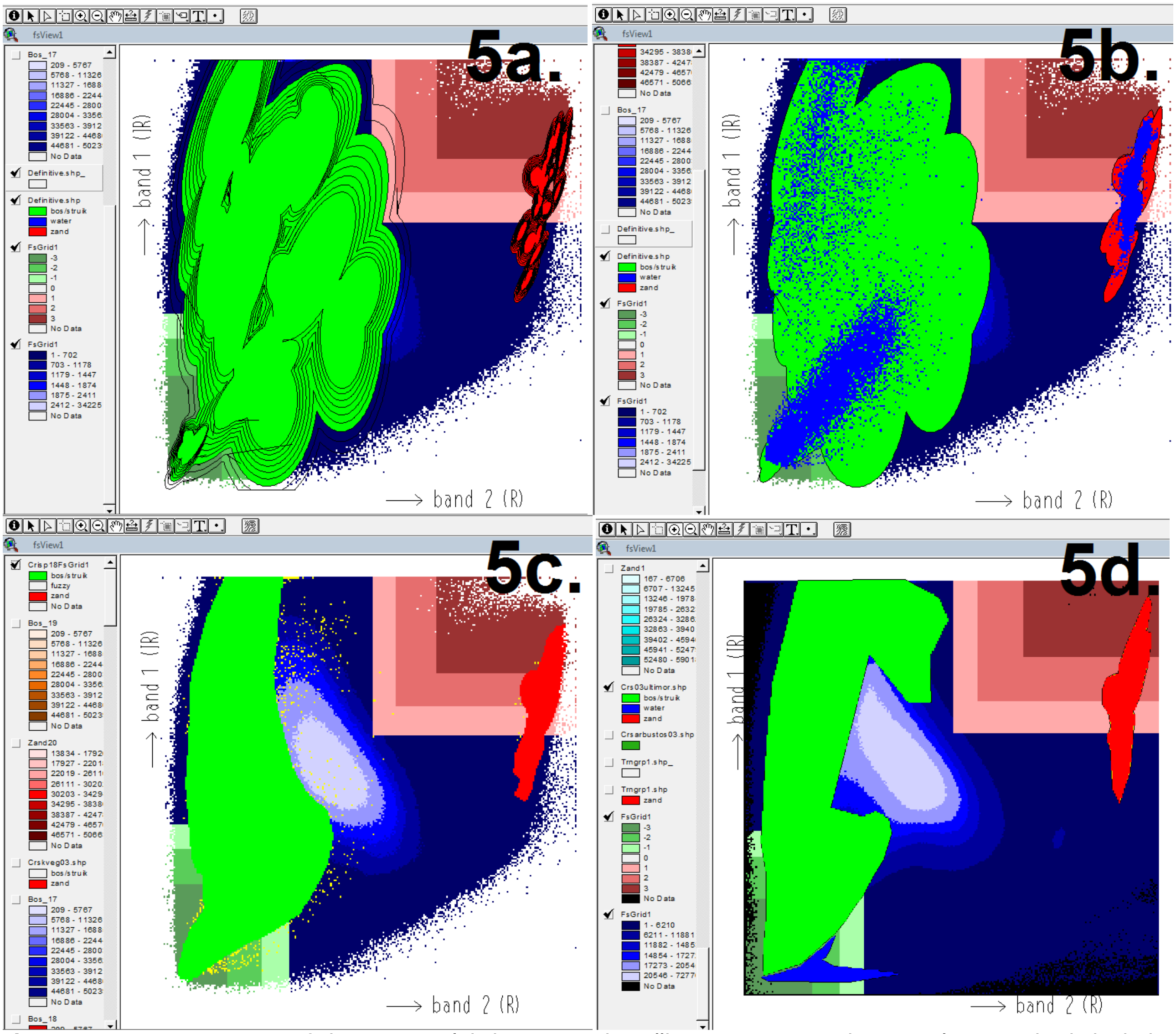


Figure 5a. Feature space of the Kraansvlak in 2003. The ellipses represent the samples standard deviation (Crisp class forest/shrub is shown in green and crisp class bare sand in red). **Figure 5b.** In this picture, the standard deviation ellipses were removed and the samples red and infrared properties were plotted (blue dots). **Figure 5c.** Picture showing the preliminary crisp classes polygons defined with the help of figure 5a ellipses and figure 5b point clouds. Those points not included in the preliminary polygons can be seen on the back (in yellow). **Figure 5d**. Definitive 2003 crisp classes polygons after refining the preliminary classification.

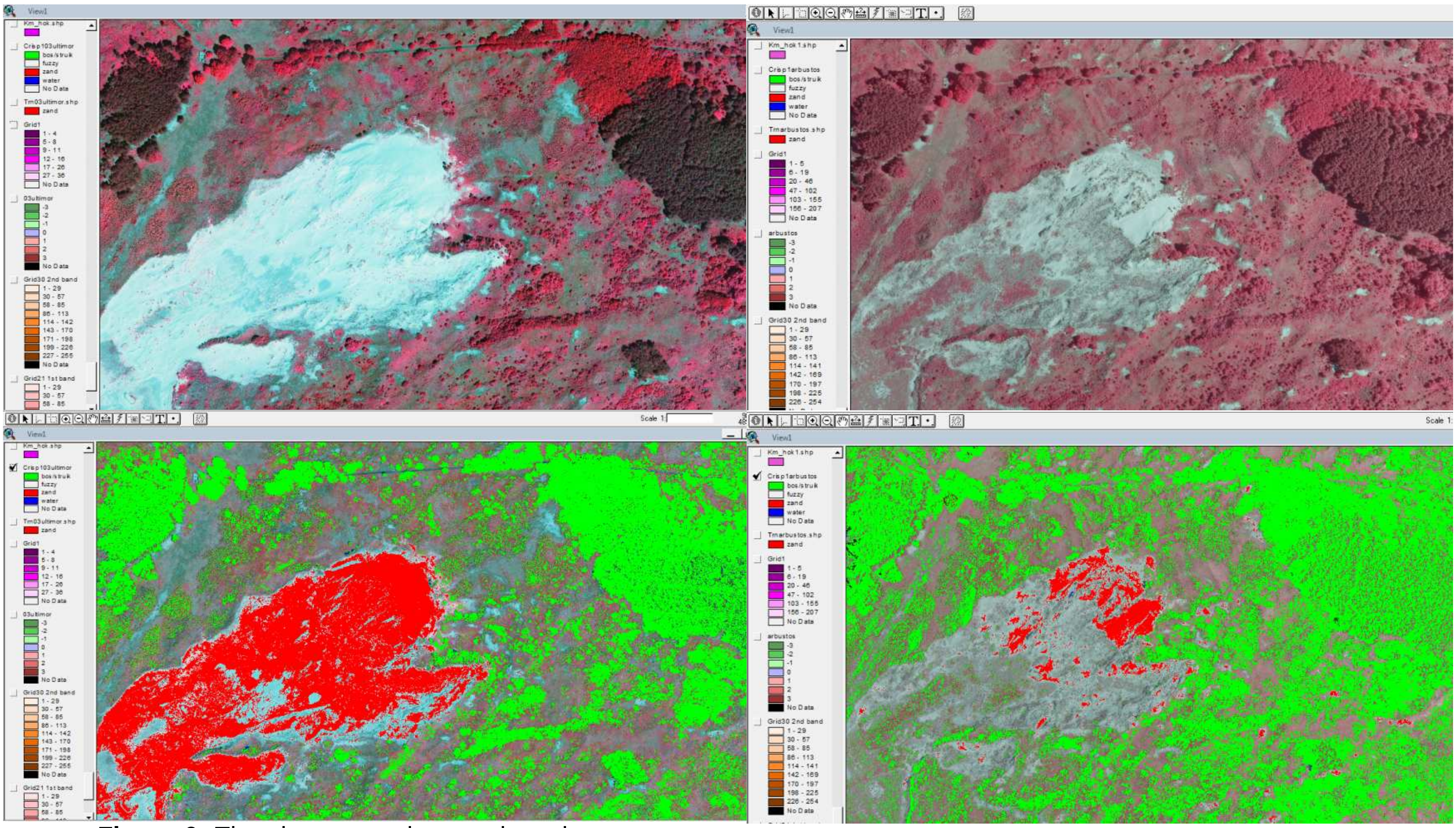


Figure 6. The pictures on the top show the same area of the Kraansvlak in 2003 (on the left) and 2009 (on the right). The pictures on the bottom show the crisp classification of these pictures (2003 on the left and 2009 on the right). Crisp class forest/shrub is shown in green and crisp class bare sand in red. If we compare the 2003 picture with the 2009 picture, a decrease in the area covered by class bare sand and the increase of class forest/shrub can be noticed.

<u>Fuzzy class function construction</u>

After obtaining a reliable crisp classification, the areas remaining unclassified were considered to be part of the fuzzy classes. It is important to keep in mind that crisp classes represent homogeneous landscapes geographically limited by crisp boundaries (convergent plant communities in Figure 2). While, fuzzy classes represent heterogeneous landscapes where the existence of continuous gradients makes it difficult to determine when a plant community is giving way to another.

The identification of fuzzy classes and membership values required a detailed description of the percentage of an area covered by mosses, tall grasses, sand, etc. Field samples gathered by Cees de Vries in 2005 and 2007 were used for the interpretation of fuzzy classes. These samples were gathered with the aim of monitoring the Kraansvlak vegetation development using DICRANUM. Each sample describes the percentage of the sampled area covered by each of the fuzzy classes and the sample location expressed in RD coordinates. Recording the samples exact location using a DGPS allowed linking the vegetation composition of certain sample with the reflection value showed by that sample in the airborne pictures. As a result, the radiometric characteristics of fuzzy classes and their membership values were obtained.

The samples radiometric properties can be plotted in the images' feature space (Figure 7). After plotting the samples and carrying out an interpolation the feature space diagram shows the radiometric properties of the fuzzy classes (i.e. red and near infrared reflected values) and their corresponding membership values. Finally, airborne images were classified according to feature space results. The definitive result were 6 maps, 5 (one per fuzzy class) showing the spatial distribution of the fuzzy classes and their membership values and one showing the distribution of the fuzzy classes combined without membership values.

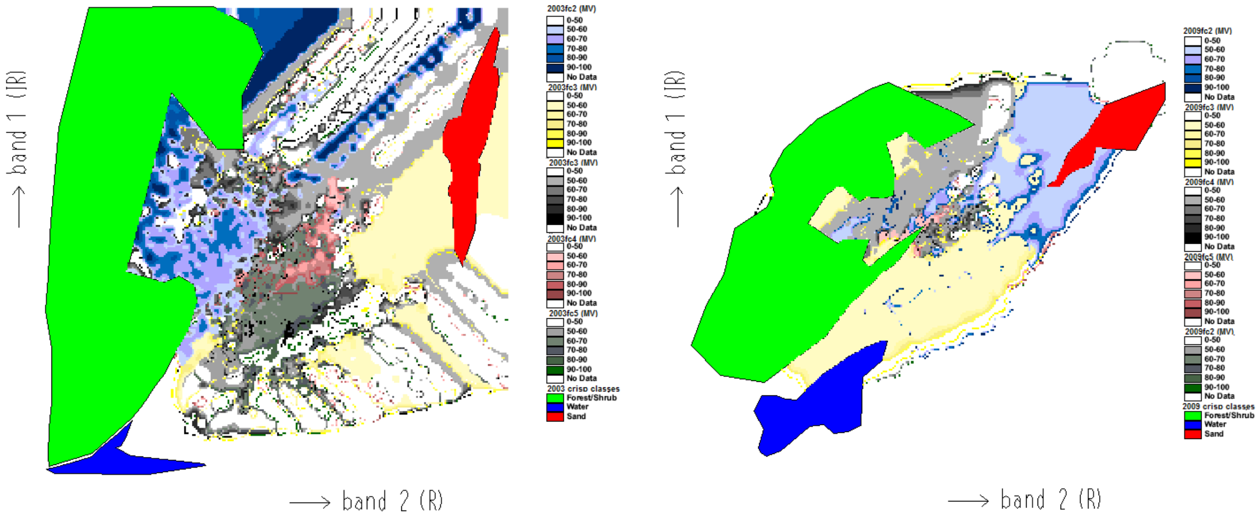


Figure 7. Feature space of 2003 (on the right) and 2009 (on the left) with the same legend. The effect of the pictures' radiometric properties can be noted in the shape of the feature space and the spatial distribution of the different class polygons.

2.1.2.C Image interpretation map construction

After constructing class functions for both crisp and fuzzy classes, the map showing the fuzzy classes spatial distribution and the one showing the crisp classes spatial distribution were merged. The resulting maps showing the definitive interpretation of the available false color infrared aerial pictures can be observed in Appendixes 2 and 3.

2.2 Bison kernel utilization distribution

In order to analyze the impact of the Bison herd on vegetation dynamics, it was necessary determining which areas were the most and least utilized by the Kraansvlak Bison herd. The definition of these areas allowed comparing vegetation development between areas with different intensity in use using ANOVA statistical test. Thus, it allowed relating changes in vegetation to Bison utilization.

For that purpose, a kernel utilization distribution was calculated using *kernel* function available in animal movement extension to ArcView (Hooge and Eichenlaub. 1997). In this study, the extension default settings were used and an ad hoc smoothing factor was calculated for every single utilization distribution map calculated.

The GPS fixes used in this study were selected from a total of 53281 GPS fixes recorded in the WGS 84 coordinate system at an hourly basis between 2007 and 2009. The fixes from the year 2007 were excluded due to the fact that the Kraansvlak was divided into two separate areas and Bison could only use half of the area available nowadays. Moreover, the activity score of every GPS fix was calculated following the methodology developed by Wester and Cromsigt (2007) and only those fixes with an activity score higher than 4 (active behavior) were selected. As a result, only 2693 GPS fixes were considered valid for the study purpose.

The valid GPS fixes were grouped according to the season of the year in which they were recorded and one utilization distribution map per season was calculated (Figures 8a, 8b, 8c and 8d). These maps were calculated with the aim of looking for seasonal differences in the use of the study area by the Bison. Due to the fact that the GPS fixes were recorded using the WGS 84 coordinate system and the rest of the maps were in the RD coordinate system, before generating the maps it was necessary converting the GPS fixes to RD coordinate system. This transformation was undertaken with the help of RD conversie tool version 3.2.

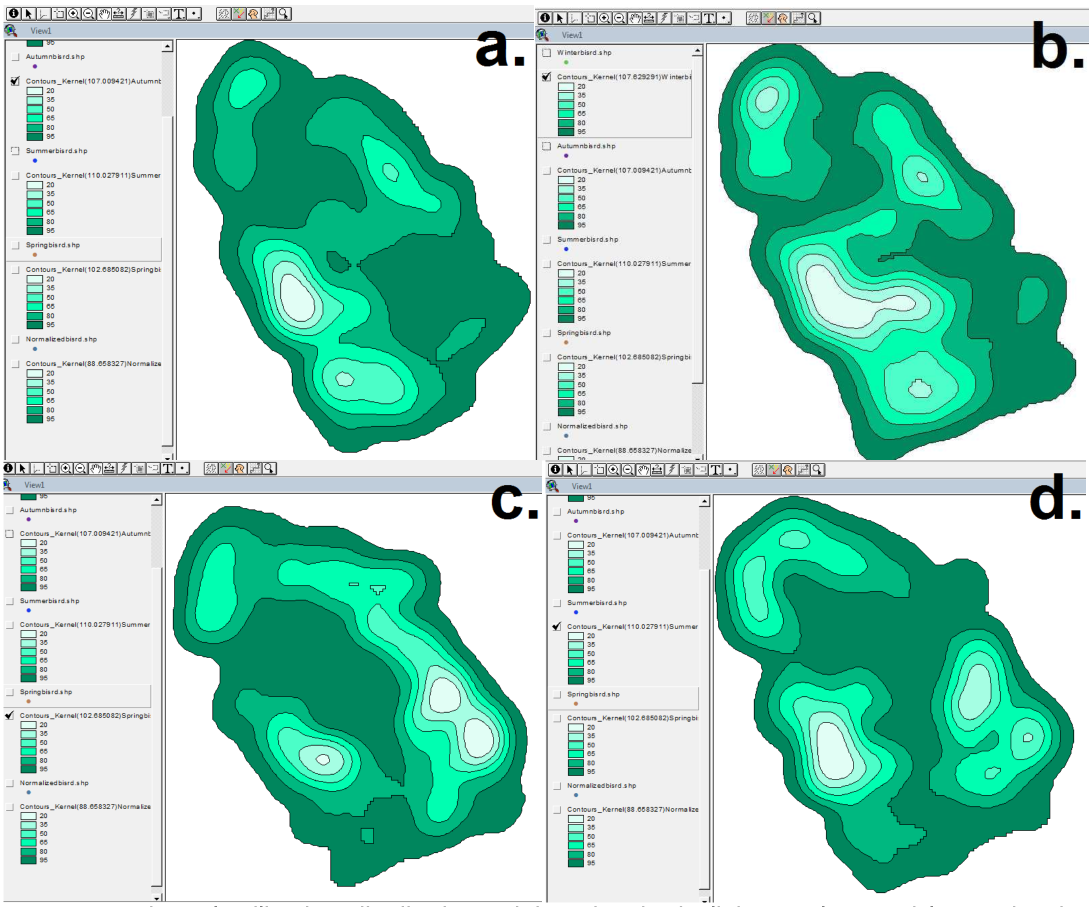
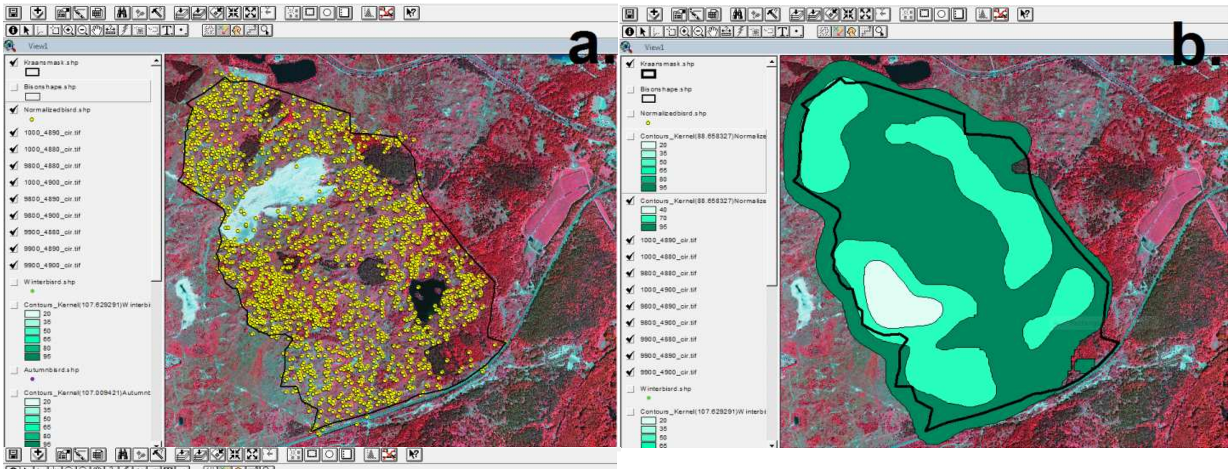


Figure 8a. Autumn kernel utilization distribution. Higher density in lighter colors and lower density in darker colors (Density values from higher to lower density: 20, 35, 50, 75, 95) **Figure 8b.** Winter kernel utilization distribution with the same legend and density values as 8a. **Figure 8c.** Spring kernel utilization distribution with the same legend and density values as 8a. **Figure 8d.** Summer kernel utilization distribution with the same legend and density values as 8a.

As it can be noted in figures 8a to 8d, the Bison herd uses the space in different ways depending on the season of the year. Furthermore, the amount of valid GPS fixes varied between seasons from a maximum of 881 valid Spring fixes to a minimum of 533 valid Autumn fixes. In order to have a balanced representation of the use of the study area by the

Bison herd in the years 2008 and 2009, the same amount of samples per season was used (533). As a result, 2132 GPS fixes gathered in the Kraansvlak between april 2008 and October 2009 were used to calculate the Kraansvlak Bison herd kernel utilization distribution.

The resulting map can be observed in figure 9b. Figure 9a shows the location of the GPS fixes used for calculating the kernel utilization distribution map. Figure 9b shows the calculated kernel utilization distribution with three density classes: high (0-40), medium (40 to 70) and low (70 to 95). Figure 9c is an overlay between the kernel and the GPS fixes used. The black thick line surrounding the fixes in the three pictures is the fence limiting the study area.



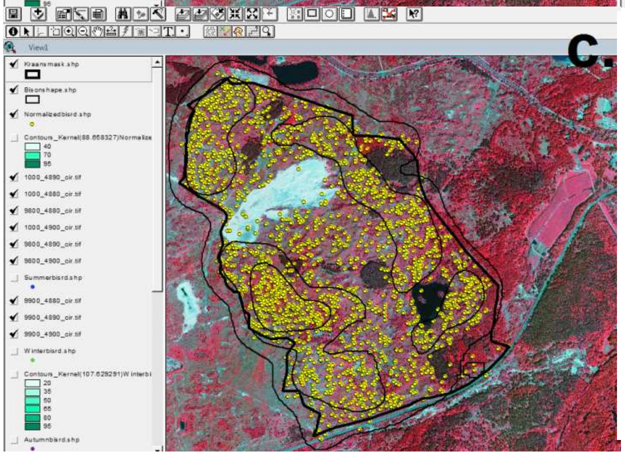
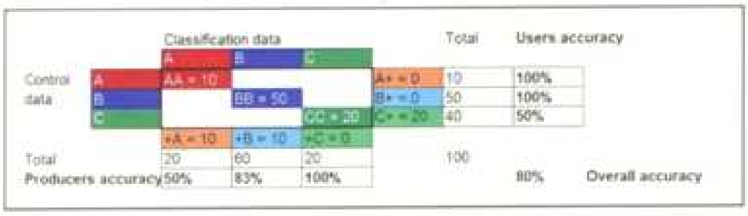


Figure 9a. Location of the GPS fixes used for calculating the Kraansvlak Bison herd utilization distribution. **Figure 9b.** 2008-2009 kernel utilization distribution. (Density values from higher to lower density: 40, 70 and 95) (40=cream; 70=pink; 95= green). **Figure 9c.** The kernel performance can be observed in this picture on the bottom showing an overlay between the fixes and a transparent kernel.

2.3. Statistical analysis

2.3.1 Accuracy assessment of image interpretation maps

The performance of the undertaken image interpretation was assessed with the help of confusion or error matrices (Lillesand and Kiefer 2004) (Figure 6). This methodology allows comparing ground truth samples with the interpretation made by DICRANUM classification process (Assendorp 2010). The use of confusion matrices allows assessing the study overall accuracy, the DICRANUM classification process accuracy and the accuracy of the gathered field data.



	Classification data				Total	Users accuracy
Control data	A	B	C			
A	AA = 10			A+ = 0	10	100%
B		BB = 50		B+ = 0	50	100%
C			CC = 20	C+ = 20	40	50%
	+A = 10	+B = 10	+C = 0			
Total	20	60	20		100	
Producers accuracy	50%	83%	100%			80% Overall accuracy

Error or confusion matrix

Figure 10. Error or confusion matrix showing producer's and user's accuracy. The classification process' overall accuracy is shown as well. (Assendorp 2010)

2.3.1.A Crisp classes accuracy assessment

DICRANUM extension comes with a validation function. When using DICRANUM's validation function two validation methods are available. In the first method, a series of classified areas are shown on the screen and the software asks you to grade the classification performance in a 0 to 9 scale. The second one is based on 200 "on screen training points" (Figure 11). For every single point the software asks you to classify the area within the circle. This methodology was considered more objective and was used for crisp classes validation.

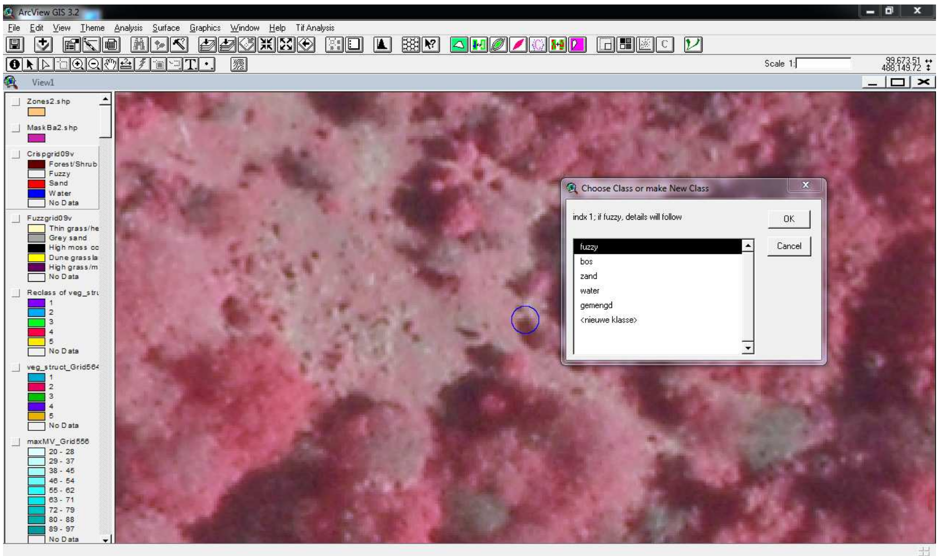


Figure 11. In this image, an example of an on screen training point is shown. The window where you have to choose between the different vegetation classes is shown, as well.

The reason to choose this methodology for the crisp classes is that crisp classes can be easily identified on the aerial picture without the need of expert knowledge. The final outcome of this validation method is an excel spreadsheet showing the classification undertaken during the validation process and the DICRANUM's classification for each "on screen training point" (Figure 12).

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	ID	FUZZY_OR_	MV1	MV2	MV3	MV4	MV5	CRISPNR	CMV1	CMV2	CMV3	CMV4	CMV5
2	0	fuzzy	0	0	0	0	100	0	34	56	3	2	4
3	1	bos						-3	2	0	0	14	25
4	2	fuzzy	0	0	20	70	10	0	12	46	9	22	12
5	3	bos						-3	0	0	0	1	17
6	4	fuzzy	0	0	0	40	60	0	10	2	2	34	39
7	5	bos						-3	0	0	0	3	39
8	6	bos						-3	0	0	0	2	42

Figure 12. Short piece of the table resulting from the validation process. The first column is the sample's ID, while columns B to G show the validation classification and columns H to M the DICRANUM's classification.

In order to obtain the producer's, user's and crisp classification overall accuracy, the table in Figure 12 was then converted into an accuracy matrix like the one in Figure 10.

2.3.1.B Fuzzy classes accuracy assessment

The reason to use a different method for the fuzzy classes is that the slight visual differences between the different fuzzy classes required of an expert opinion. As it was not possible receiving assistance from an expert, half of the samples gathered by Cees de Vries for the images' interpretation were used only for validating the fuzzy classification (i.e 118 samples were used in the validation of the classification of 2003 image and 53 in the case of the classification of 2009 image).

The method is not very different from the "on screen training" method used in the validation of the crisp classes. The main difference is that instead of using "on screen training points" ground truth field plots were used (Figure 13).

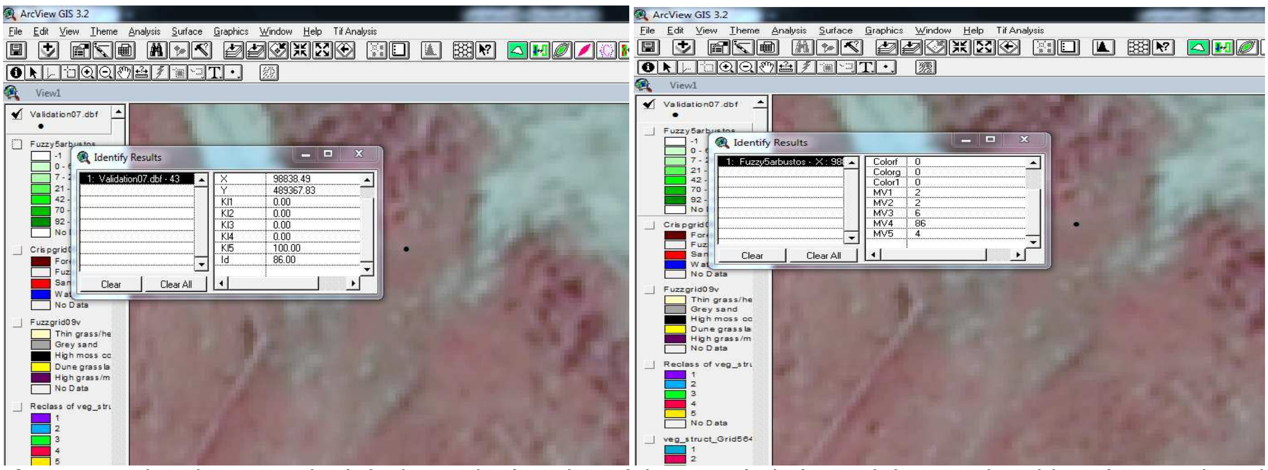


Figure 13. The picture on the left shows the location of the sampled plot and the membership values assigned to that plot by Cees de Vries. On the other picture the membership values assigned by DICRANUM is shown.

For each field sample the membership values assigned by DICRANUM was looked up (Figure 13). Once all the samples' DICRANUM classification was known, a table comparing the field samples' membership values and DICRANUM classification membership values was built (Figure 14).

	A	B	C	D	E	F	G	H	I	J	K	L
1	Sample points						DICRANUM classification					
2	MV1	MV2	MV3	MV4	MV5	F. class	MV1	MV2	MV3	MV4	MV5	F. class
3	0	0	0	100	0	4	3	3	4	28	62	5
4	0	0	0	50	50	5	2	2	5	19	71	5
5	0	0	0	80	20	4	2	3	4	44	47	5
6	0	0	0	100	0	4	2	3	5	38	52	5
7	0	100	0	0	0	2	4	37	11	33	15	2
8	0	100	0	0	0	2	3	46	15	31	5	2

Figure 14. Short piece of the table resulting from the fuzzy classes validation process. The column "F.class" shows the assigned fuzzy class according to each point membership values (MV1, MV2, MV3, MV4 and MV5).

Instead of the membership values' accuracy, we wanted to compare the fuzzy classes' accuracy. For that purpose, every single sample was classified under its corresponding fuzzy class. As it was mentioned in a previous chapter, fuzzy classes are determined according to their membership values, because the membership values represent the probability of a pixel to belong to that specific fuzzy class. As a result, the points were classified under the fuzzy class presenting the highest membership value within that point. This can be observed in figure 14. The producer's, user's and fuzzy classification overall accuracy, was calculated after transforming the table into an accuracy matrix (Figure 10).

2.3.2 Analysis of Bison impact on vegetation development

In order to analyze the impact of the Bison herd on vegetation development in the study area it was first necessary to develop a parameter measuring vegetation development. Vegetation development can be measured looking at the percentage of one vegetation category turning into another vegetation type or looking at the changes occurring in every single vegetation category one by one. In this study, the later was the utilized methodology to measure vegetation development.

For that purpose, one map per vegetation class (crisps and fuzzy classes) per year was first generated (Figure 15). Taking into account the vegetation structure maps resulting from the DICRANUM methodology presented 7 vegetation categories and 2 airborne images were interpreted (2003 and 2009), 14 maps showing the spatial distribution of one vegetation category were produced (Figure 16). The categories were selected with the help of *map query* function available in ArcView software.

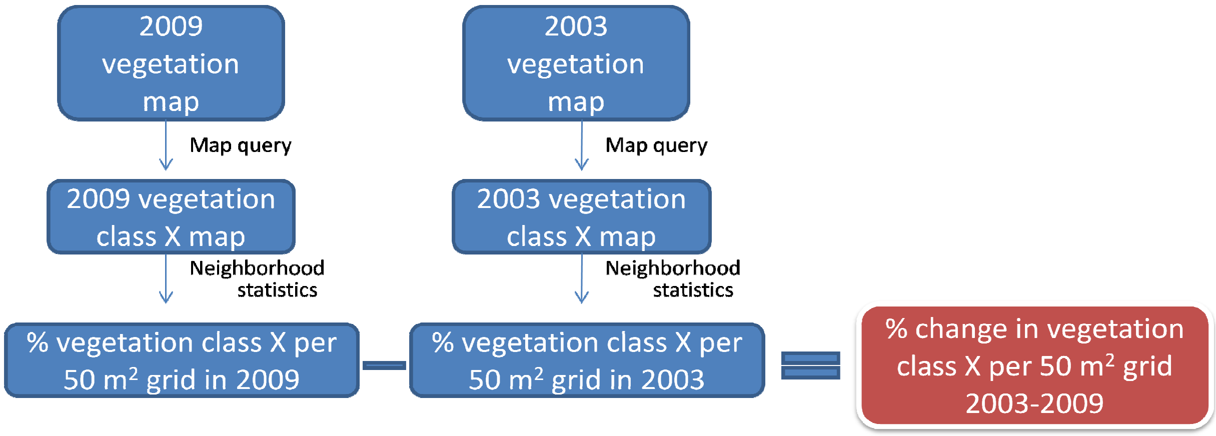


Figure 15. Diagram explaining briefly how the parameter "percentage of change" was calculated.

After producing one map per vegetation category per year, the density of a certain vegetation category per 50 m grid was calculated in the form of percentage of the grid covered by a certain vegetation category (the last picture in Figure 16). Finally, the percentage of change in a certain vegetation class between 2003 and 2009 per square grid was calculated making a simple map subtraction using ArcView map calculator (Figure 15).

The end result were 7 maps (one per vegetation class) showing the parameter "percentage of change". This parameter goes from -1 to 1 (0 = no change, <0 = decrease and >0 = increase).

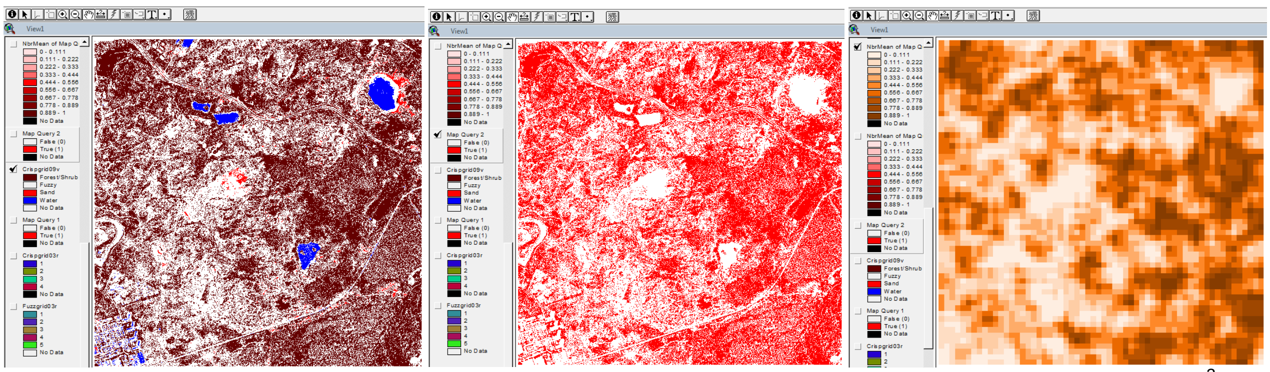


Figure16. In these images, the process resulting in the map "% of vegetation class forest/shrub per 50 m^2 grid square in 2009" is shown. The first image is the crisp classification of 2009 (forest/shrub=brown; water=blue; sand=red). The image in the middle shows only the class forest/shrub after it was selected from the crisp classes map (woody=red; no wood=white). The last one is the map "% of vegetation class forest/shrub per 50 m^2 grid square in 2009" (light areas=no/few woody vegetation (≈0); dark areas=high density of woody vegetation (≈1)).

Two series of ANOVA tests were carried out in order to look for significant differences in vegetation development. First, a control area outside the fence was established. For that purpose, a mask limiting that area was created. The created mask included only natural areas, all the roads, railroads, buildings and other artifacts that could affect the study results were excluded from the mask. Afterwards, one mask of the enclosed area was created and one ANOVA per vegetation class was undertaken comparing vegetation development inside and outside the fence (Figure 17).

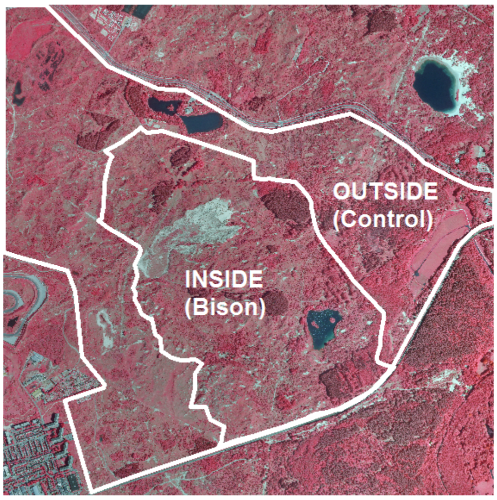


Figure17. Picture showing the area covered by the two masks generated in order to check for significant differences in vegetation development inside and outside the Kraansvlak.

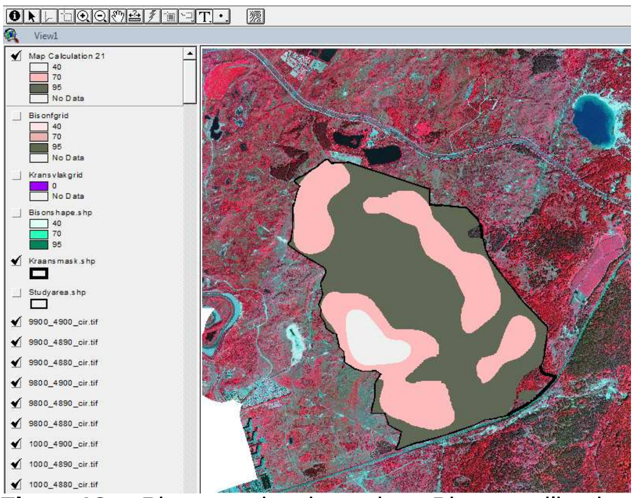


Figure18. Picture showing the Bison utilization categories used in the second series of ANOVA tests (High density areas=cream; medium density areas=pink; low density areas= green).

The second series of ANOVA tests compared vegetation development occurring in areas with different Bison utilization distribution (Figure 18). Once again, one ANOVA per vegetation class was undertaken. As it can be noted in Figure 18, the mask of the study area was used to get rid of those areas of the kernel utilization distribution falling outside from the study area.

3. RESULTS

3.1 Validation results

The interpretation of airborne images using DICRANUM appeared to perform better when interpreting the crisp classes than when interpreting the fuzzy classes, drawing crisp classes' classification 91.4% and 79.2% DICRANUM accuracy values for 2003 and 2009 images respectively (Tables 3 and 4). However, when speaking about fuzzy classes, DICRANUM accuracy values drop to 38.22% and 50.62% for 2003 and 2009 images respectively (Tables 5 and 6).

Fuzzy classes overall accuracy is highly affected by the accuracy of fuzzy class 3 (high moss cover), which draw values of 0% accuracy in both 2003 and 2009 images (Table 5 and 6). In fact, fuzzy classes overall accuracy rises to 49.4% (2003) and 63.3% (2009) when this class is not included in the calculations.

It is important to mention that the problem in the interpretation and validation of class 3 stems from its scarcity in the study area which made it difficult to gather reliable field samples. As an example, in 2007 only 5 samples from a total of 110 were from this vegetation type.

When speaking about the differences in accuracy between the images of 2003 and 2009. 2003 image classification performs better in the interpretation of crisp classes (91.4%), while 2009 image classification performs better in the interpretation of fuzzy classes (50.4%).

In a general way, the DICRANUM classification process can be considered to perform well. In the crisp classification of 2003 image all the classes show accuracy values over 80%. Despite of the fact 2009 crisp classification accuracy values are lower than

2003 CRISP CLASSES ACCURACY MATRIX

		DRICANUM				TOTAL	
		Forest	Sand	Water	Fuzzy		U. Accuracy
USER	Forest	81	0	0	13	94	86.17
	Sand	1	2	0	0	3	66.67
	Water	2	0	6	0	8	75.00
	Fuzzy	17	0	0	76	93	81.72
TOTAL		101	2	6	89		77.39
DICR. Accuracy		80.20	100.00	100.00	85.39	91.40	

Table 3. 2003 crisp classes accuracy matrix. The diagonal green boxes represent the samples in which my classification (user) coincides with DICRANUM's classification. The yellow boxes represent the total number of samples classified under a certain vegetation class both by DICRANUM (yellow row) and myself (yellow column). Accuracy values are also shown (DICRANUM accuracy in row DICR. Accuracy and user accuracy in column U. Accuracy)

2009 CRISP CLASSES ACCURACY MATRIX

		DRICANUM				TOTAL	
		Forest	Sand	Water	Fuzzy		U. Accuracy
USER	Forest	67	0	0	36	102	65.69
	Sand	0	0	0	0	0	No data
	Water	0	0	4	1	5	80.00
	Fuzzy	25	0	0	68	93	73.12
TOTAL		92	0	4	105		72.93
DICR. Accuracy		72.83	No data	100.00	64.76	79.20	

Table 4. 2009 crisp classes accuracy matrix with the same explanation as Table 3.

2003 FUZZY CLASSES ACCURACY MATRIX

		DICRANUM					TOTAL		
		FC1	FC2	FC3	FC4	FC5		U. Accuracy	
FIELD SAMPLES	FC1	6	5	0	1	1	13	46.15	
	FC2	3	9	0	7	1	20	45.00	
	FC3	0	8	0	9	1	18	0.00	
	FC4	2	6	1	26	7	42	61.90	
	FC5	0	3	1	8	13	25	52.00	**Without FC3**
TOTAL		11	31	2	51	23		41.01	51
DICR. Accuracy		54.55	29.03	0.00	50.98	56.52	38.22		47.77

Table 5. 2003 fuzzy classes accuracy matrix with the same explanation as Table 3. The only difference is that instead of user's accuracy, in this table the field samples' accuracy is measured.

2009 FUZZY CLASSES ACCURACY MATRIX

		DICRANUM					TOTAL		
		FC1	FC2	FC3	FC4	FC5		U. Accuracy	
FIELD SAMPLES	FC1	11	5	0	0	0	16	68.75	
	FC2	1	7	0	2	1	11	63.64	
	FC3	0	0	0	1	1	2	0.00	
	FC4	0	0	1	5	4	10	50.00	
	FC5	1	0	1	3	11	16	68.75	**Without FC3**
TOTAL		13	12	2	11	17		50.23	62.78
DICR. Accuracy		84.62	58.33	0.00	45.45	64.71	50.62		63.28

Table 6. 2009 fuzzy classes accuracy matrix with the same explanation as Table 5.

those of 2003, an overall accuracy of 79.20% is yielded.

Regarding the fuzzy classes 6 out of the 10 fuzzy classes tested drew accuracy values over 50%. Indeed, if class 3 is not taken into consideration 75% of the fuzzy classes interpreted showed accuracy values higher than 50% and 87.5% over 45%.

3.2 Vegetation development results inside/outside

As it was explained above, image interpretation classes (crisp and fuzzy) were established in order to get an image of the pictures vegetation structure. The established image interpretation classes allowed the identification of grass and shrub encroachment processes, as well as, those habitat types relevant for the conservation of biodiversity (Table 2). The name of some of these classes was shortened in order to make the results and discussion section more comprehensible. Table 7 shows the original term used by Assendorp for the definition of image interpretation classes, the term that will be used in the results and discussion sections (vegetation classes) and the vegetation cover attached to each of these classes. Note that the established image interpretation classes represent habitat types.

Image interpretation classes	Shortened term	Vegetation cover
Bare sand (cc1)	Bare sand	-No vegetation cover at all
Thin grass/herb cover with blond sand (fc2)	Sand blowout	-Dominated by blond sand. -Few pioneer species
Intermediate herb/moss cover with grey sand (fc3)	Grey sand	-Dominated by mosses. -Some herbaceous and woody plants
High grass cover with litter (fc4)	Tall grasses	-Dominated by grasses and herbs
High moss cover (fc5)	Mosses	-Soil totally covered by mosses and lichens -No/few grasses
High moss cover and low grass cover (fc6)	Short grasses	-Soil totally covered by mosses and low herbs
Shrubs and woods (cc7)	Woody	100% coverage of woody plants

Table 7. Table showing the correspondence between the original image interpretation classes and the term used in results and discussion section to refer to them.

Before having a look at differences in vegetation development between the enclosed area (inside) and the control area (outside), general trends in vegetation development on the whole classified area will be exposed with the help of the pie charts in Figure 19.

Increases in area covered 2003-2009:
-Woody vegetation (class Forest/shrub) +8%.
-Sand blowout +3%.
-Short grasses +1%.

Decreases in area covered 2003-2009:
-Tall grasses -8%.
-Bare sand -3%

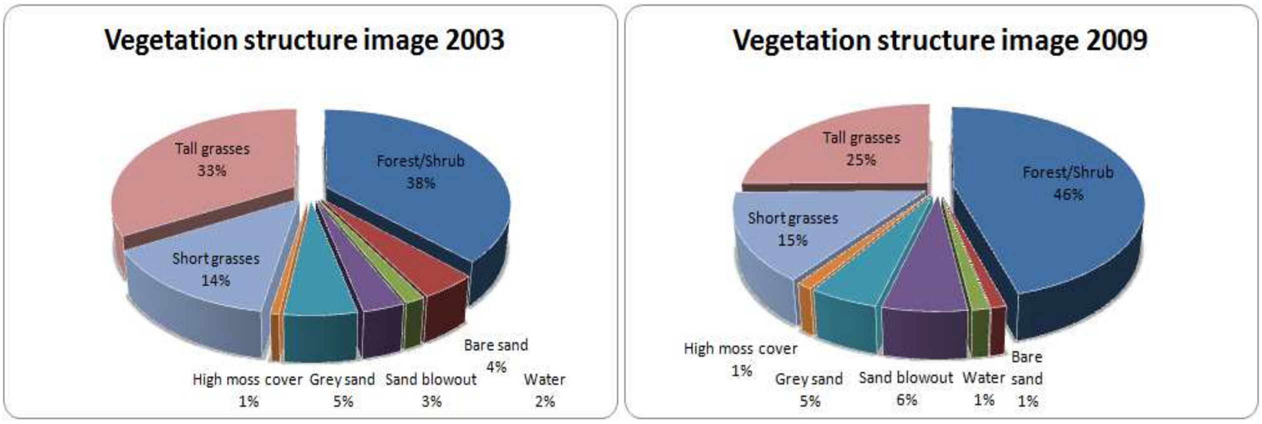


Figure 19. Pie charts showing vegetation structure of the classified area in the years 2003 and 2009 (in percentage of the total classified surface covered by each of the vegetation categories).

The existence of significant differences between autonomous vegetation development (outside) and vegetation development inside the Kraansvlak were tested with the help of the parameter "percentage of change" in vegetation class X. Figure 20 shows average values of this parameter inside and outside the Kraansvlak for the seven image interpretation classes.

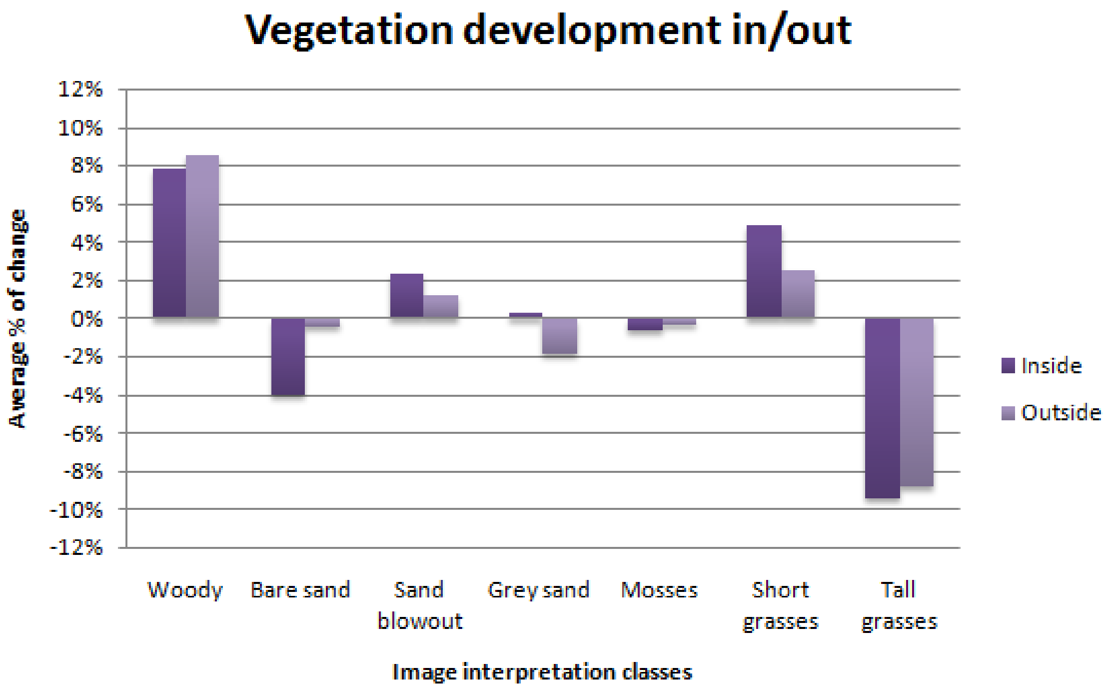


Figure 20. Chart showing average values of the parameter "percentage of change" for the seven vegetation classes inside and outside the Kraansvlak. (Y = average percentage of change; X = Image interpretation classes)

In this chart, image interpretation classes tall grasses and woody showed similar average values in the Kraansvlak and control area. For the rest of the image interpretation classes, the ANOVA tests carried out found significant differences in the average "percentage of change" in 4 of the 5 categories with a confidence level of α=0.01 (Appendix 4). If we compare vegetation development inside and outside the Kraansvlak in the period 2003-2009, in the enclosed area there was:

-A highly significant decrease in the area covered by bare sand ($P=1.04\ e^{-18}$).
-A highly significant increase in the area covered by grey sand ($P=3.38\ e^{-7}$).
-A significant increase in the area covered by short grasses (P=0.0029).
-A significant increase in the area covered by sand blowout (P=0.0061).

3.3 Vegetation development and Bison

After looking for significant differences in vegetation development between the enclosed area and the surroundings, significant differences between areas presenting different level of utilization by Bison were tested (Appendix 5). Average percentage of change of the seven image interpretation classes in areas with high, medium and low Bison utilization categories are shown in Figure 21.

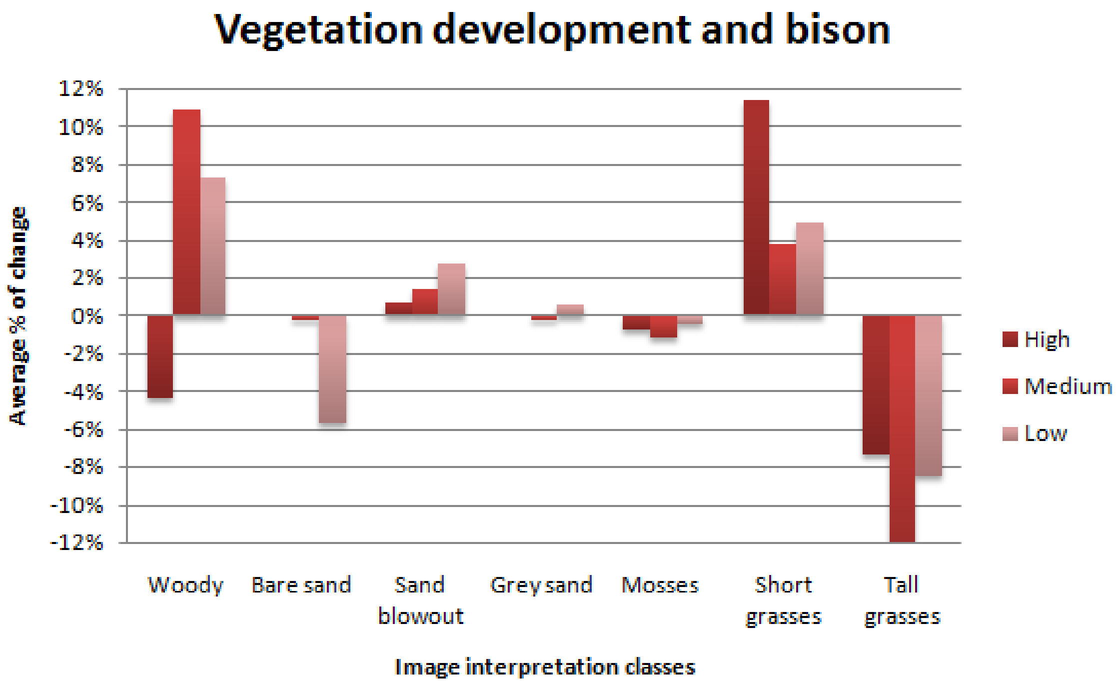


Figure 21. Chart showing average values of the parameter "percentage of change" for the three Bison utilization categories (High=0-40, Medium=40-70 and Low=70-95). (Y = average percentage of change; X = Vegetation classes).

Main observed trends include:
-Areas with high Bison utilization values:

  -A highly significant decrease in the area covered by woody vegetation ($P=4.28\ e^{-5}$).
  -The highest average increase in short grasses takes place in these areas (+0.11).

-Areas with medium Bison utilization values:

-The highest average increase in woody vegetation takes place in these areas (+0.11).

-The highest average decrease in tall grasses takes place in these areas (-0.12).

-Areas with low Bison utilization values:

-A highly significant decrease in the area covered by bare sand ($P=5.49\ e^{-7}$).

-The highest average increase in sand blowout takes place in these areas (+0.028).

-The highest average increase in grey sand takes place in these areas (+0.005).

4. DISCUSSION & CONCLUSION

The aim of this study was to “test the capacity of the Bison to act as a natural manager which contributes to the preservation of biodiversity” by testing “the capacity of Bison to counteract phenomena such as, grass and shrub encroachment or their capacity to promote the formation of sand pits”.

For that purpose, 2 research questions were formulated:

<u>Question 1</u>
Which are the main changes in vegetation structure at the Kraansvlak area in the period 2003-2009?

<u>Question 2</u>
-Can those changes in vegetation structure be ascribed to Bison activity?

In this discussion section, each of the previously formulated research questions will be answered according to the study results.

<u>Question 1</u>
Which are the main changes in vegetation structure at the Kraansvlak area in the period 2003-2009?

When comparing vegetation development inside and outside the Kraansvlak a number of significant differences were found in the image interpretation classes: bare sand, sand blowout, grey sand and short grasses (Appendix 4).

The significant increase in the image interpretation class grey sand taking place at the Kraansvlak in the period 2003-2009, results from the transformation of a large artificially created sandy area into an area covered by incipient vegetation (Figure 22). The explanation for this large change observed in Figure 22, is that this sandy area was created artificially by the area managers after digging up the ground in the year 2003. In the following years, natural succession transformed this bare habitat into a combination of sand blowout, grey sand, short grasses and some shrubs (Figures 22 and 24).

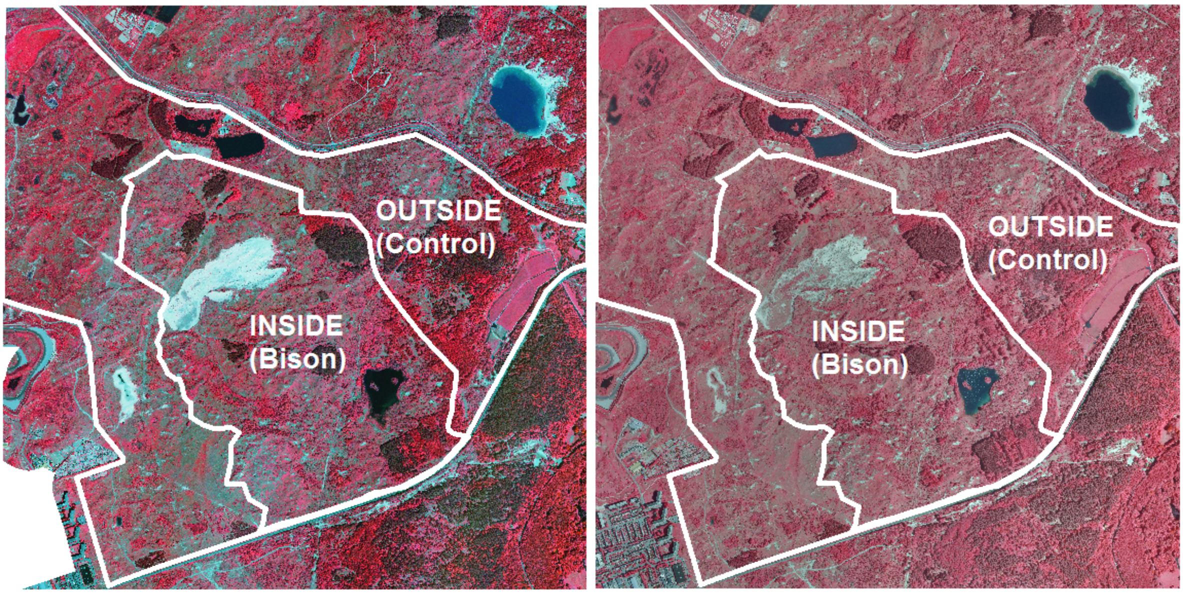


Figure 22. 2003 aerial picture with delimited control and Bison areas (picture on the left) and 2009 aerial picture with delimited control and Bison areas (picture on the right). The succession that took place in the big sand pit in 6 years can be observed.

In reference to short grasses class, it is important to mention that despite of the fact that this class is increasing both at the Kraansvlak and at the control area (4.8% vs. 2.5%), significant differences were found (P=0.0029). These significant differences may be ascribed to the existence of a larger grazing pressure at the Kraansvlak than at the control area. Grazing will imply the transformation of tall grasses class into short grasses class and according to this, a significant decrease in tall grasses class should also be taking place. Despite of not being significant, the decrease in tall grasses class is larger inside than outside (-9.4% Vs -8.8%).

The decrease in image interpretation class short grasses can be caused by two different phenomena. On the one hand, tall grasses turn into short grasses class due to grazing pressure. On the other hand, natural succession will transform areas with tall grasses into shrubs. In figure 20, it can be noted that the transformation of tall grasses into shrubs due to natural succession seems to be the main trend both at the Kransvlak and control area.

This trend is especially strong outside, where the decrease in tall grasses class has an average value of -8.8% and the increase in woody class has an average value of +8.6%. This is very different from what can be observed at the Kraansvlak, where despite of the fact that the average decrease in tall grasses class is larger (-9.4%) than in the control area, the average increase in woody class is shorter than in the control area (+7.8%). This will mean that dune degradation by grass and shrub encroachment was at the least, slowed down at the Kraansvlak.

Question 2
-Can those changes in vegetation structure be ascribed to Bison activity?

In order to answer this question, one ANOVA per vegetation class was carried out. These ANOVA tests compared the average percentage of change taking place in areas with different intensity in use by Bison. From the seven ANOVA test carried out, significant differences were only found on woody ($P=4.28\ e^{-5}$) and bare sand image interpretation classes ($P=5.49\ e^{-7}$).

The significant decrease in the surface covered by woody class in the area showing high Bison utilization can be observed in Figure 23 (woody vegetation = dark brown). This decrease takes place despite of the fact that woody class increases at the control area and at the areas with medium and low intensity in use (Figure 21).

European Bison were classified as intermediate grazers by Hoffman (1989). According to Hoffman's rumiants classification, intermediate grazers are versatile grazers capable of feeding on grasses, herbs, buds, branches and tree bark at different percentages. The importance of each of these food types on the Bison diet varies depending on food availability and the environmental circumstances. As an example, the diet of the European Bison that inhabit the Balowietza forest in Poland consists in 33% woody vegetation, 61% grasses and 6% herbs (Gebczynska & Krasinka 1972).

In order to gain some insight on the Kraansvlak Bison diet, a series of sample plots were established in 2008. These plots' vegetation was sampled twice a year (Winter and Summer). In 2011, Sikkes carried out a regression analysis using the data series from the period 2008-2011. In this study, three significant trends were found at the Kraansvlak sample plots and the three of them implied a reduction of woody cover. This study, found significant decreases over time in the number of Spindle trees (Euonymus europaeus), Sea buckthorns (Hippophae rhamnoides) and Wild Privets (Ligustrum vulgare) (Sikkes 2011).

The decrease of these species can be ascribed to Bison, because Bison feed on the bark of these trees and peals them until they are dead. As an example, in 2011 Spindle trees have been reported to be almost extinct from the Kransvlak. In response to the extinction of their preferred food, Bison have been reported to shift their feeding preferences to Sea Buckthorn shrubs (Sikkes 2011). All this findings are consistent with the reduction of woody vegetation found in the areas with high intensity in use by Bison and will be backing the hypothesis that Bison can help to counteract shrub encroachment.

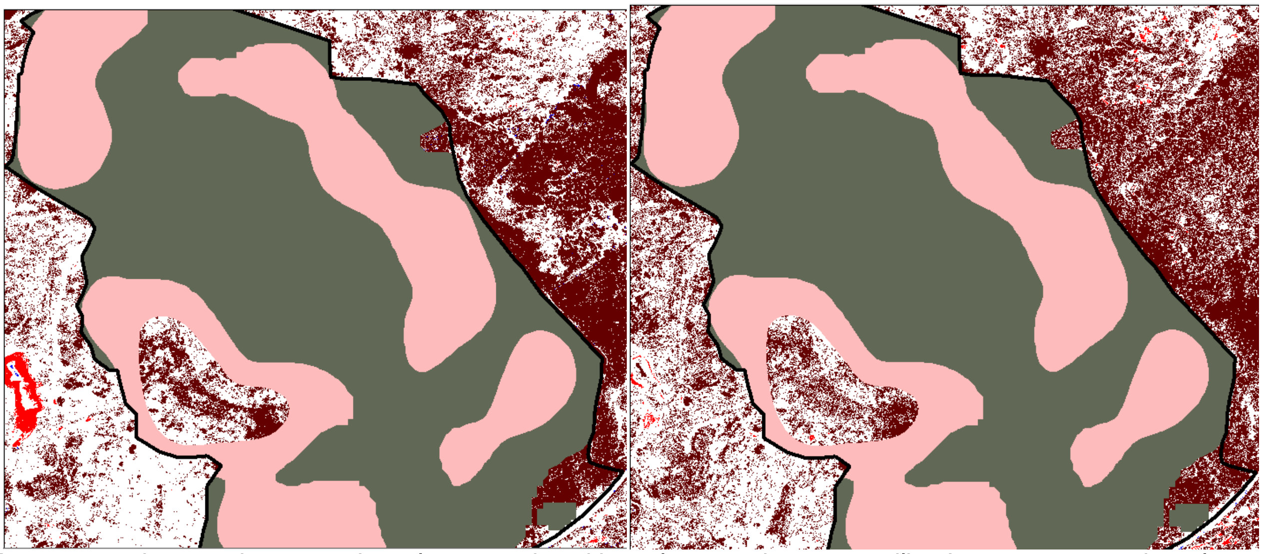


Figure 23. Changes in vegetation class woody taking place at the most utilized areas. 2003 crisp classes classification on the left and 2009 crisp classes classification on the right (woody=dark brown; bare sand=red and water=blue). Bison utilization kernel showing medium and least utilized areas (medium=pink and low=green). The transparent window on the bottom left is utilized intensively by Bison.

As it was mentioned before, significant differences were also found in the average percentage of change of bare sand class. In this case, the largest changes took place in the least utilized areas by Bison (Figures 21, 22 and 24). In figure 24, the dramatic decrease of bare sand class (in red) at the least utilized areas can be easily noticed. Nevertheless, this decrease is mainly caused by the ongoing process of natural succession taking place in the artificially created sandy area back in 2003. Thus, these changes cannot be ascribed to the presence or absence of Bison but to management measures implemented by the area managers.

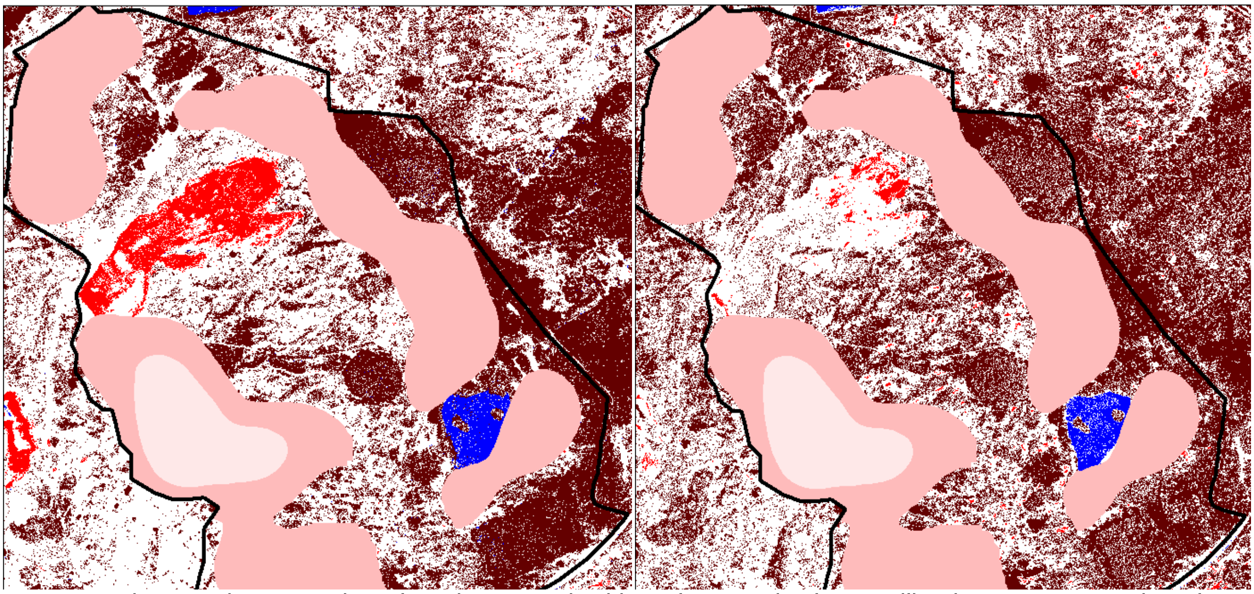


Figure 24. Changes in vegetation class bare sand taking place at the least utilized areas. 2003 crisp classes classification on the left and 2009 crisp classes classification on the right (woody=dark brown; bare sand=red and water=blue). Bison utilization kernel showing medium and least utilized areas (medium=pink and low=green).

Finally, in the most utilized areas the highest average increase in short grasses class takes place (+0.11 Vs +0.049 and +0.037 in low and medium areas respectively). Bison were the only grazer species living at the Kraansvlak in the period 2007-2009 and grasses represent 61% of the Bison diet at the Balowietza forest (Gebczynska & Krasinka 1972). However, despite of the fact that a significant increase in class short grasses was found at the Kraansvlak in the period 2003-2009 (Figure 20), no significance was found when speaking about areas showing different intensity in use (Figure 21).

The significant increase in short grasses class taking place at the Kraansvlak in the period 2003-2009 could be a consequence of the introduction of grazers in the Kraansvlak. In fact, apart from the Bison, between 2005 and 2007 there were 12 Konnik horses and 15 Highland cattle individuals living at the Kraansvlak (Appendix 6). The presence of different grazers with different habitat and food preferences at the Kraansvlak in the period 2003-2009 could be masking the impact of the Bison herd on short grasses class between 2007 and 2009. Thus, the absence of significant differences between areas with different intensity in use by Bison could be a consequence of the promotion of short grasses caused by other grazers, in areas with medium and low intensity in use by Bison.

Hypothesis

Finally, we will compare to the study hypothesis with the results obtained. The study hypothesis was:

The introduction of Bison *Bison bonasus* in a degraded dune coastal area will bring about a decrease in the area covered by tall grasses and shrubs, favoring the development of indigenous pioneer species and promoting biodiversity.

The first part of the hypothesis has been already contrasted in the previous sections drawing the following conclusions:

-Bison by debarking and killing trees can help to counteract shrub encroachment.
-The decrease in tall grasses took place both at the Kraansvlak and control areas. Thus, it cannot be ascribed to Bison activity.

In reference to the promotion of biodiversity, it is important to bear in mind that the established image interpretation classes allowed the identification of grass and shrub encroachment processes, as well as, those habitat types relevant for the conservation of biodiversity. According to the classification established by Assendorp (2010), image interpretation classes tall grasses (fc4), mosses (fc5) and woody (cc7) were considered to represent undesirable habitats hampering the preservation of the highly diverse habitats grey sand (fc3) and short grasses (fc6) (Tables 2 and 7).

Therefore, if Bison was promoting biodiversity, significant increases in image interpretation classes grey sand and short grasses should be taking place at those areas with high intensity in use by Bison.

As it was mentioned before, the increase in class grey sand, results from the process of natural succession that took place between 2003 and 2009 in the large sand pit at the Kraansvlak. Thus, the promotion of biodiversity that this increase could imply cannot be ascribed to Bison activity.

Regarding image interpretation class short grasses, despite of the fact the largest average increase in class short grasses takes place in those areas with the highest intensity in use, no significant differences were found. Thus, the significant averagre increase in class short grasses found at the Kraansvlak cannot be ascribed solely to Bison activity.

The study results allow drawing the following conclusions:

-Despite of the fact the largest average increase in class short grasses takes place in those areas with the highest intensity in use, it cannot be stated that Bison helps to promote those habitats important for the preservation of coastal dunes, i.e. short grasses and grey sand.
-The introduction of large herbivores in the Kraansvlak seems to counteract the process of grass encroachment while promoting short grasses (image interpretation class fc6) and thus, biodiversity.
-Nor Bison neither other grazers seem to promote the other important habitat for the preservation of coastal dunes biodiversity, i.e. grey sand.

4.1 Management advices

These results were obtained despite of the fact that in 2009 there were only 10 Bison at the Kraansvlak and they were living there only for 2 years. The impact of the Bison herd would be best assessed if pictures from 2007 and 2011 were used to carry out the same kind of research.

In reference to the DICRANUM classification process, the use of pictures taken using different devices may have an impact on the study results. In fact, while 2003 picture seems to yield more accurate classification of crisp classes, 2009 picture appears to perform better when classifying fuzzy classes. In order to avoid bias coming from this, it would be better to carry out the images' interpretation using pictures taken with the same devices and methodology.

Apart from the pictures radiometric properties, the method used for gathering the samples needed for the fuzzy classification may also have an impact on the classification performance. In this case, the samples used for the fuzzy classification of 2003 picture represented mixed habitats (e.g. 20% sand blowout, 50% grey sand, 0% mosses, 30% short grasses and 0% tall grasses), while the samples used for the classification of 2009 picture represented only one habitat type (e.g. 0% sand blowout, 0% grey sand, 0% mosses, 100% short grasses and 0% tall grasses). In this study, the samples used for the classification of 2009 picture performed better when carrying out the fuzzy classification (50.62% vs 38.22%). The potential impact of the sampling methodology should be taken into consideration for future fuzzy classes sampling.

Regarding the study results, it can be stated that the introduction of large grazers in the Kraansvlak can help to counteract grass encroachment and promote biodiversity. More specifically, grazers were capable of reducing the surface covered by tall grasses while promoting short grasses in a significant way. Besides, the introduction of Bison can help to counteract shrub encroachment. However, the capacity of the Bison to promote highly diverse habitats was not proved. As it was mentioned before, the study results were constraint by the limited number of Bison living at the Kraansvlak in 2009, and by the fact that these Bison were introduce only 2 years before the study tested their impact on vegetation. If the same study was carried out using a picture from 2011, the impact of Bison on vegetation could be better tested.

However, the recovery of coastal dunes does not only depend on tackling the dunes' degradation process, but on promoting important habitats for the preservation of the dunes biodiversity. In reference to this, the introduction of grazers in the Kraansvlak was found to promote in a significant way one of the habitats important for the preservation of biodiversity. However, nor Bison neither other grazers were found to promote grey sand.

According to the results obtained, grey sand class increases slightly at the Kraansvlak (average % of change of class grey sand at the Kraansvlak = 0.3%). Due to the fact that in the control area an average decrease of -1.9% was found, the slight increase found at the Kraansvlak was enough to be significant. If we look at the evolution of this vegetation class in areas with different intensity in use (Figure 21), it can be noted that this class is only increasing in the areas with low utilization. Leading us to the conclusion that the slight increase observed is probably caused by the process of natural succession taking place at the artificially created sandy area (Figure 22).

Taking into account that the ongoing process of natural succession is likely to entail the extinction of the remaining areas of grey sand, it would be crucial for the preservation of biodiversity applying measures directed towards the promotion of the habitat type grey sand.

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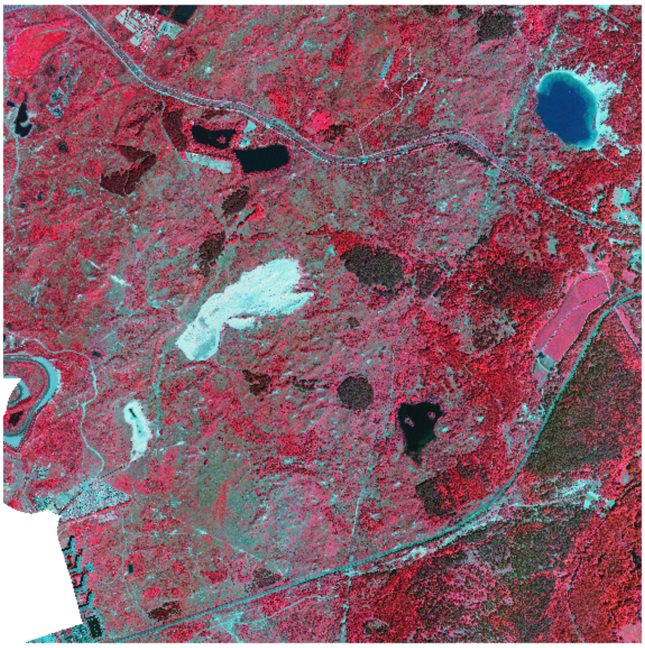
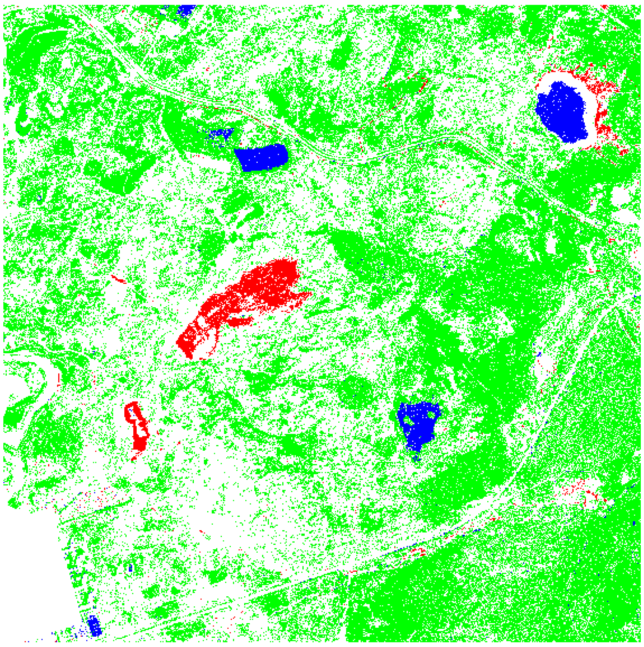
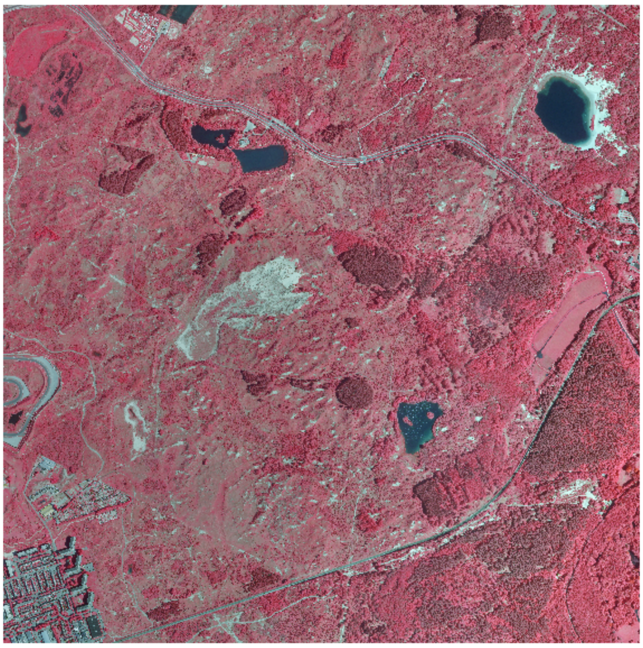
APPENDIX 1

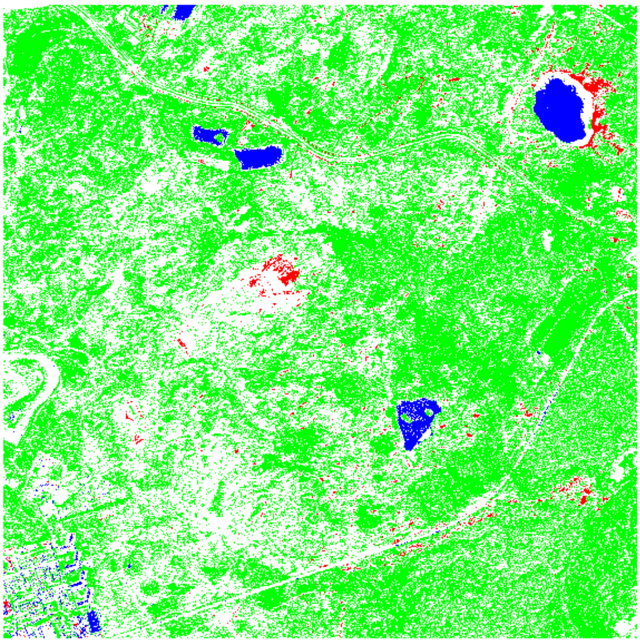
2003 aerial picture and its crisp classification





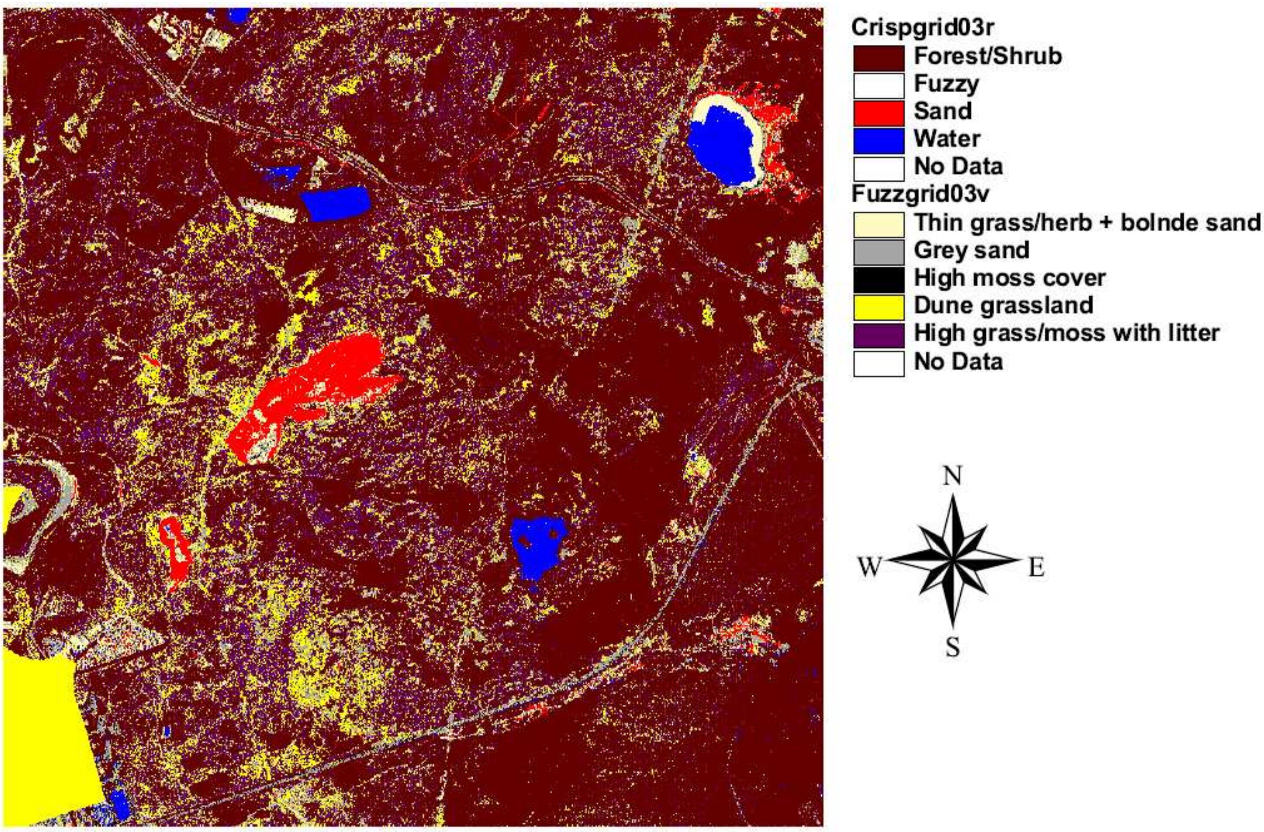
2009 aerial picture and its crisp classification





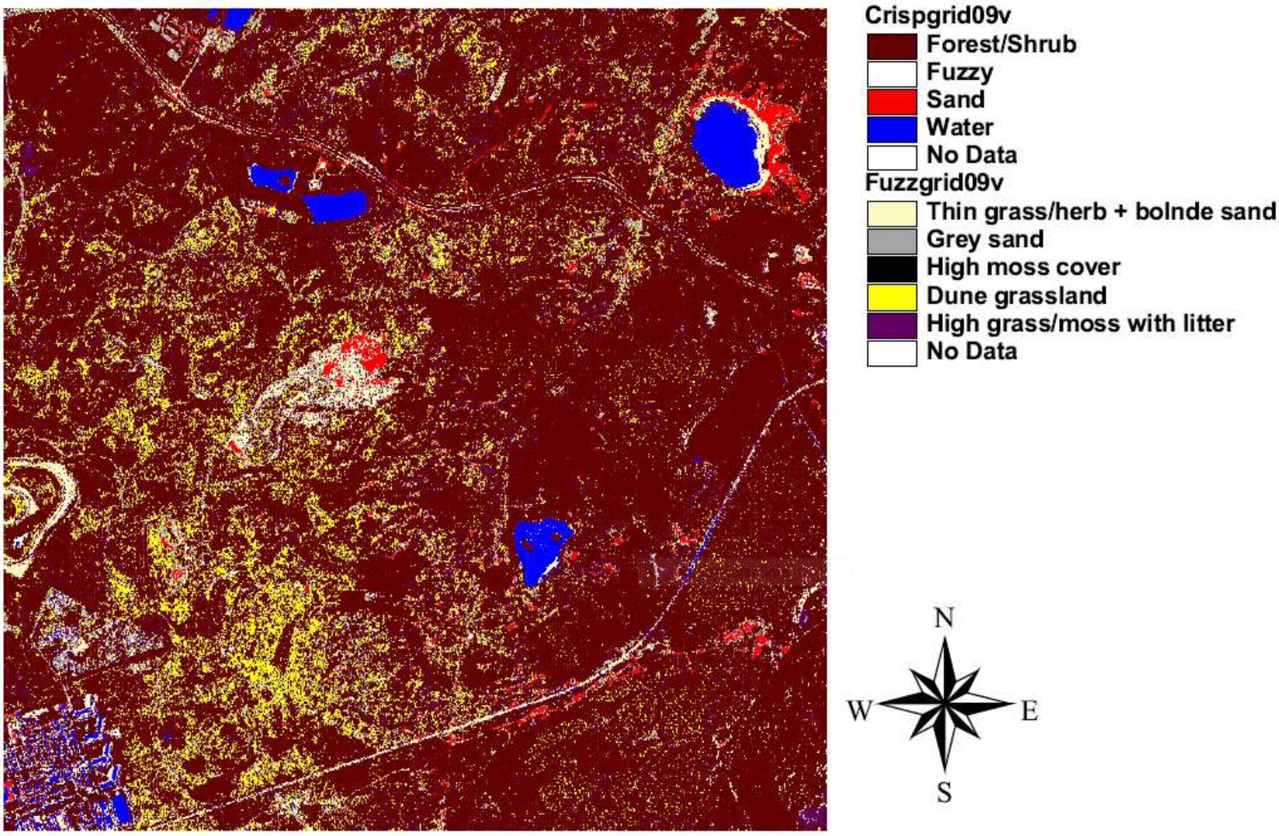
APPENDIX 2

2003 image interpretation with crisp and fuzzy classes



APPENDIX 3

2009 image interpretation with crisp and fuzzy classes



APPENDIX 4

Anova: WOODY IN/OUT

SUMMARY

Groups	Count	Sum	Average	Variance
Inside	806	63.21	0.078424	0.033506
Outside	1241	106.29	0.085649	0.044033

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.025503	1	0.025503	0.639333	0.424045	3.84601
Within Groups	81.5742	2045	0.03989			
Total	81.5997	2046				

Anova: BARE SAND IN/OUT

SUMMARY

Groups	Count	Sum	Average	Variance
Inside	806	-32.25	-0.04001	0.018226
Outside	1241	-4.95	-0.00399	0.001321

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.634111	1	0.634111	79.50758	1.04E-18	3.84601
Within Groups	16.30986	2045	0.007975			
Total	16.94397	2046				

Anova: SAND BLOWOUT IN/OUT

SUMMARY

Groups	Count	Sum	Average	Variance
Inside	806	18.86	0.0234	0.010659
Outside	1241	14.88	0.01199	0.007023

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.063606	1	0.063606	7.523833	0.006142	3.84601
Within Groups	17.28827	2045	0.008454			
Total	17.35188	2046				

Anova: GREY SAND IN/OUT

SUMMARY

Groups	Count	Sum	Average	Variance
Inside	806	2.53	0.003139	0.008392
Outside	1241	-23.12	-0.01863	0.008761

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.231563	1	0.231563	26.8758	2.38E-07	3.84601
Within Groups	17.61983	2045	0.008616			
Total	17.85139	2046				

Anova: MOSSES IN/OUT

SUMMARY

Groups	Count	Sum	Average	Variance
Inside	806	-5.39	-0.00669	0.000902
Outside	1241	-4.24	-0.00342	0.001173

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.005227	1	0.005227	4.902369	0.02693	3.84601
Within Groups	2.180569	2045	0.001066			
Total	2.185796	2046				

Anova: SHORT GRASSES IN/OUT

SUMMARY

Groups	Count	Sum	Average	Variance
Inside	806	39.22	0.04866	0.027624
Outside	1241	31.69	0.025536	0.030571

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	0.26129	1	0.26129	8.884088	0.002911	3.84601
Within Groups	60.14542	2045	0.029411			
Total	60.40671	2046				

Anova: TALL GRASSES IN/OUT

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
Inside	806	-76.03	-0.09433	0.049821
Outside	1241	-109.11	-0.08792	0.052271

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.020071	1	0.020071	0.391197	0.531741	3.84601
Within Groups	104.922	2045	0.051307			
Total	104.9421	2046				

APPENDIX 5

Anova: WOODY BISON UTILIZATION DENSITY

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
LOW	560	40.98	0.073179	0.0326
MEDIUM	216	23.55	0.109028	0.030769
HIGH	30	-1.32	-0.044	0.05057

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.667341	2	0.33367	10.18566	4.28E-05	3.006936
Within Groups	26.30536	803	0.032759			
Total	26.9727	805				

Anova: BARE SAND BISON UTILIZATION DENSITY

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
LOW	560	-31.81	-0.0568	0.025193
MEDIUM	216	-0.44	-0.00204	0.000334
HIGH	30	0	0	0

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.517418	2	0.258709	14.67685	5.49E-07	3.006936
Within Groups	14.15448	803	0.017627			
Total	14.6719	805				

Anova: SAND BLOW OUT BISON UTILIZATION DENSITY

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
LOW	560	15.56	0.027786	0.014067
MEDIUM	216	3.08	0.014259	0.00306
HIGH	30	0.22	0.007333	0.000779

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.036563	2	0.018281	1.718222	0.180044	3.006936
Within Groups	8.543722	803	0.01064			
Total	8.580285	805				

Anova: GREY SAND BISON UTILIZATION DENSITY

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
LOW	560	2.97	0.005304	0.009431
MEDIUM	216	-0.44	-0.00204	0.006637
HIGH	30	0	0	0.001669

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.008706	2	0.004353	0.518077	0.595864	3.006936
Within Groups	6.747252	803	0.008403			
Total	6.755958	805				

Anova: MOSSES BISON UTILIZATION DENSITY

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
LOW	560	-2.75	-0.00491	0.00082
MEDIUM	216	-2.42	-0.0112	0.001112
HIGH	30	-0.22	-0.00733	0.000779

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.006186	2	0.003093	3.449207	0.032242	3.006936
Within Groups	0.720069	803	0.000897			
Total	0.726255	805				

Anova: SHORT GRASSES BISON UTILIZATION DENSITY

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
LOW	560	27.75	0.049554	0.026173
MEDIUM	216	8.04	0.037222	0.028656
HIGH	30	3.43	0.114333	0.044405

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.158094	2	0.079047	2.874841	0.057006	3.006936
Within Groups	22.07946	803	0.027496			
Total	22.23755	805				

Anova: TALL GRASSES BISON UTILIZATION DENSITY

SUMMARY

Groups	*Count*	*Sum*	*Average*	*Variance*
LOW	560	-47.31	-0.08448	0.050763
MEDIUM	216	-26.5	-0.12269	0.045879
HIGH	30	-2.22	-0.074	0.056018

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.240376	2	0.120188	2.42093	0.089487	3.006936
Within Groups	39.86521	803	0.049645			
Total	40.10559	805				

APPENDIX 6

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Kraansvlak												
Bison								3	6	10	14	16
Konik horses						12	12	12			5	9
Highland cattle						16	16	16				
Rabbits	4	6	4	3	4	5	5	5	4	6	18	-
Wild												
Roe deer	114	133	156	130	160	106	109	138	209	134	61	56
Fallow deer	13	11	37	18	58	52	48	96	92	123	60	155

Timeline of grazers at the Kraansvlak (Sikkes 2011)