Forside

Eksamensinformation
NIGK12500E - Nature Management Thesis 30 ECTS, Department of Geosciences and Natural Resource Management - Kontrakt:137778 (Mads Østergaard Brun)

Besvarelsen afleveres af
Mads Østergaard Brun
wzl230@alumni.ku.dk

Eksamensadministratorer
Eksamensteam, tel 35 33 64 57
eksamen@science.ku.dk

Bedømmere
Rita M. Buttenschøn
Eksaminator
rmb@ign.ku.dk
+4535331712

Steffen Brøgger-Jensen
Censor
steffen.brogger@gmail.com

Besvarelsesinformationer

Titel: Evaluating grazing in natural areas, with data from virtual fencing and remote sensing: A Case study from Fanø, Denmark
Titel, engelsk: Evaluating grazing in natural areas, with data from virtual fencing and remote sensing: A Case study from Fanø, Denmark
Tro og love-erklæring: Ja
Indeholder besvarelsen fortroligt materiale: Nej

UNIVERSITY OF COPENHAGEN
FACULTY OF SCIENCE

Evaluating grazing in natural areas, with data from virtual fencing and remote sensing: A case study from Fanø, Denmark

Mads Østergaard Brun

Supervisor: Rita Merete Buttenschøn
Submitted on: 31st of May 2023

Name of department:	Geosciences and Natural Resource Management
Author(s):	Mads Østergaard Brun
Title:	Evaluating grazing in natural areas with virtual fencing and remote sensing: A case study from Fanø, Denmark
Supervisor:	Rita Merete Buttenschøn
Submitted on:	31st of May 2023
Number of characters:	62.584

Image of cow on front page taken by:	Mads Østergaard Brun
Image of landscape on front page taken by:	Caroline Bechsgaard Sørensen

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Preface

This thesis is part of a larger study, which aim is to investigate the use of virtual fencing in Denmark. The thesis is 30 ECTS points and completes my Master of Science (MSc) in Nature Management, at the Faculty of Science, University of Copenhagen. The report is written in the period 6th of February 2023 to the 31st of May 2023.

Thank you to everyone involved with virtual Fencing on Fanø, whose hard work have made the project possible. It has been an honour to work with this first of its kind project in Denmark, which in no doubt will establish the foundation for the potential use of virtual fencing in Denmark.

I would like to thank my supervisor Rita Merete Buttenschøn, whose incredible knowledge and experience have helped immensely, even on weekends and with short notice. In general, thank you to the professors at the Faculty of Science, who have always been available when help was needed.

Lastly, I would like to thank my family and friends for giving me the well needed opportunity to just relax, have fun and recharge before returning to working on the thesis. Most importantly I would like to thank my girlfriend Caroline whose support and love have been essential for me to get through this process.

Submitted on the 31st of May 2023

Mads B. Bran

Abstract

There is a rapid decline in biodiversity around the globe, and while many efforts have been made to try and revert the decline of biodiversity, the decline is still ongoing. While grazing as a management tool for increasing biodiversity is often used, it does come with challenges, and virtual fencing has therefore been proposed as a solution to some of these challenges. This thesis is part of a larger study which investigates the use of virtual fencing in a study site on the Island of Fanø, Denmark.

This thesis investigates the use of the GPS data from the grazers in the virtual fencing project, in relation to a landscape analysis using GIS. The monitoring data from the cattle were analysed in QGIS by creating heatmaps for specific intervals of the study period, while also creating maps of the paths used by the cattle. A landscape analysis was created using Object Based Image Analysis, which classified the landscape into habitats by supervised classification. The landscape was further analysed using Sentinal-2 data to calculate the Normalised Vegetation Index. Furthermore, a terrain analysis was undertaken. The spatial mapping of the cattle and the landscape was further analysed and compared in Excel.

The thesis found that the habitat preferences of the cattle was very dependent on whether the cattle received supplementary feeding or not. The activity of the cattle was further found to decrease during the autumn and winter when supplementary feeding was provided. Landscape elements such as diches and points of interest such as drinking spots and resting spots, were found to have an impact on the grazing intensity of the surrounding habitats. Wet habitats were found to be preferred for grazing, and even within nutrient rich habitats the cattle were found to selectively graze the more nutrient rich areas. This was made apparent due to the use of NDVI, which together with OBIA proved to be promising tools for landscape analysis, although further studies should be made to improve the use of remote sensing tools. Remote sensing in conjunction with virtual fencing could be a valuable tool in nature management.

Introduction

Biodiversity has attracted an increased awareness within the last couple of decades, both due to the benefits that biodiversity can provide for human health, as well as the economic values that biodiversity can provide through ecosystems services (Singh, 2002: Roy & Marion, 2009). More recently however, the awareness for biodiversity has increased due to the fact that biodiversity is declining rapidly and that we are on the verge of a 6th mass extinction (Barnosky, et al., 2011). The immense decline in biodiversity and the ominous predictions for the future, resulted in a global conservation strategy at the Convention on Biological Diversity in Rio De Janeiro in 1992 (CBD, 1992). In Europe this resulted in the implementation of the habitat directive which aims to ensure the conservation of multiple rare, threatened and or endemic species within the EU member states and hereby Denmark (Council Directive 92/43/EEC, 1992).

Recently in 2020, the Danish government passed a historic nature- and biodiversity package which aims to further protect and enhance biodiversity in Denmark. This included the establishment of 15 new large Nature National Parks (NNP) where nature and biodiversity are prioritized. This will for the majority of the NNP's be supported by implementing a grazing regime. The biodiversity package also included the conversion of 75.000 ha forest to natural forests, part of which are included in the 15 NNP's, meaning that parts of these natural forests also will be managed by grazing (Miljøministeriet, 2020). The overall recommendations for the management of these newly appointed areas for biodiversity, is to allow for natural dynamics and to break up the sharp and non-natural vegetation boundaries (Møller, et al., 2018).

Grazing has been proposed and used as a management tool for increasing biodiversity in natural areas for decades (Buttenshcøn, et al., 2021: Rosenthal, Schautzer, & Eichberg, 2012). The main purpose of the grazing is to keep the woody vegetation from afforesting, the area while also allowing the herbaceous vegetation to bloom, which is achieved by having the most optimal grazing pressure (Rupprecht, Gilhaus, & Hölzel, 2016). Determining the correct grazing pressure can be difficult however, especially in a natural environment with a variety of habitats that each provide different amounts of food resources which furthermore changes throughout the year. In addition to that, certain habitats can be sensitive to overgrazing and erosion from the grazers, in certain periods throughout the year. While grazing of salt marshes is known to benefit breeding birds (Tinbergen, Ens, Koffijberg, Dijkema, & Bakker, 2015), trampling of nests during the breeding season has been found to increase with increased livestock numbers (Mandema, Tinbergen, Ens, & Bakker, 2013).

While guidelines for the optimal grazing pressure in specific habitats specifically for the benefit of increasing biodiversity has been proposed (Buttenschøn R. M., 2014), these guidelines can also be a challenge when estimating the size and distribution of the habitats. This can potentially be even more challenging in the new NNP's, where habitats are expected to occur in a mosaic due to natural dynamics in large areas. While most habitats in Denmark is mapped either through the national Nature Protection Act (Bekendtgørelse af lov om naturbeskyttelse, 2021) or through the Natura-2000 Habitat Act (Habitatbekendtgørelsen, 2021), this mapping of habitats is mainly based on field surveys, which can make it difficult to assess the distribution of the habitats when they occur in a mosaic. For more accurate mapping of habitats, remote sensing and the use of semi-automatic classification may help. Current literature also documents the potential of remote sensing in the conservation of biodiversity (Pettorelli, et al., 2014: Turner, et al., 2003). The use of multispectral satelite data furthermore promotes the calculation of vegetation indices, which can be attributed to a range a characteristics such as plant growth, and water and nutrient levels within the plant (Xue & Su, 2017), that can be valuable when estimating the most optimal grazing pressure of the habitats.

Keeping the grazing herbivores within the desired grazing area requires ongoing monitoring of the herbivores, as well as practical solutions such as physical fencing, along with maintenance of fences. Traditionally, herbivores have been kept within the desired grazing area using physical fences, and the monitoring has been done by manually searching the area for the herbivores. The establishment and the ongoing maintenance of the physical fence however can be expensive, especially in natural areas where terrain, hydrology and vegetation can make it difficult to gain proper access to the fence. These circumstances can likewise make it difficult for the supervisor of the herbivores to properly monitor their wellbeing. Physical fencing is also inflexible, if for example the need for excluding a sensitive habitat from grazing should arise. Physical fencing can also be problematic for the movement of wildlife such as deer (McKILLOP & Sibly, 2008). Recently, virtual fencing has been proposed as a solution that can help lighten these problems, while also allowing detailed monitoring of the grazing pressure.

Virtual fencing works by establishing an invisible virtual fence, which is made apparent to the grazers by auditory warnings and low electric impulses. The auditory warnings and the electric impulses are administered by a collar, which houses a GPS unit, batteries, and a small solar panel along with the technology needed for the auditory warnings and electric impulses. The use of these collars however is illegal in a number of European countries, including Denmark. The current regulations in Denmark prohibit the use of virtual fencing, due to the concerns and uncertainty of the possibly negative effect that this system may have on the welfare of the animals.

This thesis is part of a larger ongoing project, which aim is to investigate whether virtual fencing can be used on cattle without a negative impact on the cattle's welfare. The project is situated on the island of Fanø and has been started on the initiative of Dan Pode Poulsen, who owns the land on which the project is carried out. The cattle are owned by Bente and Michael Baun. The project is followed by scientists from Aarhus University and Copenhagen University, as well as Nationalpark Vadehavet and the municipality of Fanø. The project is financed by 15. Juni Fonden, Hedeselskabet and Markus Jebsens Naturpulje. The collars that are used in this project are provided by the company NoFence© (No Fence, 2023).

The aim of this thesis is to evaluate the habitat- and food preferences of the cattle within the study at Fanø, while considering the effects that the behaviour of the cattle exerts on the different habitats. This was accomplished by performing spatial analysis of the cattle's movements and relating this to a landscape analysis, both performed using GIS.

Methods

The study site

The study was conducted in an area grazed by cattle, located on the central east coast of the island of Fanø in the southwestern part of Jutland, Denmark (Figure 1). The total area of the study site is approximately 65 ha. The area is protected as part of a Nature-2000 site (N89) designated both as a habitat, bird-protection (F53) and RAMSAR site (Miljøportalen, 2023). The geology of the study site mainly consists of course sandy soil deposited by glacial meltwater that have been superimposed by marine sand deposited by wind, while the eastern most area is silty bay mud with a high organic content (Gravesen, 2023). The western part of the study site mainly consists of conifer forests, and towards east is a mosaic of open habitats such as dry and wet heath, dunes, and meadows with scattered vegetation of trees and bushes. Along the eastern coastline is a large salt marsh. Several streams and ditches run through the study site. A small part of the salt marsh was virtually excluded from the grazing for parts of the study period, as it was used for cutting hay.

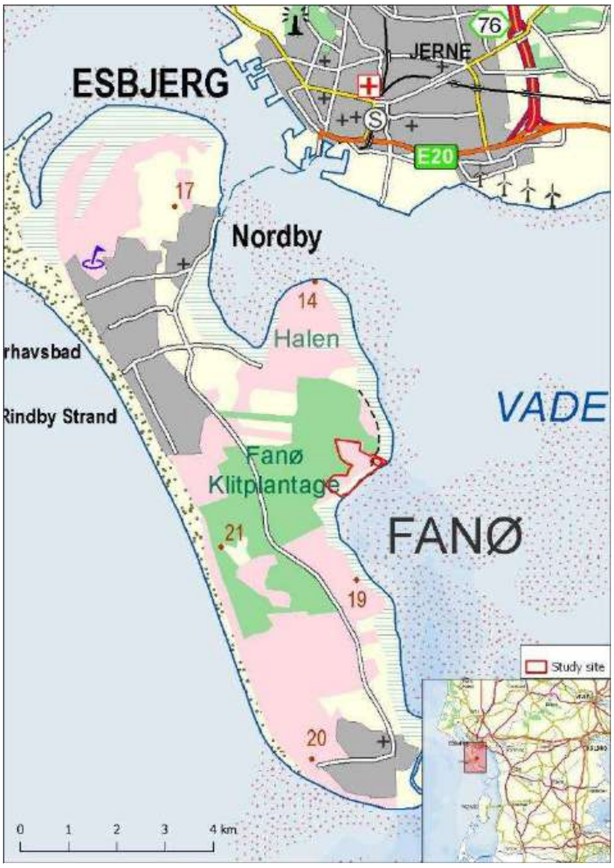

Figure 1: The study site is situated on the eastern part of Fanø, which is an island in the Wadden sea at the southwestern coast of Jutland, Denmark.

A few summer house residencies are located within the study site, and a public dirt road going all the way through the study site can be found following the transition between the coarse sand and the bay mud. Historic maps shows that the study site has been uncultivated and has appeared as a mosaic of open habitats with only a few ditches apparent in the salt marsh. Arial imagery from 1945 however showed that a handful of areas appeared to have been cultivated or at least moved. This is most apparent in the northern area where the large meadow can be found today, however most of what is now the wet habitats such as the central wet dune and the southern meadow have also been cultivated or at least moved. From the arial imagery in 1945 it is also apparent that the salt marsh has been moved. From 1945 to 1995 there is no arial imagery or maps documenting the management of the study site. Moving of the salt marsh and the meadows seems to have taken place throughout the years from 1995 until the recent years, while moving of the central wet dune appears to have been halted. (Miljøportalen, 2023). Since late spring of 2021, the area has been used as a test site for the use of virtual fencing in the management of nature areas.

Spatial analysis of cattle movements

Data sources

The initial GPS data for this thesis is collected from the 29th of May 2021 to the 28th of February 2023. During this period the collars continuously monitored the position of the cattle. The position of the cattle was logged every 15 minutes, when an auditory signal was given, when an electric impulse was given or when changes such as when collars transitioned from an inactive to an active fence. Furthermore, every 30 minutes a message with solar charge, activity etc was logged. The different message types that are logged can be seen in Table 1.

Table 1: The different message types are described by their technical name, the frequency by which they are logged and the number of observations within the study site during the period from the 29th of May 2021 to the 28th of February 2023. The table below contains all messages including duplicates, which are later deleted. This thesis furthermore only use the poll messages from the 1st of January 2022 to the 28th of February 2023.

Message type	*Frequency*	*Count*
status	Occasionally	2.579
seq	Every 30 minutes	390.990
client_zap	Occasionally	554
client_warning	Occasionally	5.661
poll	Every 15 minutes	1.179.149

This study only uses the positional data from the poll messages that were logged every 15 minutes. In the spring and summer of 2021, the virtual border was changed many times to slowly familiarize the cattle to the collars and the virtual fence, and in the autumn of 2021 the interval between the logging of the poll messages was temporarily changed. To ensure that the data is spatially and temporally consistent, all of 2021 have therefore been excluded from this thesis. The data period for this analysis is therefore from the 1st of January 2022 to the 28th of February 2023.

The data was furthermore divided into two time periods, which were defined by a change in the management of the cattle, that influenced the behaviour of the cattle significantly. The cattle received supplementary fodder during the winter of 2022 and the winter of 2023. The periods from the 1st of January to the 20th of April 2022 and from the 24th of November to the 28th of February is therefore regarded as the period with supplementary feeding. The period from the 21st of April 2022 to the 23rd of November 2022 is regarded as the period without supplementary feeding. The positional data from these two time periods, were used to create heatmaps of the whereabouts of the cattle.

Heatmaps

Heatmaps for the two time periods, with and without supplementary feeding was created. Individual heatmaps for every month of the study period was also created. The heatmaps were created by counting the number of data points in a 5x5 meter polygon grid covering the entire project area. This 5x5 meter polygon grid was also used as an analysis layer for all the other GIS analysis.

Paths

The movement patterns of the cattle were analysed by drawing lines between each subsequent GPS location for every individual cattle. The length of the lines was then calculated, so the lines had information of the distances that the cattle had travelled in 15 minutes. This was done respectively for the data with supplementary feeding and without supplementary feeding. Every 5 meter along the lines, points were made. By distancing the points at 5 meters distance it ensures that each point is only counted once in the 5x5 meter grid. Using the same 5x5 meter grid that was used for the heatmap, the points created by the paths was then counted for each 5x5 polygon with the length of the line corresponding to the point being added as the count. This resulted in at heatmap where the longer paths are more apparent.

Landscape analysis

GIS data sources

The vegetation and landscape were analysed using Sentinal-2 data, digital elevation models (DEM) and orthophotos containing information in the near-infrared spectrum, provided by Styrelsen for Dataforsyning og Infrastruktur (SDFI, 1, 2023).

The DEM data is derived from a point cloud which is gathered by airplane using LiDAR, where 1/5 of Denmark is updated every year (SDFI, 2, 2023). This means that the DEM data for the study site is updated every fifth year, most recently in 2020 (SDFI, 3, 2023). The grid size of the DEM is 0,4 m, the horizontal accuracy of the cells is 0,15 m and the vertical accuracy is 0,05 m (SDFI, 4, 2023). The DEM data is provided both as terrain data and surface data.

The orthophotos are gathered by airplane which takes photos where each pixel is adjusted to the position of the airplane in relation to the DEM. This ensures that the orthophotos can be used for measurements. The photos for the orthophoto are taken every year before leaf-out in the period 1st march to 1st may. The orthophotos are produced as a 4-band RGBNir (Red, Green, Blue, Near-infrared), with a pixel size of 12,5 cm (SDFI, 5, 2023).

The Sentinal-2 data is satellite imagery collected by 2 individual satellites phased at 180 degrees, resulting in a revisit frequency of 5 days. The satellites carry a multi-spectral instrument capable of collecting data from 12 different wavelengths of the electromagnetic spectrum, at different spatial resolutions (The European Space Agency, 2023). Although the high revisit frequency of 5 days provides great flexibility, the usability of the data is dependent on the cloud cover at the time of capture.

All GIS analysis was conducted in QGIS Desktop 3.22.3 (QGIS, 2023), using both native QGIS processes, and third-party processes from the OrfeoToolbox (OTB) provider plugin (Orfeo, 2023), Semi-automatic classification plugin (Congedo, 2018) and GDAL (GDAL, 2023).

Topography

The DEM surface data was imported into QGIS using a WMTS service, and the data from the study site was then prepared for further analysis by exporting the data as a local GeoTIFF file. The heterogeneity of the terrain was calculated using the Terrain Ruggedness Analysis (TRI) from the GDAL Raster analysis library. The TRI is calculated for each cell in the DEM data, by calculating the summed difference between each cell and its eight neighbour cells. The calculation of TRI is therefore dependent on the accuracy and the resolution of the DEM. With a vertical accuracy of 0,05 m and a grid size of 0,4 m, the TRI should be sensitive to small scale topography and can be used as on objective quantitative measure for small- and large-scale topographic heterogeneity (J., D., & Robert, 1999). This raster data was used for the visual representation of TRI. The TRI raster data values were then sampled with a point layer in a 5x5 m grid. This sampled TRI value was then jointed to the 5x5 m polygon grid, for both periods with- and without supplementary feeding.

Habitat analysis using SCP

Several methods for vegetation analysis using GIS were used. One of the methods that were used was semi-automatic classification of land cover using the Semi-automatic classification plugin (SCP) in QGIS. Sentinal-2 satellite data was downloaded for the test site using SCP, and the raster bands were converted to reflectance while also correcting for atmospheric scattering. The Sentinal-2 data consists of 12 different bands with different resolutions (Table 2).

Table 2: The table shows the 12 different bands present in the Sentinal-2 data, their resolution and central wavelength, along with a description. (GISGeography, 2023).

Band	*Resolution*	*Central Wavelength*	*Description*
B1	60 m	443 nm	Ultra Blue (Coastal and Aerosol)
B2	10 m	490 nm	Blue
B3	10 m	560 nm	Green
B4	10 m	665 nm	Red
B5	20 m	705 nm	Visible and Near Infrared (VNIR)
B6	20 m	740 nm	Visible and Near Infrared (VNIR)
B7	20 m	783 nm	Visible and Near Infrared (VNIR)
B8	10 m	842 nm	Visible and Near Infrared (VNIR)
B8a	20 m	865 nm	Visible and Near Infrared (VNIR)
B9	60 m	940 nm	Short Wave Infrared (SWIR)
B10	60 m	1375 nm	Short Wave Infrared (SWIR)
B11	20 m	1610 nm	Short Wave Infrared (SWIR)
B12	20 m	2190 nm	Short Wave Infrared (SWIR)

Land cover types can be classified based on their spectral signatures in the different bands. By drawing regions of interest, an algorithm can be used to predict the land cover types for larger areas. After creating the regions of interest that was used for training the classification of the different vegetation types, it was found that the spectral signatures between the different vegetation types were very similar. This was likely due to the resolution of the data, which caused the reflectance of the different vegetation types to blend. The Sentinal-2 data was therefore not found to be sufficient to classify the different vegetation types at the desired scale using the SCP method.

Calculating NDVI

The sentinel-2 data however were used to calculate the Normalized Difference Vegetation index (NDVI). The NDVI quantifies vegetation by measuring the difference between the near infrared, which vegetation strongly reflects, and the red light, which vegetation strongly absorbs. The NDVI is calculated using NIR (Band 8 in Sentinal-2) and Red (Band 4 in sentinel-2) using the following formula:

$$NDVI = \frac{(NIR - Red)}{(NIR + Red)}$$

Healthy vegetation with a higher chlorophyl concentration reflects more near-infrared (NIR) and green light compared to other wavelengths, while also absorbing more red and blue light. The formula gives a number between -1 and +1, with a high reflectance in the NIR spectrum and a low reflectance in the red spectrum yielding a high NDVI value. NDVI can be used as a standardized way to measure healthy vegetation and can be used as a proxy of the vegetations nutritional value for the grazing cattle.

As sentinel-2 data is collected very frequently, it was possible to calculate the NDVI for the two periods with and without supplementary feeding. The sentinel-2 data for the period without supplementary feeding was collected on the 16th of June 2022 on a day with 0,3% cloud cover for the data set. The sentinel-2 data for the period with supplementary feeding was collected on the 8th of March 2022 on a day with 0,2% cloud cover for the data set.

Habitat analysis using OBIA

As vegetation analysis using Sentinal-2 data proved to be unsatisfactory for other than the calculation of NDVI, vegetation analysis using Object Based Image Analysis (OBIA) was used. This approach analyses the raster data at an object level instead of working on a pixel level, which is an approach that is particularly well adapted for high resolution images such as the orthophotos from SDFI (Hossain & Chen, 2019). The processing of the data was made using Orfeo Toolbox (OTB) which was installed in QGIS.

The OBIA analysis consisted of a segmentation of the raster data, zonal statistics of the segmentation results, joining of classification id from a training sample to the segmented results, training of vector classifier using the segmented results with the classification id and vector classification of the segmentation results as the final vegetation classification result. This process is described further in the following sections.

Raster data was imported into QGIS and clipped, so that the raster data covered the project area. The raster data that was used for this analysis was Ortofoto forår 12,5 cm, CIR from SDFI from the spring of 2022 (SDFI, 5, 2023). This data has a resolution of 12,5 cm and the bands of the layer are near infrared (NIR), red (R) and green (G).

Using the segmentation process from Orfeo Toolbox, segmentation of the raster data as vector data was then performed. The objective of segmentation is to partition an image into a set of disjointed regions that are different according to texture, colour, and shape (Hossain & Chen, 2019). This is a critical and important step in OBIA as it determines the quality of the final analysis. Several algorithms for segmenting the vegetation such as mean-shift, connected components and watershed were tested. A region-based approach using mean-shift segmentation algorithm was chosen for the final analysis as this algorithm proved to give the best results, and because a region-based approach is considered to give better results than edge-based algorithms (Hossain & Chen, 2019). The settings were then adjusted until the segmentation result was no longer under-segmented at vegetation borders that were considered critical for the analysis. In the final analysis, the spatial radius of the mean-shift algorithm was 10 and the range radius was 15. Zonal statistics of the input raster data were then calculated for each segment of the segmentation result. The important statistics used in the analysis were the mean and standard deviation of each band within each segment.

A training sample was then made, where several points for each habitat type were plotted. It was found that some habitats were required to be subdivided into several types for the final vegetation analysis to be satisfactory. This was the case in the meadow, where additional management such as hay cutting in certain areas has given the habitats a significantly different appearance compared to the rest of the meadows. Additional points in the training sample were added subsequently until the final classification proved satisfactory. Table 3 shows a list of the habitat types, their corresponding classification id and the number of geometries that were used in the final analysis.

Table 3: The table show the different habitat types that were used as a training sample for the classification model. The classification of the different habitat types is also presented, along with the number of geometries used in the final classification model.

Habitat type	*Classification id*	*# of geometries*
Salt marsh	2	54
Dune heath	3	46
Heathland	4	30
Meadow – type 1	5	18
Meadow – type 2	12	22
Meadow – type 3	13	20
Bare ground	6	30
Wet dune	7	41
Water	8	30
Buildings	9	29
Trees	10	30

The classification id was then joined to the segmented result with the zonal statistics of the raster data. These segments containing the classification id and the zonal statistics, were then used to train a vector classifier model. The training features for training the model were the mean and the standard deviation of the Nir, red and green band, and the classification id was used as a supervised classification training id. The vector classification model was then used to predict the classification id of the segmented raster data, resulting in a map with a prediction of the habitat type. The classification id of meadow type 12 and meadow type 13 was then changed to the same classification id as meadow type 5.

The predicted habitat type was then added to the 5x5 meter grid used in the previous analysis, by adding the classification id of the predicted habitat type that had the largest overlap with each 5x5 meter cell. The classification id of the predicted habitat type in the 5x5 meter grid was then added to the observation points of each month. While the model in general proved to give satisfactory results, a critical area of interest was manually corrected into the correct habitat type. This was in an area where supplementary feeding was given. The habitat type of this area was not predicted correctly, likely due to the increased activity of the cattle and the effects of the supplementary feeding changing the spectral signature of the area significantly compared to the other areas. Due to the high activity of the cattle in this area, it was assessed that the correct habitat type was needed to not skew the results of the following statistical analysis.

Statistical analysis of cattle movements and the landscape

After all the spatial analysis of the cattle movements and the landscape analysis were made in QGIS, and the results was added to the 5x5 meter grid. The 5x5 meter grid was exported as an xml (Excel) file for further statistical analysis in Excel. The vector layer of the paths and their lengths was also exported as an xml file for further statistical analysis in Excel.

Paths were analysed by creating graphs of the lengths and the number of paths of each length. The mean, median and the standard deviation of the path length were also calculated. Graphs and calculations were created for both periods with- and without supplementary feeding. The TRI was analysed by calculating the average TRI within each habitat. The sum of the observation points in each habitat was calculated for the period with- and without supplementary feeding. The frequency of each habitat was calculated, and the frequency of the observation points in each habitat for both periods was also calculated. To evaluate the suitability of the habitats for grazing, boxplots of the NDVI in each habitat for both periods were made. The average NDVI in each habitat for both periods was also calculated independently.

Results

Spatial analysis of cattle movements

Heatmap – With supplementary feeding

In the combined period of the 1st of January 2022 to the 20th of April 2022 and from the 24th of November 2022 to the 28th of February 2023 where the cattle received supplementary fodder, it was found that the cattle mainly stayed in the north-western meadow. This is the area where the cattle received supplementary feeding. The cattle rarely moved away from this area, and when they did it was to the nearby areas or along the road passing through the study site (Figure 2).

Figure 2: The heatmap from the periods with supplementary feeding. The increasingly red colors means that there have been more observations. The heatmap show that the cattle is rarely observed outside of the area where they receive supplementary fodder.

Heatmap – without supplementary feeding

In the period from the 21st of April 2022 to the 23rd of November 2022 where the cattle did not receive supplementary feeding, they were observed in almost all the study area. The cattle however were rarely registered in the northern part of the study site and have not been registered in a specific part of the southern forest. During a field study, it was found that this area is surrounded by ditches corresponding to the border which the cattle has been registered at. The cattle were seen in certain hotspots throughout the area, most notably at the feeding site in the northern meadow and at three distinctive hotspots along the road where the cattle were found to be resting at dry high spots. Hotspots can also be found at the western part of the study site within the forested areas (Figure 3).

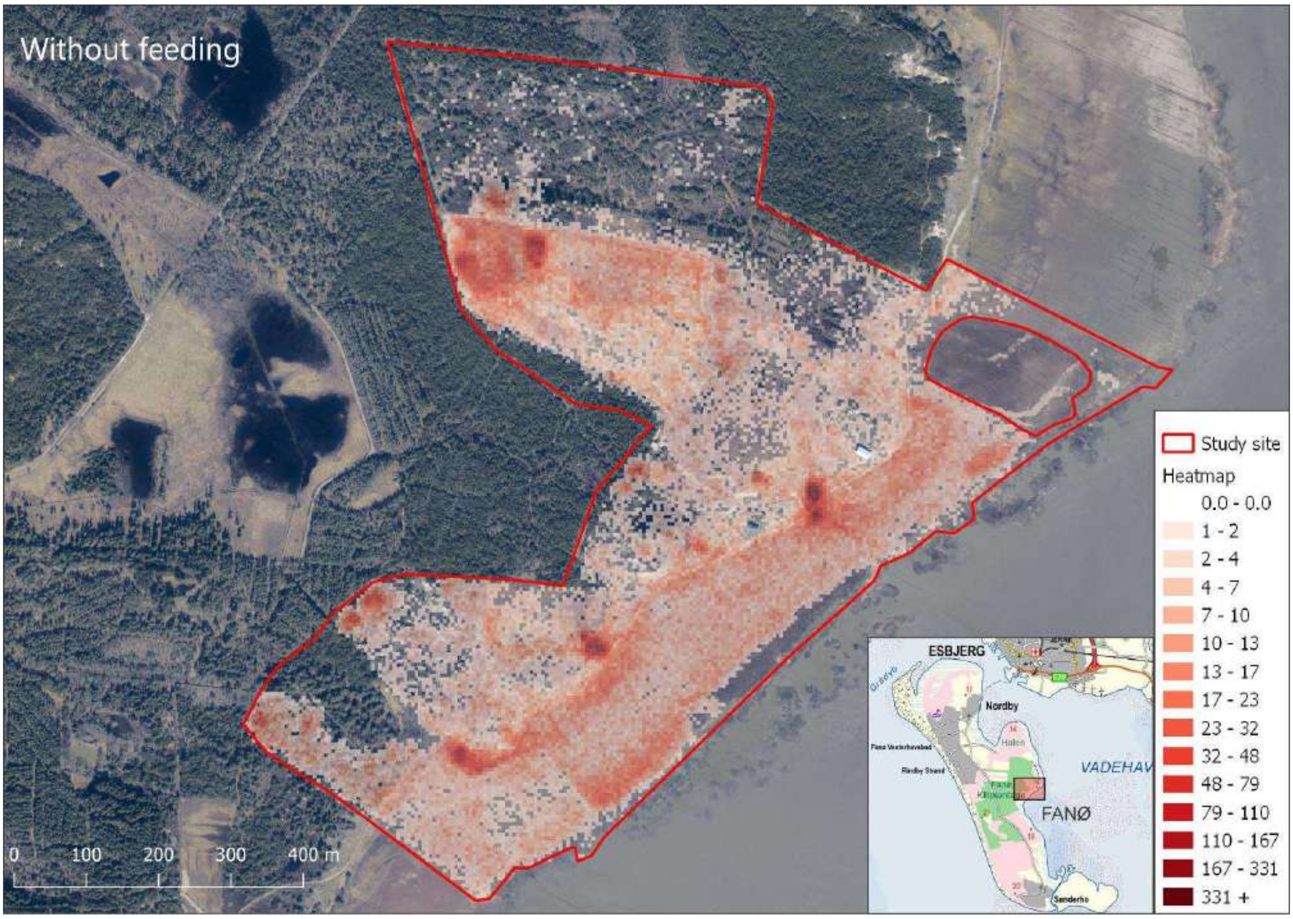

Figure 3: The heatmap from the period without supplementary feeding. The increasingly red colors means that there have been more observations. The heatmap shows that the cattle is observed throughout the study site, although certain hotspots can be found at points of interests such as resting spots.

Heatmap for each month

Heatmaps for each month of the study period was created, resulting in a total of 14 heatmaps. The heatmaps show how the cattle mainly stay within the large northwestern meadow close to the feeding sites, during the periods with supplementary feeding. After April 2022, the heatmaps show that the cattle have started grazing throughout the entire study site, although mainly in the salt marsh. The cattle is still seen at the hotspots within the feeding site until august, where significant hotspots at the feeding site are no longer visible. At some point during September when the virtually fenced off salt marsh in the south is opened for the cattle to enter, the cattle is found grazing the area visibly more compared to the other parts of the salt marsh. During November when supplementary feeding is resumed at the feeding sites again, hotspots at the feeding sites are again very visible until no activity outside of the feeding sites can be seen throughout the final months of the study period (Figure 4, Figure 5, and Figure 6).

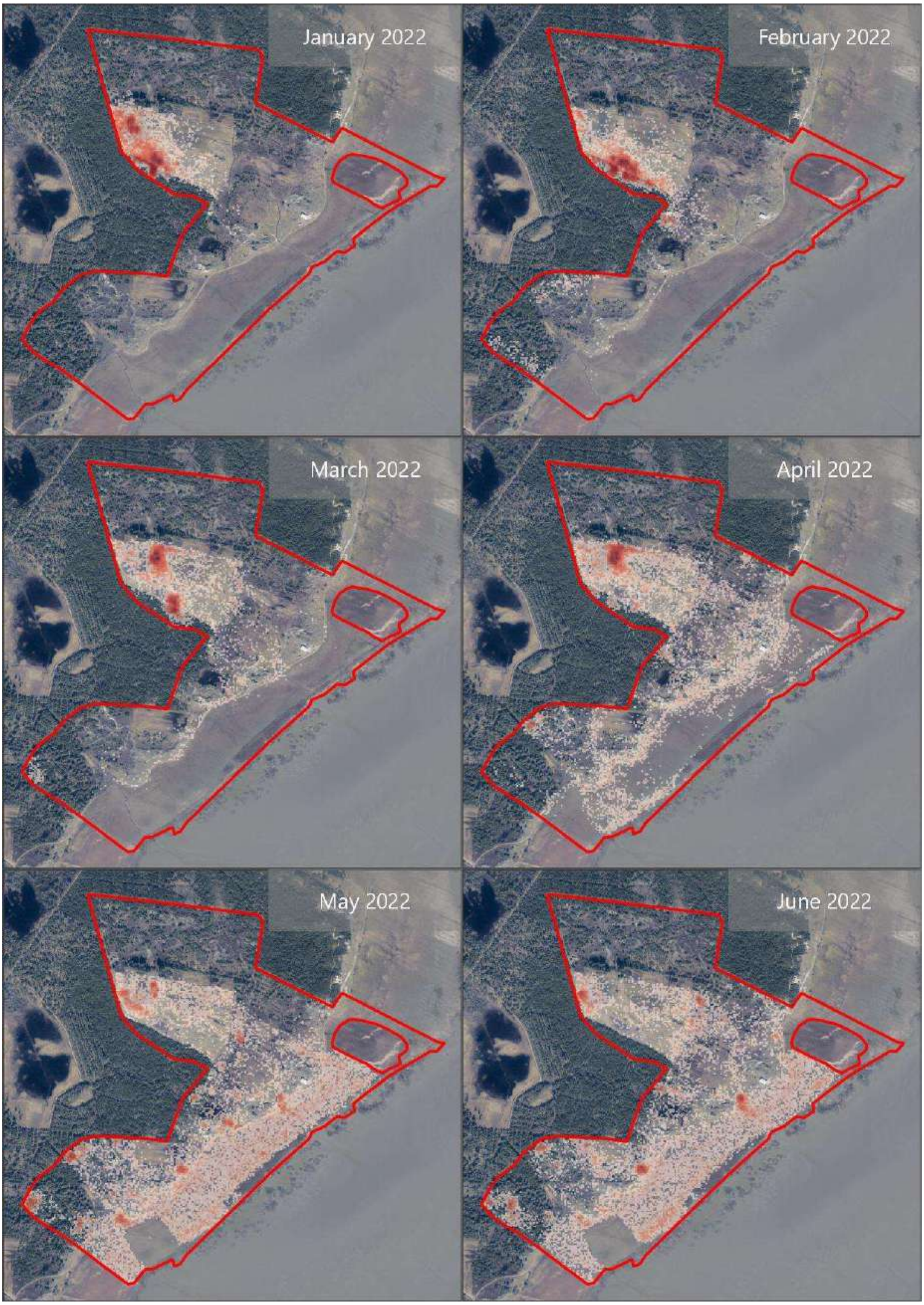

Figure 4: Heatmaps for the months of January 2022 until June 2022. An overview and a legend for the heatmaps can be found on figure 6.

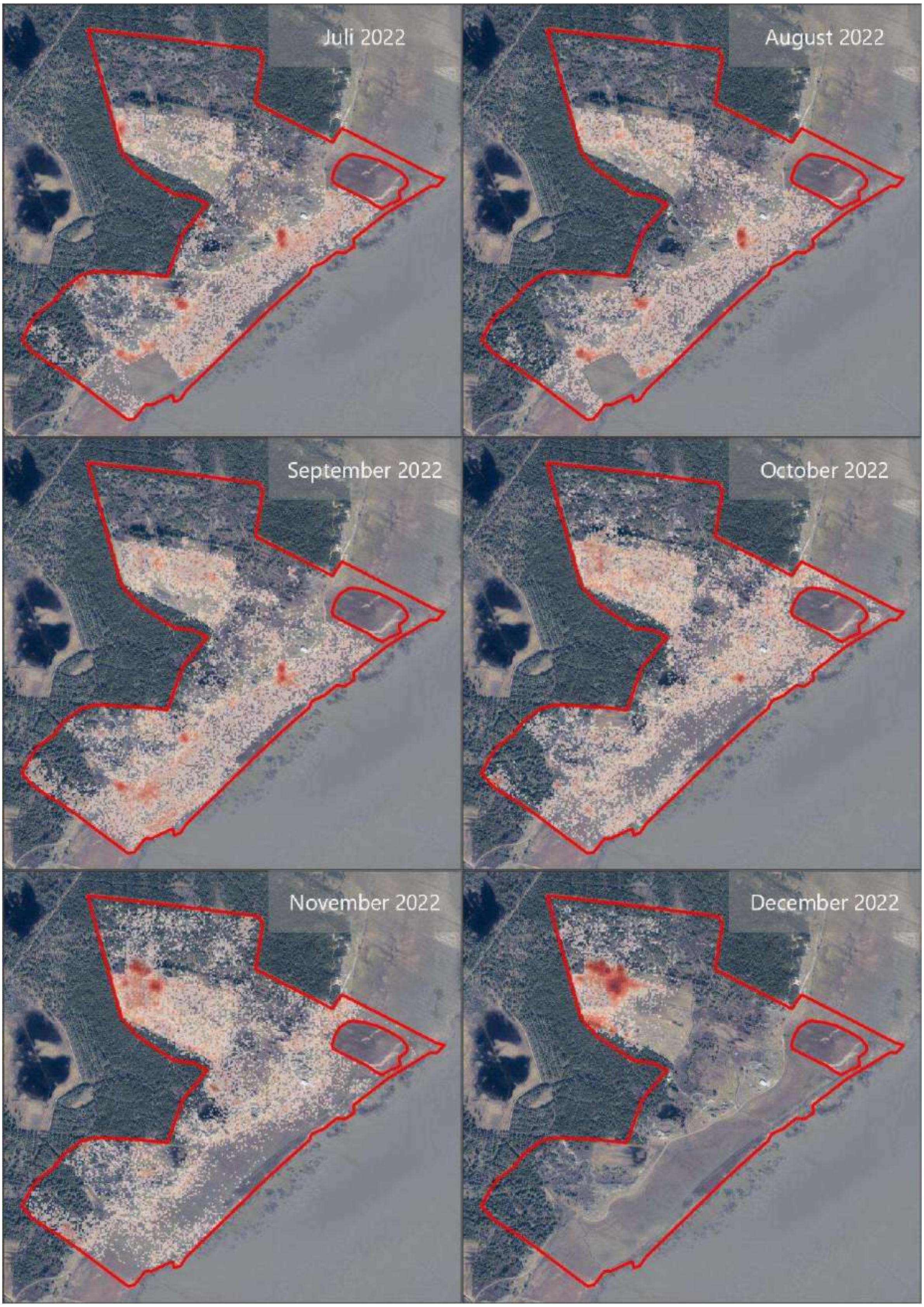

Figure 5: Heatmaps for the months of July 2022 until June December 2022. An overview and a legend for the heatmaps can be found on figure 6.

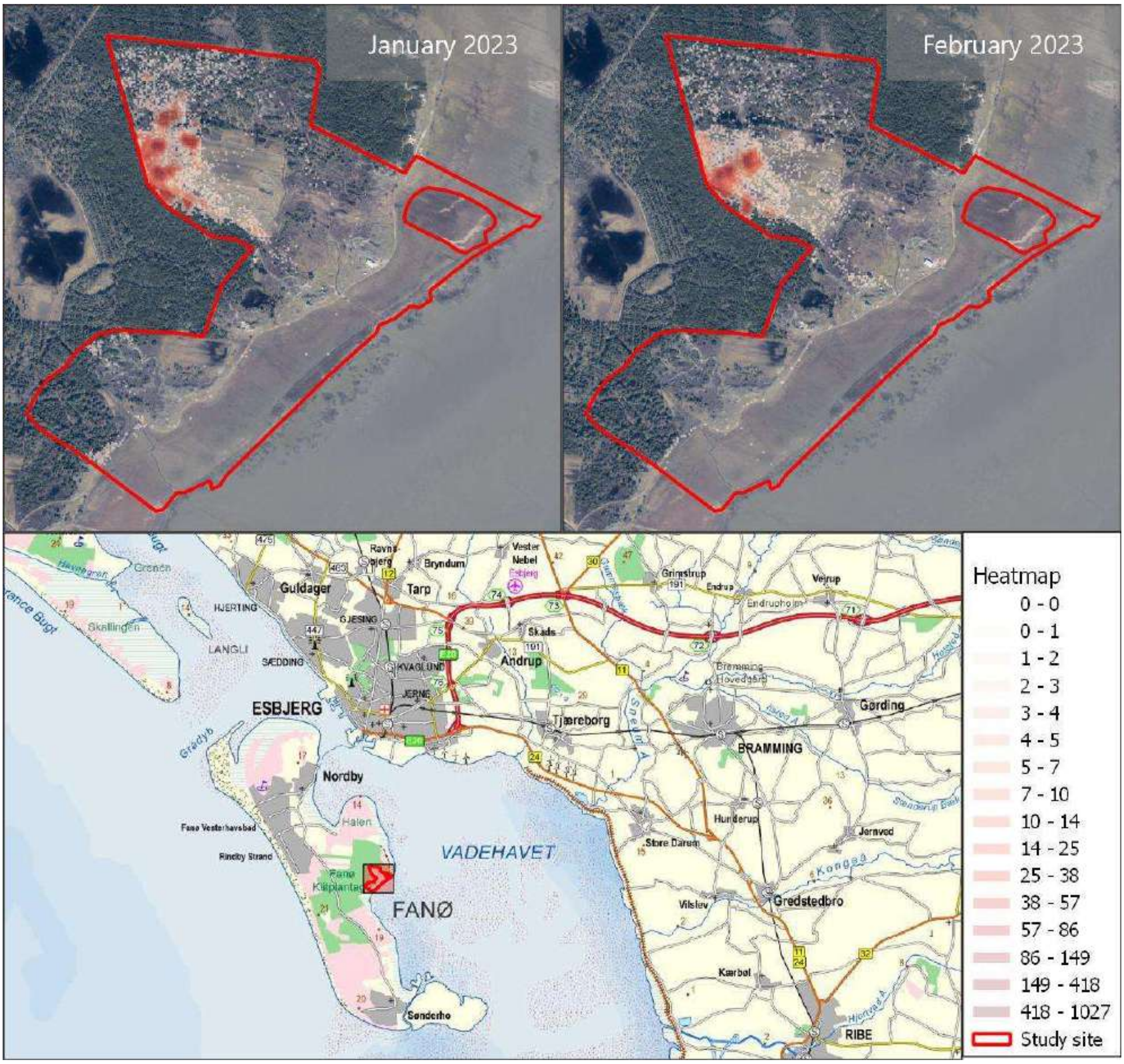

Figure 6: Heatmaps for the months of January 2023 and February 2023. The figure includes an overview of the heatmaps and a legend, which is also applicable for figure 4 and figure 5.

Paths

In the combined period of the 1st of January to the 20th of April 2022 and from the 24th of November to the 28th of February where the cattle received supplementary fodder, the summed path length within the 5x5 meter grid, show that the activity outside out of the meadow where they receive supplementary fodder is very low compared to the meadow (Figure 7).

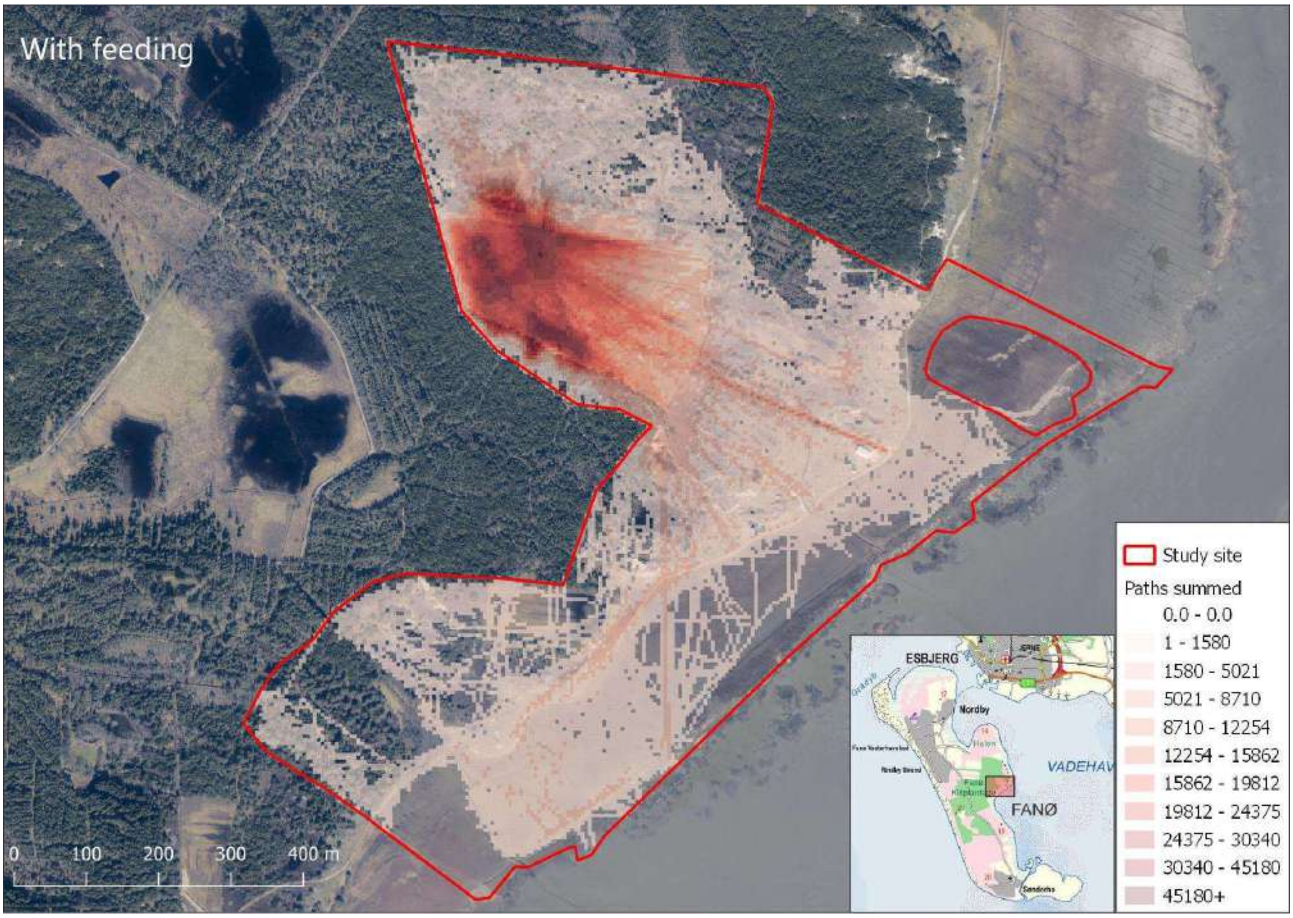

Figure 7: A map of the summed path length registered in the period with supplementary feeding. The redder the areas are, the longer is the summed path length that have been registered. The map shows that there is a much higher activity in the area with supplementary feeding, although at least some activity can be found throughout the entire study site.

In the period from the 21st of April 2022 to the 23rd of November 2022 where the cattle did not receive supplementary feeding, there is activity in most of the study site, corresponding well with where the cattle have been registered in the heatmap. It is apparent however that the road mostly was used for longer distances, as the road is more highlighted in the path map compared to the heatmap. It is also apparent that the cattle have pathways to and from certain points of interest such as the resting hotspots found throughout the study site (Figure 8).

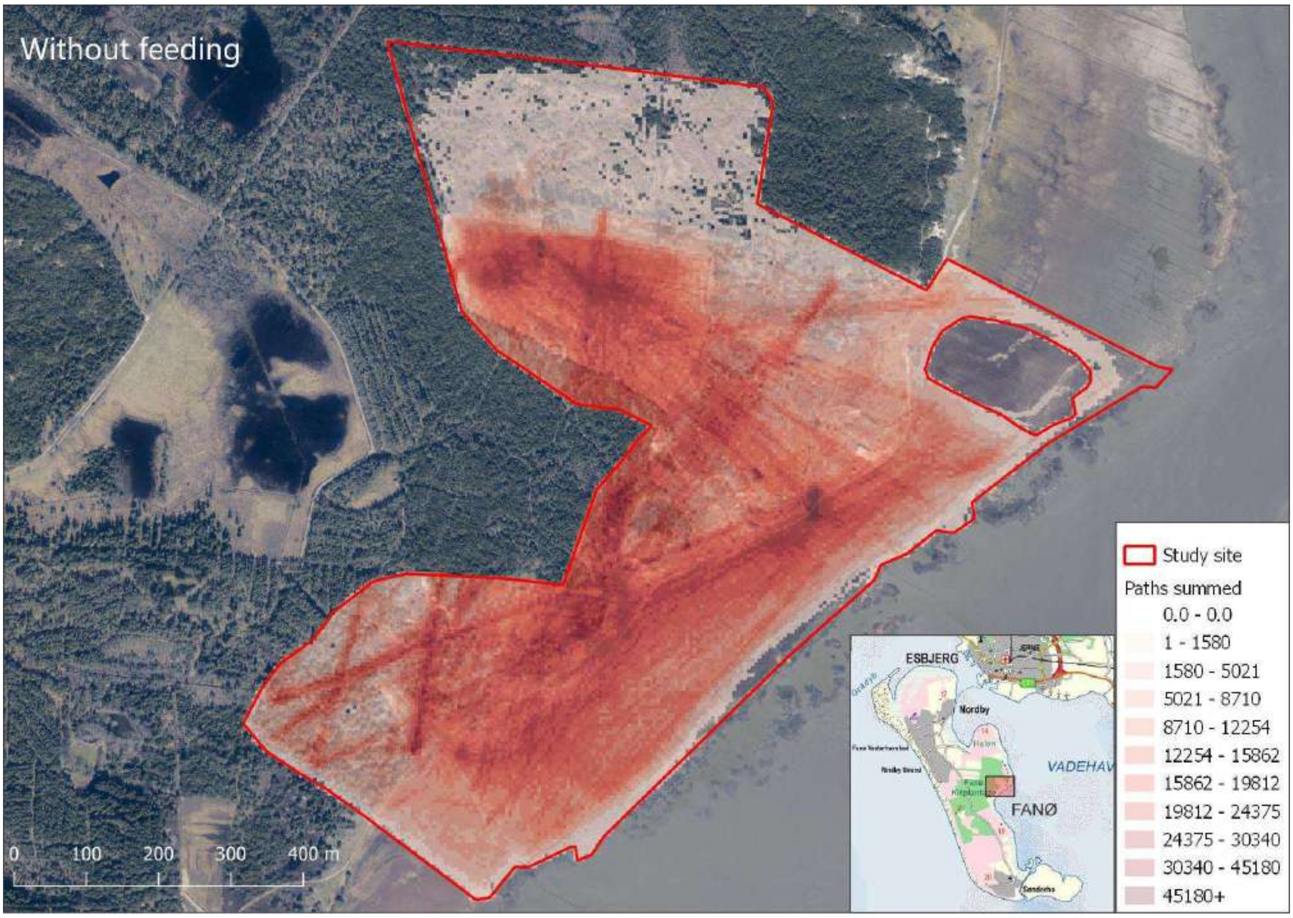

Figure 8: A map of the summed path length registered in the period with supplementary feeding. The redder the areas are, the longer is the summed path length that have been registered. The map show that there is an evenly high activity throughout the study site.

The path length in the period without feeding and the period with feeding is shown in the Figure 9, where both graphs are skewed towards the shorter path length. When looking at the mean and the median in Table 4, it is apparent that the path lengths in general are longer during the period without feeding. The standard deviation of the path lengths is also higher, meaning that there is greater variation in the path lengths. The cattle therefore seem to be more active in the period without supplementary feeding, than in the periods with supplementary feeding.

Table 4: The table shows the mean, the median and the standard deviation of the path lengths in the period with- and without supplementary feeding.

	Without feeding	***With feeding***
Mean	50	30
Median	27	20
Standard deviation	81	35

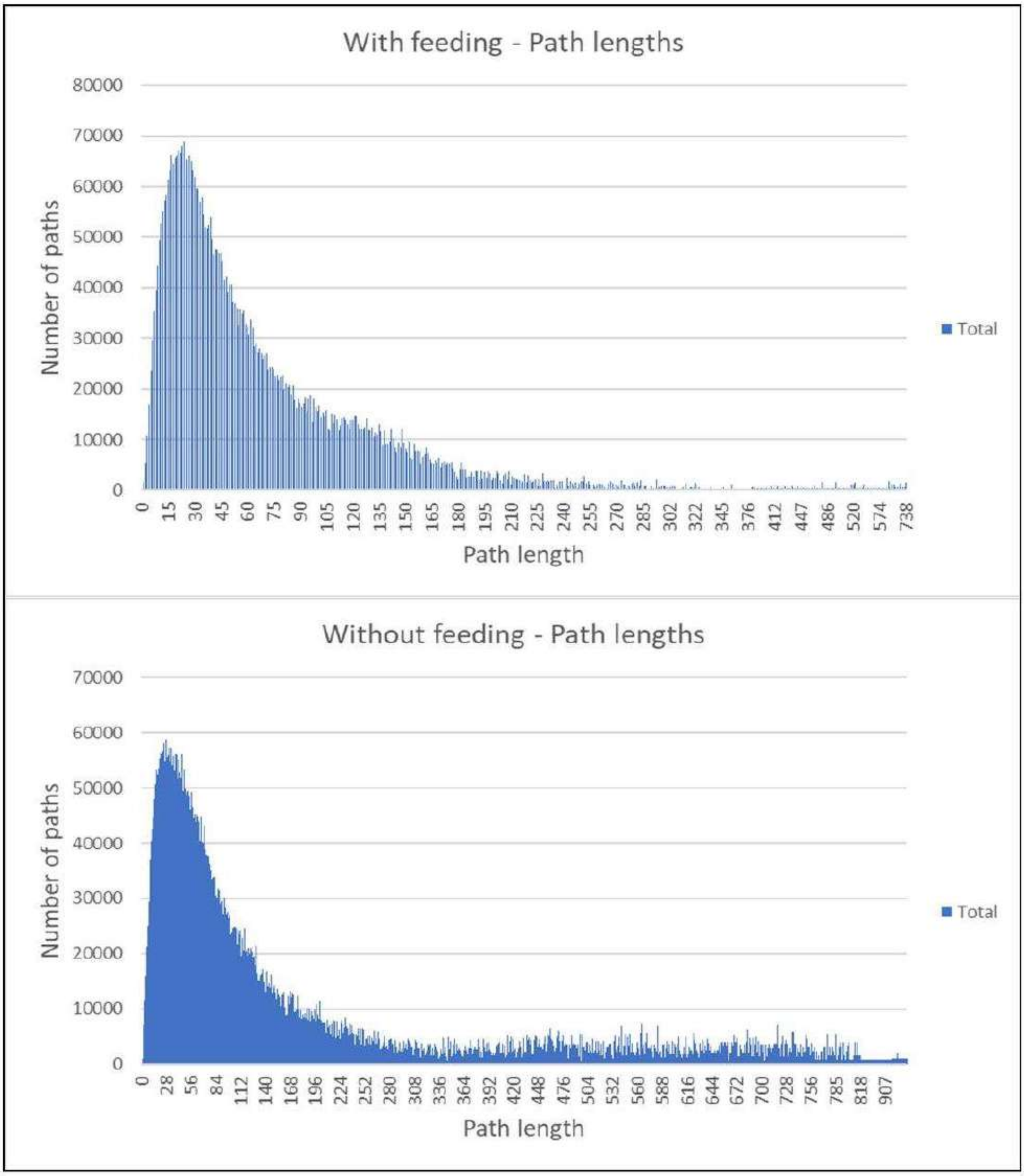

Figure 9: The figure shows two graphs of the number of paths lengths. On the x-axis is the path length in meters and on the y-axis is the number of paths. The top graph is for the periods with supplementary feeding, and the bottom graph is for the period without supplementary feeding. Note that the axis are different for the two periods. The difference in coloration is due to unknown formatting issues.

Landscape analysis in GIS

Topography – TRI

Using Terrain Ruggedness Analysis (TRI) it can be seen that variations in topography are highest throughout the heathland and the dunes with heath, as well as within the forested areas. In the area with meadow and salt marsh, there is much less variation in the topography of the terrain. This contrast is very apparent in the northern meadow where even though the meadow and the forested area north of the meadow is in the same elevation plane, the TRI is higher in the forested area than in the meadow (Figure 10). Figure 11 shows the average TRI within each habitat, and this result further supports the visual interpretation of the TRI in figure 10. The results of Figure 11 shows that the highest TRI can be found where there is bare ground, followed by dune heath, heathland and forested areas, while the salt marsh is found to be the habitat with least topographic variation.

Figure 10: The figure shows the topography of the study site by terrain ruggedness analysis (TRI) and contours. The red colouration shows the TRI, where red colors indicate an increased variation of topography. The contours are shown with a 1-meter contour line.

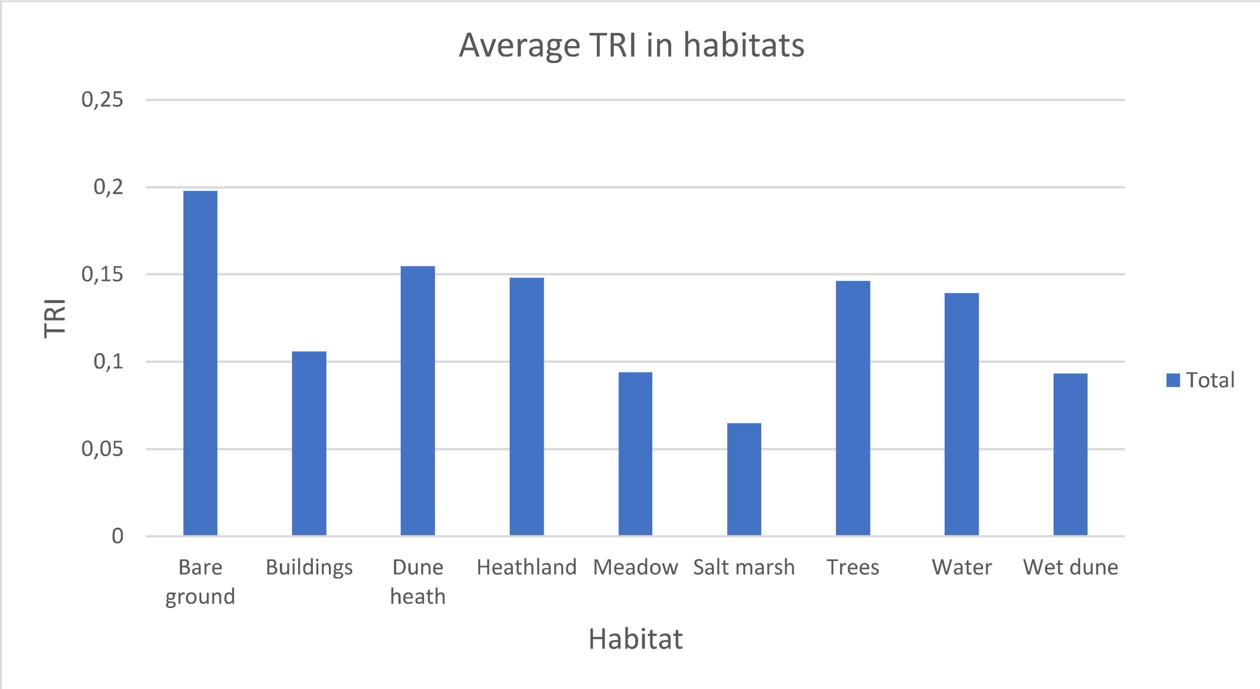

Figure 11: The figure show the average TRI within the different habitats. Salt marsh is found to have the least variation in topography while bare ground is found to have the highest variation in topography.

NDVI – With supplementary feeding

In Figure 12 the Normalized Difference Vegetation Index (NDVI) on the 8th of March 2022 in general is lower in the salt marsh than most of the other areas. The forested areas are found to have the highest NDVI, however this is most likely due to the evergreen trees that dominate the forest.

Figure 12: The figure shows the Normalized Difference Vegetation Index (NDVI) of the study site, based on Sentinal-2 data from the 8th of March 2022.

On figure 13 a box plot of the NDVI in each habitat during the period with supplementary feeding can be seen. Trees are found to have the highest NDVI, followed by dune heath and heathland. The salt marsh is found to have the lowest NDVI. The NDVI of the salt marsh and the meadow however is not as grouped as the NDVI of the trees, heathland, and the dune heath.

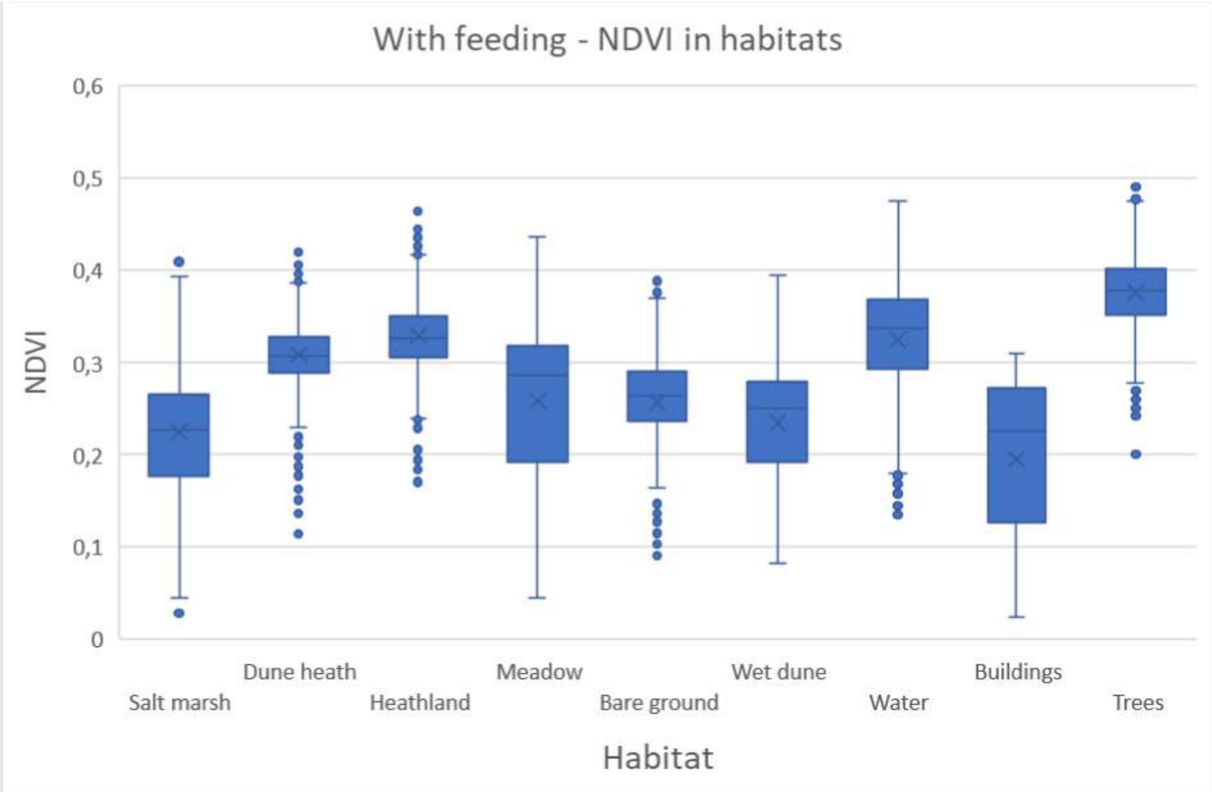

Figure 13: The figure shows a boxplot of the NDVI within the different habitats, based on Sentinal-2 data from the 8th of March 2022.

The average NDVI in each habitat is shown numerically in Table 5. Of the habitats relevant for the cattle, the salt marsh and the wet dune was found to have the lowest average NDVI of 0,22 and 0,23. The meadow was also found to have a low average NDVI of 0,26, while the dune heath and the heathland was found to have the highest average NDVI of 0,31 and 0,33, apart from trees which were found to have an average NDVI of 0,38.

Table 5: The table shows the average NDVI within each habitat, based on Sentinal-2 data from the 8th of March 2022.

Habitat	Average of NDVI
Salt marsh	0,22
Dune heath	0,31
Heathland	0,33
Meadow	0,26
Bare ground	0,26
Wet dune	0,23
Water	0,32
Buildings	0,19
Trees	0,38

NDVI – Without supplementary feeding

In Figure 14 it is found that the NDVI on the 16th of June 2022 is highest in the meadow, parts of the salt marsh and in the wet dunes. The dry habitat such as the heathland, the dune heath and the forested areas are found to have a lower NDVI than the other habitats.

Figure 14: The figure shows the Normalized Difference Vegetation Index (NDVI) of the study site, based on Sentinal-2 data from the 16th of June 2022.

On figure 15 a boxplot of the NDVI in each habitat during the period without supplementary feeding can be seen. The figure show that the NDVI is highest in the salt marsh followed by the meadow and the wet dunes. The NDVI however is very similar in all the habitats.

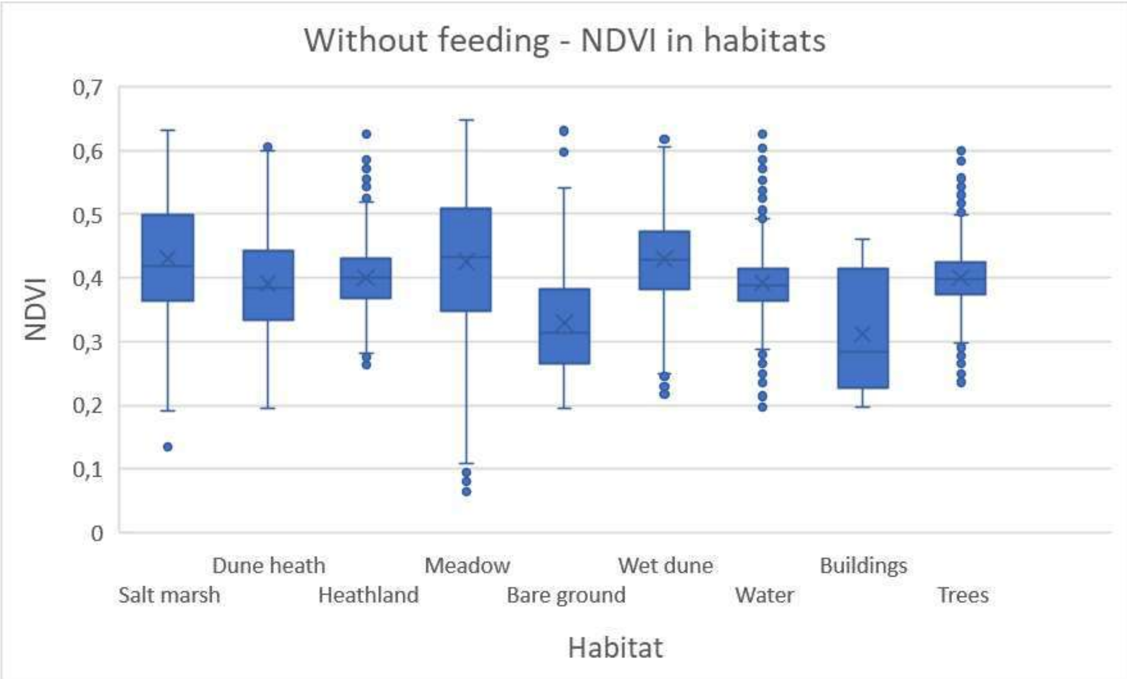

Figure 15: The figure shows a boxplot of the NDVI within each habitat, based on Sentinal-2 data from the 16th of June 2022.

The average NDVI of each habitat is shown numerically in table 6. All habitats relevant for the grazing cattle have an almost identical average NDVI, although the wet habitats such as the salt marsh, the meadow and the wet dunes have the highest average NDVI. When looking at figure 14 and figure 15, it can be seen however that there is a high variation of NDVI within each of these habitats, most significantly within the salt marsh and the meadow.

Table 6: The table shows the average NDVI within each habitat, based on Sentinal-2 data from the 8th of March 2022.

Habitat	Average of NDVI
Salt marsh	0,43
Dune heath	0,39
Heathland	0,40
Meadow	0,43
Bare ground	0,33
Wet dune	0,43
Water	0,39
Buildings	0,31
Trees	0,40

Habitats

On Figure 16 the results of the OBIA can be seen. The figure shows the habitats as they have been analysed in the 5x5 meter grid. Although the analysis corresponds reasonably well with the actual habitats especially regarding the meadow, the dune heath, and the heathland, it has some struggles with correctly classifying the salt marsh from other habitats such as the wet dune and the meadow. The analysis also struggles with shadows from the trees and bushes, which wrongly is classified as areas with water. Bare ground is found to be classified correctly, as well as buildings that has also been classified correctly. The accuracy of the classification has been evaluated by comparing the classification to the nationally protected §3 nature types and the internationally protected Nature-2000 nature types (Miljøportalen, 2023), as well as by comparing the classified habitats to the habitats found during a field study on the 16th of March 2023.

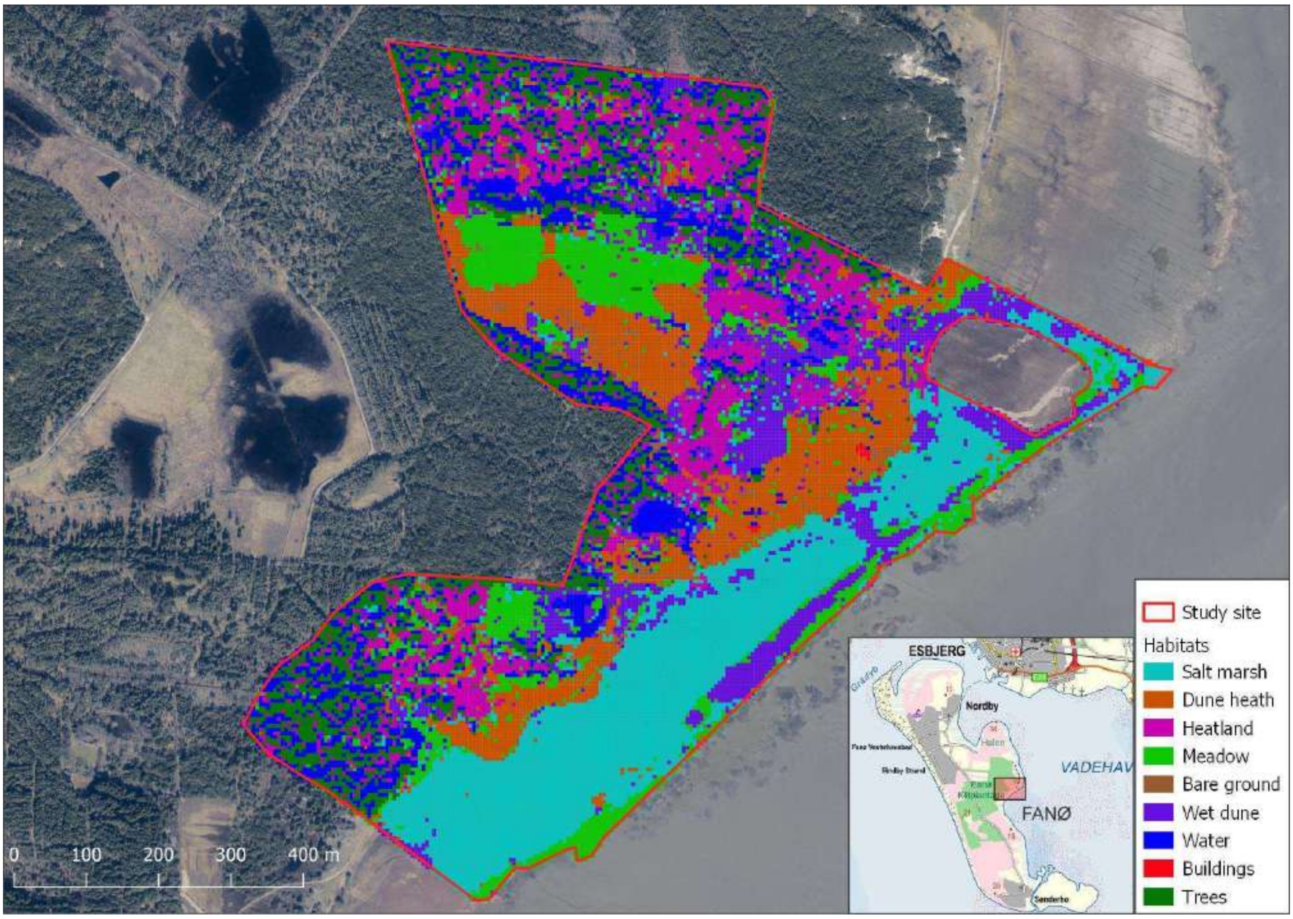

Figure 16: The figure shows the results from the OBIA analysis, as it was analyzed by the 5x5 meter grid. The different habitats are colored as shown by the legend within the figure.

Figure 17 and figure 18 shows the sum of observation points in the habitats for the period with feeding and the period without feeding respectively. In the period with feeding the cattle primarily stay in the meadow, where they received supplementary fodder, and the nearby dune heath. In the period without feeding, the cattle primarily stay in the salt marsh followed by the dune heath and the meadow.

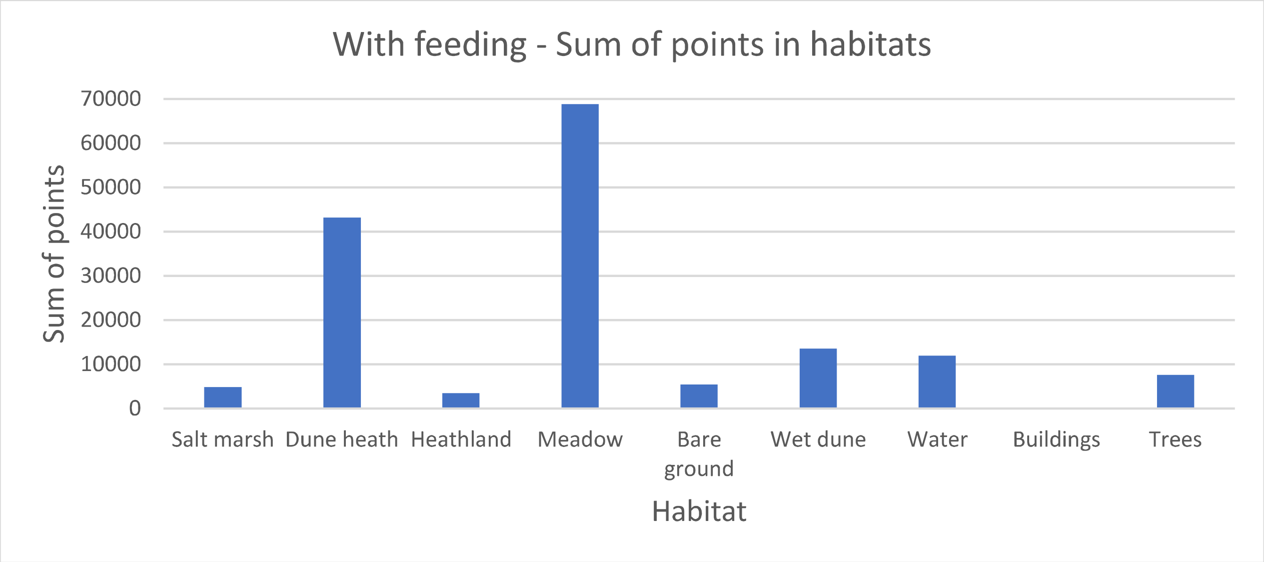

Figure 17: The figure show the sum of observation points in each habitat during the periods with supplementary feeding.

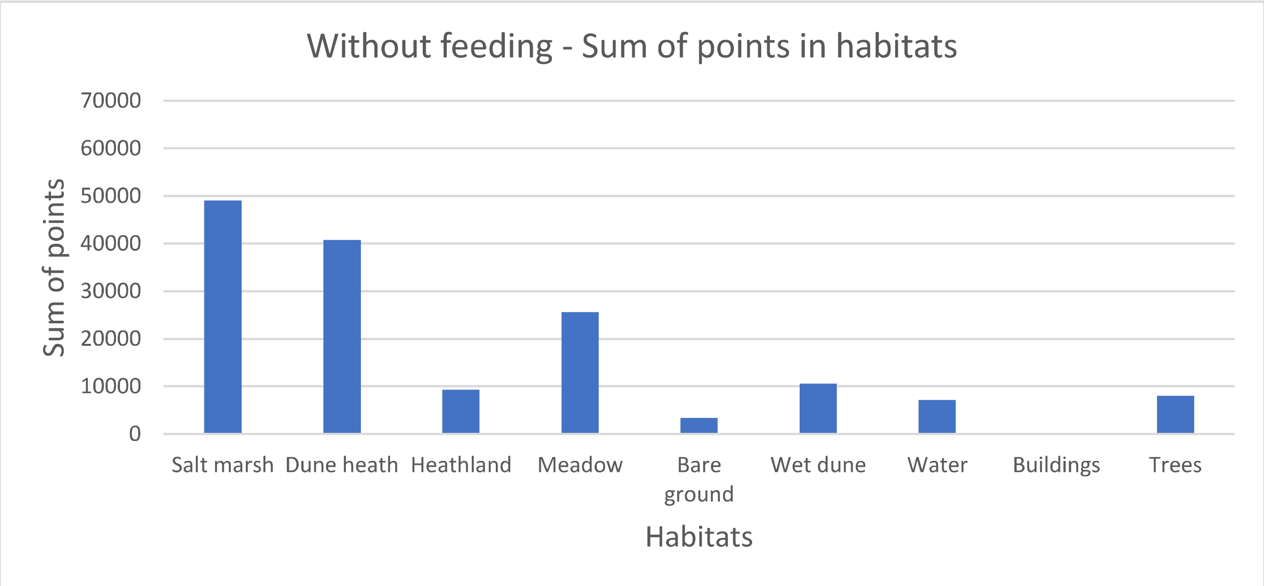

Figure 18: The figure show the number of observation points within each habitat during the period without supplementary feeding.

To further understand the grazing of the different habitats throughout the study period, a figure showing the observations for each month on the study period in habitats relevant for grazing was made (Figure 19). These results showed the gradual transition of the number of observations in each habitat, such as the meadow which is the most used habitat from January 2022 to April 2022. From May until September the most used habitat is the salt marsh, afterwards which the most used habitats become the meadow and the dune heath.

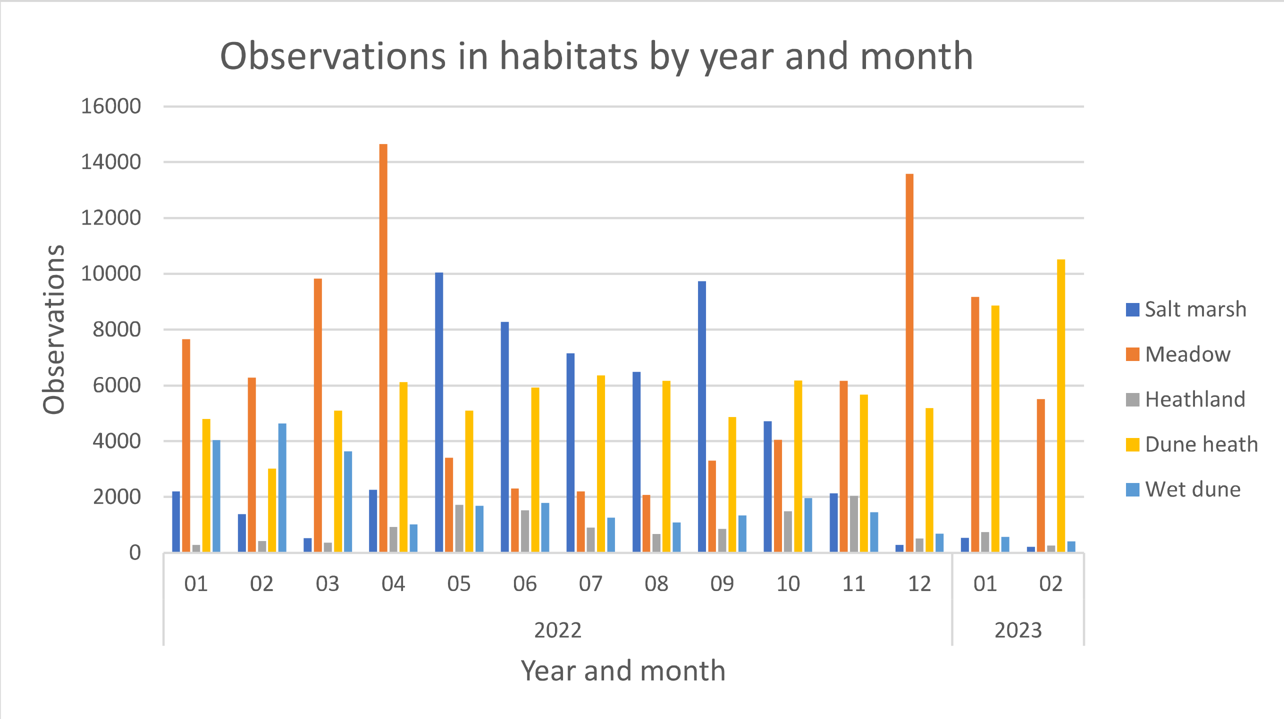

Figure 19: The figure show the number of observations in each habitat, for every month of the study period. This shows the fluctuations of which habitat the cattle is observed within during a season.

Table 7 show the area of each habitat and the relative frequency of the habitat. The table also show the number of observation points in each habitat, for the period with feeding and without feeding. The relative frequency of the observation points with feeding and without feeding is also calculated in the table. The largest habitat was found to be the salt marsh, which the cattle was observed significantly more during the period without feeding. The dune heath and the heathland were found to cover almost the same area. The dune heath however was by far the most preferred habitat of the two with 27% of the observations in both periods. The observations in the heathland on the other hand were found to be 6% and 2% for the period without feeding and with feeding respectively. Although the meadow only covered 13% of the study site, the cattle were observed in this habitat for 17% of the observations in the period without feeding and 43% of the observations in the period with feeding.

Table 7: The table shows the area of the different habitats and the percent coverage of the area. The table further shows the number of observations within the different habitats and the percentage of the points in these habitats, both for the period without feeding and for the period with feeding.

			Without feeding		***With feeding***	
Habitat	**Area (m^2)**	**Area (%)**	**Points, sum**	**Points (%)**	**Points, sum**	**Points (%)**
Salt marsh	139.800	22%	49.037	32%	4.844	3%
Dune heath	91.575	14%	40.756	27%	43.198	27%
Heathland	87.850	14%	9.245	6%	3.468	2%
Meadow	82.725	13%	25.589	17%	68.818	43%
Water	77.850	12%	7.113	5%	11.990	8%
Wet dune	77.625	12%	10.521	7%	13.566	9%
Trees	75.525	12%	8.015	5%	7.617	5%
Bare ground	8.150	1%	3.363	2%	5.426	3%
Buildings	675	<0%	28	<0%	86	<0%
Sum	641.775	100%	153.667	100%	159.013	100%

Discussion

The main objective of this thesis was to investigate the habitat and food preferences of cattle enclosed by a virtual fence. This was possible due to the opportunities that a virtual fence provides regarding the monitoring of the grazers. The thesis also explored the use of satellite imagery and orthophotos as a data source for semiautomatic classification of habitats.

A major factor which proved to affect the behaviour of the cattle, was the use of supplementary feeding. The periods with- and without supplementary feeding was therefore analysed separately. During the periods where the cattle received supplementary feeding, the cattle rarely strayed away from the feeding sites (Figure 2). During the period without supplementary feeding, the cattle was found to appear throughout the entire study site (Figure 3). There is limited studies on supplementary feeding and the effect it has on the food choice of cattle in natural areas (Krysl & Hess, 1993), although studies on the effect of supplementary feeding on European Bison (*Bison bonasus*), showed a significant reduction in the browsing of woody vegetation in herds that received supplementary feeding (Kowalczyk, et al., 2011). When all-year grazing is used in nature management, the intentions of the grazing during winter is mainly to decrease the cover of woody species while also altering the plant composition towards smaller light demanding species, resulting in a higher species richness (Denise, Gilhaus, & Hölzel, 2016). With the grazing patterns and behaviours observed in this thesis, this effect is most likely not as pronounced as it could be.

The monthly heatmaps show that the cattle are still connected to the feeding sites months after supplementary feeding has halted, which could be due to residual fodder or the familiarity and connection that the cattle have to the area. The monthly heatmaps also show that the cattle respond very quickly to the supplementary feeding, and almost instantly concentrate their whereabouts to the feeding site and the surrounding areas, when supplementary feeding is restarted. This is important to consider when starting the supplementary feeding, as very little grazing effect outside of the feeding areas is achieved from this point. The cattle are also found to quickly respond to the opening of a temporarily excluded part of the salt marsh, which is most likely due to the newly developed presence of un-grazed pastures. This area could also be particularly interesting for the cattle, due to the fresh growth of vegetation occurring after hay cutting, which is supported by this area having a higher NDVI compared to the nearby salt marsh (Figure 14). The number of observations in the salt marsh lowers quite significantly in October (Figure 19), which is also clearly visible in the heatmap for October (Figure 5). This change in behaviour could possibly be due to an increase in rain occurring during September 2022 (DMI, 2023), which could make the salt marsh increasingly more inaccessible for the cattle due to the wet surface ground. During months without supplementary feeding the cattle mainly grazed the salt marsh, however they were also observed in the other habitats most noticeably in the dune heath (Figure 19), which was mainly used for resting. The different habitats are used for grazing to a varying extent, and some habitats are preferred for resting. It seems that a variety in habitats is needed to fully satisfy the needs for the cattle. It would be interesting to observe the further change in grazing behaviour as the seasons change, if the supplementary feeding was not restarted in November, as a variety in habitats could prove even more beneficial for the success of the grazing. Information on the behaviour of the cattle within the habitats could also be supplemented by manually monitoring them.

Heathlands are comprised of mainly *Calluna vulgaris* which cattle have been found to exclude in their diet compared to grasses (Fraser, Theobald, Griffiths, Morris, & Moorby, 2008), although during autumn and winter when grasses are withered, cattle will eat *Calluna vulgaris* (Putman, Ekins, & Edwards, 1987). The *Calluna vulgaris* at the study site however was found be old and degenerated with low nutritional values causing it to be unattractive as fodder (Buttenschøn & Buttenschøn, 1982). Since the cattle is provided with supplementary fodder during autumn and winter, it is therefore to be expected that the cattle in this study site would prefer the other habitats for grazing. This is truly the case, as the observations of the cattle in the heathland during the period with no supplementary feeding was only 6%, while the area of the heathland was found to be 14% of the study site (Table 7). In comparison, the observations of the cattle in the salt marsh during the same period was 32%, while the area of the salt marsh was 22% of the study site (Table 7). This could also explain why there is almost no observations in the northern part of the study site above the large meadow, as this area is mainly comprised of heathland with scattered trees (Figure 16). There is however also a partial barrier in the form of a ditch between these two areas, which could further refrain the cattle from entering the heathland with scattered trees. This type of barrier could also be the reason that there are absolutely no observations in a part of the southern forest, which is surrounded by ditches.

Apart from the salt marsh, the cattle where mainly observed in the dune heaths during the period without supplementary grazing. 27% of the observations was observed within the dune heath, which comprise of 14% of the habitats by area. This is somewhat surprising as the dune heaths are commonly regarded as a habitat with a low primary production and therefore low feed value for the cattle. When comparing the heatmap (Figure 3) with the habitats (Figure 16), it is however clear that the observations in the dune heath are concentrated in hotspots. These hotspots were found to be resting spots, meaning that while there were many observations in the dune heaths, most of the time spend in this habitat were most likely spend resting and ruminating instead of grazing.

In an enclosure with a diversity in habitats, you allow the grazers to choose the habitat which they prefer. This study found that the grazers are very selective on which habitat they choose to graze, and it was found that they preferred the wet and nutrient rich habitats such as the salt marsh and the meadow, while also selectively grazing the more nutrient rich areas within these habitats.

The classification of habitats is a crucial part of understanding the landscape and what it can provide for biodiversity. This understanding furthermore provides the foundation for choosing the best possible management, which can support the development of increased biodiversity in the landscape. While in-field studies provide valuable information on specific species and landscape characteristics, this type of monitoring often fails to objectively classify habitats, so they are spatially precise, especially when they occur in a mosaic. For this reason, the use of GIS analysis which can classify habitats can be a valuable tool in landscape analysis (Pettorelli, et al., 2014: Turner, et al., 2003). Depending on the method for this type of analysis, the data further provides temporal flexibility, as orthophotos and especially satellite imagery is made more frequently. This thesis explored both the use of SCP and OBIA for classifying habitats.

SCP is a semiautomatic classification program which make use of the readily available Sentinal-2 data. This Data has valuable information in many different wavelengths, which each can provide distinct information about the types of land cover when classifying them (Phiri, et al., 2020). However, it was found that the 10x10 meter resolution of the data was too large for the scale of the analysis required in this study. As the minimum resolution of the data was 10 meters, it was found that the different habitats when they occurred in a mosaic would blend, thus losing valuable information on habitats on a smaller scale. If the resolution of data like Sentinal-2 could be available in a higher resolution in the future, it could provide valuable information on habitats and their development on a smaller scale.

Due to the use of SCP proving to be unsatisfactory for the aim of this thesis, other methods for classifying habitats was explored. A recently developed method that is much better at classifying high resolution images is to do object-based image analysis (Hossain & Chen, 2019), which in general proved to correctly classify the habitats within the study site, however not without its faults. The segmentation analysis had trouble with under/over segmentation in certain areas. This problem could possibly be mitigated with more advanced segmentation software that can also segment using digital elevation models or LiDAR intensity. With these additional inputs for the segmentation, the afterwards classification could possibly also have been improved considerably. The classification model that was used in this thesis could not correctly distinguish between shadows and water, but with additional inputs which could be used for the statistics in the model, the results could have been better. Shadows could potentially be distinguished from water by implementing a digital elevation model in the analysis, which would make it possible to tell if the segment was flat. While the results of the classified habitats was verified subjectively by comparing the habitats to existing mapping of habitats (Miljøportalen, 2023), a proper validation using verified and precise test data would have been preferred. This could have been possible with in field classification of habitats using a precise handheld GPS.

While the Sentinal-2 data was not used to classify habitats using SCP, the data was instead used to calculate the NDVI which gave some interesting results. The NDVI was found to be much lower in all the habitats during the periods with supplementary feeding with an average between 0,19 and 0,38, compared to the periods without supplementary feeding which had an average between 0,31 and 0,43. This is to be expected due to the dormancy which plants enter during winter, resulting in withered plant parts on the surface. The NDVI of the salt marsh during winter could possibly be recorded as a value lower than the actual value, due to the high amounts of water during the winter which absorbs the near-infrared and reflects the red light resulting in a lower NDVI. This could also be the case for the wet dunes, which in this area often are entirely flooded during winter. Although the average NDVI in the period without feeding is very similar (Table 6), the habitats with the highest NDVI appears to be the salt marsh, wet dunes and the meadow which are all wet habitats. When looking at Figure 14, this is also clearly visible with the habitats standing out with a greener colour. This result could be explained by the law of minimum (Ebelhar, Chesworth, & Paris, 2008), where water in this case could be the limiting factor for plant growth.

It can also be seen that the NDVI of the salt marsh differs significantly in the middle of the salt marsh compared to the outer parts of the salt marsh which seems to have a higher NDVI than the middle. When comparing the NDVI in the salt marsh (Figure 14) and the heatmap for the period without feeding (Figure 3), it is noticeable that the cattle spend more time grazing in the areas that have a higher NDVI. While it is expected that the cattle actively graze areas that have higher food value, it is surprising that there is a noticeably difference in the grazing pattern even within a habitat that in general has high food values. The correspondence of the higher grazing pressure within the salt marsh and the higher NDVI values, is a result which advocates for the use of NDVI as a tool for evaluating the food resources in natural areas when using herbivores as a nature management tool.

While the NDVI was chosen due to its capability for explaining the food value of the different habitats, its potential still suffers from the low resolution causing the values at the habitat borders to be blended. If the Danish national ortophotos from SDFI were available as data with the wavelength of the bands instead of a light value, this data could be used for calculating NDVI in a much higher resolution than when calculating the NDVI from the sentinel-2 data. The strength of the Sentinel-2 data, however, is that this data is available considerably more frequent, meaning that an estimate for the food value can be estimated throughout the entire grazing season.

It was found that the cattle travelled much shorter distances during periods with supplementary feeding compared to the period without supplementary feeding. This change in behaviour could be a result of the feeding which supply the cattle with enough fodder to sustain themselves during the winter within short distances. During the periods with supplementary feeding, the cattle is primarily registered at the supplementary feeding sites (Figure 2), which supports the theory that supplementary feeding is causing them to travel shorter distances. Another factor causing this change in behaviour is most likely also due to the cattle responding to the lower temperatures by lowering their activity, which is a known phenomenon (Malecheck & Smith, 1976). A study by Malechek & M. Smith also found that the distances cattle travel daily is highly related to the average daily wind velocities, causing them to move around much less. Wind is possibly a significant factor in the behaviour of the cattle on Fanø, as the wind velocities on Fanø during the winter months are known to be higher than the rest of the year (DMI, 2023). As the paths are calculated by the distance between two subsequent observations in a 15 min interval, the path maps and the path distances are only an estimate of the actual path that the cattle have taken. In reality the path distances will be longer than calculated, as the cattle would not be walking in straight lines. Some of the shorter paths might also be instances where the cattle will have travelled back and forth. The paths however can still be used as a representative estimate of the paths and distances that the cattle have travelled.

While the cattle were found to prefer certain habitats, some landscape elements, and the interrelationship of certain points of interest were also found to affect the whereabouts of the cattle considerably. Most noticeable was the resting spots scattered around in the area, which the cattle continuously returned to even from longer distances (Figure 8) and resting for long periods (Figure 3). Whether the resting spots were chosen for their characteristics such as dryness and wind exposure, or the closeness to the preferred grazing habitats is unknown, but the habitats in the vicinity of the resting spots were nonetheless grazed more compared to similar habitats further away (Figure 3). The resting spots might also have been chosen due to them being near drinking spots, which is found to affect the distribution of cattle significantly (Ganskopp, 2001). The increased distribution of cattle around the drinking spots, could possibly have negative effects on breeding birds in the adjacent salt marsh, as trampling of nests has been found to increase around drinking spots (Mandema, Tinbergen, Ens, & Bakker, 2013). It is also very apparent that landscape elements such as the road, which allow for easier movement, affects the behaviour of the cattle. This is particularly noticeable on the path maps showing that there is an increased activity on and around the road. This could lead to the habitats adjacent to the road being grazed more than habitats further away from the road. The effect of certain landscape elements potentially causing an increase in the activity and grazing of the cattle, should be considered in the management of habitats and plants that are vulnerable to overgrazing and erosion. By actively choosing the position of freshwater drinking spots, this could also be used to control the grazing, by for example placing drinking spots near areas where more intensive grazing is wanted.

Conclusion

The habitat preferences of the cattle on Fanø were found to be very dependent on whether the cattle received supplementary feeding or not. In the period with supplementary feeding, the cattle lowered their activity and mainly stayed in the vicinity of the feeding sites which were situated in a meadow. The cattle were found to quickly respond to supplementary feeding, by focusing their whereabouts to the feeding sites. In the period without supplementary feeding, the cattle were more dependent on the food resources in the different habitats, and they were mainly found grazing in the wet habitats, with the salt marsh being the most prominent feeding site followed by the wet dune. It was found that the cattle selectively were grazing the more nutritious vegetation within the salt marsh. This search for food resources within the habitats also led to an increase in the activity of the cattle. Certain points of interest were further found to influence the behaviour of the cattle, which seemed to graze more around resting spots and drinking spots. Furthermore, ditches acting as a barrier were found to withhold the cattle from grazing in certain parts of the study site.

The use of GPS collars to virtually fence nature areas appear to be a promising tool for nature conservation, not only for its practicality of use, but also for the added benefit of monitoring the grazing. By combining this information with landscape analysis from remote sensing, the effects of grazing on the landscape can be objectively and quantitatively measured and evaluated at a high resolution of scale. While the mapping of habitats in this thesis showed promising results, additional studies should be made to improve and verify the results further.

References

Barnosky, A. D., Matzke, N., Tomiya, S., Wogan, G. O., Swartz, B., & Quental, T. B. (2011). *Has the Earth's sixth mass extinction already arrived?* Nature.

Bekendtgørelse af lov om naturbeskyttelse, LBK nr 1986 (10 27, 2021).

Buttenschøn, R. M. (2014). *Vejledende græsningstryk for udvalgte naturtyper.* IGN, Københavns Universitet.

Buttenschøn, R. M., & Buttenschøn, J. (1982). Grazing experiments with cattle and sheep on nutrient poor, acidic grassland and heath; I: Vegetation Development. II: Grazing Impact. III: Animal Nutrition. *Natura Jutlandica*, 1-48.

Buttenshcøn, R. M., Fløjgaard, C., Byriel, F. B., Clausen, K. K., Gotlieb, L., Kanstrup, N., . . . Ejrnæs, R. (2021). *Effekt af rewilding på planterigdom.* Aarhus Universitet, DCE – Nationalt Center for Miljø og Energi.

CBD. (1992). *Convention on Biological Diversity.* Retrieved from https://www.cbd.int/convention/text/

Congedo, L. (2018). *Semi-Automatic Classification Plugin*. Retrieved from https://buildmedia.readthedocs.org/media/pdf/semiautomaticclassificationmanual-v5/latest/semiautomaticclassificationmanual-v5.pdf

Council Directive 92/43/EEC. (1992, 05 21). Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A31992L0043

Denise, R., Gilhaus, K., & Hölzel, N. (2016). Effects of year-round grazing on the vegetation of nutrient-poor grass- and heathlands—Evidence from a large-scale survey. *Agriculture, Ecosystems and Environment*, 16-22.

DMI. (2023, 05 14). *Fanø*. Retrieved from Dansk Meterologisk Institut: https://www.dmi.dk/lokationarkiv/show/DK/2622340/Fan%C3%B8/#arkiv

Ebelhar, S., Chesworth, W., & Paris, Q. (2008). Enccyclopedia of Soil Science.

Fraser, M. D., Theobald, V. J., Griffiths, J. B., Morris, S. M., & Moorby, J. (2008). Comparative diet selection by cattle and sheep grazing two contrasting heathland communities. *Agriculture, Ecosystemsn & Environment*, 182-192.

Ganskopp, D. (2001). Manipulating cattle distribution with salt and water in large arid-land pastures: a GPS/GIS assessment. *Applied Animal Behaviour Science*, 251-262.

GDAL. (2023, 05 14). *GDAL*. Retrieved from https://gdal.org/

GISGeography. (2023, 05 14). *Sentinel 2 Bands and Combinations*. Retrieved from https://gisgeography.com/sentinel-2-bands-combinations/

Gravesen, P. (2023, 05 14). *Trap Danmark*. Retrieved from Fanø Kommunes Geologi: https://trap.lex.dk/Fanø_Kommunes_geologi

Habitatbekendtgørelsen, BEK nr 2091 (11 12, 2021).

Hossain, M. D., & Chen, D. (2019). Segmentation for Object-Based Image Analysis (OBIA): A review of algorithms and challanges from remote sensing perspective. *ISPRS Journal of Photogrammetry and Remote Sensing*, 115-134.

J., R. S., D., D. S., & Robert, E. (1999). A Terrain Ruggedness Index That Quantifies Topographic Heterogenity. *Intermountain Journal of Sciences*, 23-27.

Kowalczyk, L. J., Taberlet, P., Coissac, E., Valentini, A., Miquel, C., Kaminski, T., & Wójcik, J. M. (2011). Influence of manegement practices on large herbivore diet - Case of European Bison in Białowieża Primeval Forest (Poland). *Forest and Ecology Manegement*, 821-828.

Krysl, L. J., & Hess, B. W. (1993). Influence of supplementation on behavior of grazing cattle. *Journal of Animal Science*, 2546-2555.

Malecheck, J. C., & Smith, B. M. (1976). Behavior of range cows in response to winter weather. *Journal of Range Manegement*, 9-12.

Mandema, F. S., Tinbergen, J. M., Ens, B. J., & Bakker, J. P. (2013). Livestock grazing and trampling of birds' nests: an experiment using artificial nests. *Journal of Coastal Conservation*, 409-416.

McKILLOP, I., & Sibly, R. (2008). Animal behaviour at electric fences and implications for management. *Mammal Review*, 91-103.

Miljøministeriet. (2020, 12 04). *Ny natur- og biodiversitetspakke klar: Historisk løft til dansk natur*. Retrieved from https://mim.dk/nyheder/2020/dec/ny-natur-og-biodiversitetspakke-klar-historisk-loeft-til-dansk-natur

Miljøportalen. (2023, 05 14). Retrieved from Danmarks Arealinformation: https://arealinformation.miljoeportal.dk/html5/index.html?viewer=distribution

Møller, P. F., Heilmann-Clausen, J., Johannsen, V. K., Buttenschøn, R. M., Schmidt, I. K., Rahbek, C., . . . Ejrnæs, R. (2018). *Anbefalinger vedrørende omstilling og forvaltning af skov til biodiversitetsmål.* Naturstyrelsen. GEUS. Danmarks og Grønlands Geologiske Undersøgelse Rapport Bind 2018 nr. 28.

No Fence. (2023, 05 14). *No Fence*. Retrieved from https://www.nofence.no/en/

Orfeo. (2023, 05 14). *Orfeo ToolBox*. Retrieved from https://www.orfeo-toolbox.org/

Pettorelli, N., Laurance, W. F., O'Biran, T. G., Wegmann, M., Nagendra, H., & Turner, W. (2014). Satellite remote sensing for applied ecologists: opportunities and challenges. *Journal of applied Ecology*, 839-848.

Phiri, D., Simwanda, M., Salekin, S., Nyirenda, V. R., Murayama, Y., & Ranagalage, M. (2020). Sentinel-2 Data for Land Cover/Use Mapping: A Review. *Remote Sens*.

Putman, R. J., Ekins, J., & Edwards, P. J. (1987). Food and feeding behaviour of cattle and ponies in the New Forest, Hampshire. *Journal of Applied Ecology*, 369-380.

QGIS. (2023, 05 14). *QGIS*. Retrieved from https://qgis.org/en/site/

Rosenthal, G., Schautzer, J., & Eichberg, C. (2012). Low-intensity grazing with domestic herbivores: A tool for maintaining and restoring plant diversity in temperate Europe. *Tuexenia*, 167-205.

Roy, H.-Y., & Marion, P. (2009). The links between biodiversity, ecosystem services and human well-being. *BES Ecological Reviews Series*.

Rupprecht, D., Gilhaus, K., & Hölzel, N. (2016). Effects of year-round grazing on the vegetation of nutrient-poor grass- and heathlands—Evidence from a large-scale survey. *Agriculure, Ecosystems & Environment*, 16-22.

SDFI, 1. (2023, 05 14). *Dataforsyningen*. Retrieved from Styrelsen for Dataforsyning og Infrastruktur: https://dataforsyningen.dk/

SDFI, 2. (2023, 05 15). *Dataforsyningen*. Retrieved from Danmarks Højdemodel - Punktsky: https://dataforsyningen.dk/data/3931

SDFI, 3. (2023, 05 14). *Dataforsyningen*. Retrieved from Danmarks Højdemodel - Oprindelse: https://dataforsyningen.dk/data/3571

SDFI, 4. (2023, 05 14). *Dataforsyningen*. Retrieved from Danmarks Højdemodel - Overflade: https://dataforsyningen.dk/data/928

SDFI, 5. (2023, 05 14). *Dataforsyningen*. Retrieved from Forårsbilleder Ortofoto - Geodanmark: https://dataforsyningen.dk/data/981

Singh, J. S. (2002). The Biodiversity Crisis: A Multifaceted Review. *Current Science, vol 82, no 6*, 638-647.

The European Space Agency. (2023, 05 19). *Sentinel Online*. Retrieved from https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/overview

Tinbergen, J. M., Ens, B. J., Koffijberg, K., Dijkema, K. S., & Bakker, J. P. (2015). Moderate livestock grazing of salt, and brackish marshes benefits breeding birds along the mainland coast of the Wadden Sea. *The Wilson Journal of Ornithology*, 467-476.

Turner, W., Spector, S., Gardiner, N., Matthew, F., Eleanor, S., & Steininger, M. (2003). Remote sensing for biodiversity science and conservation. *Trends in Ecology & Evolution*, 306-314.

Xue, J., & Su, B. (2017). Significant Remote Sensing Vegetation Indices: A Review of Developments and Applications. *Journal of Sensors*, 17 pages.