UNIVERSITY OF GOTHENBURG

DEPARTMENT OF EARTH SCIENCES

ASSESSING METHODS FOR DISTINGUISHING BIODIVERSITY PATTERNS IN ALPINE GRASSLANDS USING SENTINEL – 2 DATA

Alexandra Petrini

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Abstract

With climate change, many aspects of the natural state and environment of our planet is changing and will continue to change. Among these, the diversity of living organisms, or biodiversity, is affected. Biodiversity is a key factor for Earth and the living organisms' survival; thus, it needs to be monitored to make sure that key species or not too many species are lost. In order to keep track of the changes in diversity a suitable and reliable method is needed to evaluate this. In this report, two data analysis methods using Sentinel-2 multispectral satellite images are examined, namely the spectral variation hypothesis (SVH) and seasonal maximum NDVI. The study has the aim of examining these methods' ability to distinguish between two types of habitats, specifically calcareous and siliceous grasslands, with different ranges of species diversity at Mt. Nuolja near Abisko, Sweden. Both methods proved to be useful when comparing the species diversity between the habitats. The calcareous grassland habitat exhibited higher values in both SVH and maximum NDVI analyses, consistent with known biodiversity patterns in these areas. The SVH showed a potential to provide more detailed information about biodiversity patterns compared to the seasonal maximum NDVI. Statistical analyses confirmed a significant difference between the two grassland habitats from the SVH analysis, demonstrating the methods' applicability. Although the results from both methods varied, they complemented each other. Additionally, this study demonstrates that the choice of principal components matters for determining spectral diversity as incorporating more adds noise to the data causing reduced information quality. Overall, SVH proved to be a useful method for assessing biodiversity patterns in subarctic grasslands, potentially aiding in biodiversity conservation efforts by providing a method for the assessment of species diversity.

Keywords: Spectral Variation Hypothesis, Maximum NDVI, Biodiversity, Sentinel-2, Multispectral Data, Species Diversity, Subalpine Calcareous Grassland, Subalpine Siliceous Grassland

Table of Contents

Table of figures

1 Introduction

The conservation of biodiversity stands as a cornerstone of human activities (IPBES, 2019; Ferreira et al., 2022), where biodiversity functions as the foundation of Earths ecosystems in which we humans depend on (Cardinale et al., 2012; Ferreira et al., 2022). In a period of time marked by unprecedented climactic and environmental challenges (IPBES, 2019), the need to monitor and assess biodiversity has never been more urgent (e.g. Wilson, 1988; Fassnacht et al., 2022; Ferreira et al., 2022). Such efforts not only deepen our understanding of ecosystem dynamics but also play a crucial role in achieving the sustainable development goals (SDGs) outlined by the United Nations (UN) (IPBES, 2019; Ferreira et al., 2022; UN, 2023). In order to keep track of all ongoing changes to the composition, extent and health of the vegetation, and to conserve its diversity, there needs to be a suitable and consistent method to assess and monitor biodiversity, including the diversity of vegetation. The most accurate method to assess biodiversity is currently field surveys, however, they are costly and time-consuming (Rocchini et al., 2010), especially if a larger area should be covered such as regional or even global scales. With today’s advances in technology, remote sensing through satellite platforms offers invaluable tools for such assessments (Rocchini et al., 2004) providing us with consistent evaluation methods (Ferreira et al., 2022). This, in turn, is allowing us to monitor and assess biodiversity over large spatial extent with high temporal and spatial resolution (Rocchini et al., 2004).

Among the various remote sensing indices used for assessing vegetation, the Normalized Difference Vegetation Index (NDVI) has been extensively used due to its sensitivity to changes to vegetation cover and productivity (Huang et al., 2020). An additional method for assessing biodiversity is the Spectral Variation Hypothesis (SVH) which estimates the species diversity through the spectral differences within images (Palmer et al, 2000; 2002). In this study the two methods are applied on Sentinel-2 multispectral images and later compared in order to determine which method is more efficient in assessing biodiversity patterns.

1.1 Biodiversity & Natura 2000

Biodiversity, which represents the variety of life on Earth, serves as a key indicator of the health of an ecosystem (Cardinale et al., 2012). The term has a broader focus encompassing all biological variation within an ecosystem while species richness refers to the number of species in a certain ecosystem and species diversity is a function of species richness and species evenness indicating their relative abundance (National Research Council US, 1999). Meaning that species diversity takes both the number of species as well as how many individuals are in each species and their distribution into account. Both species diversity and species richness are known for serving as a proxy for biodiversity (Colwell & Coddington, 1994; Gould, 2000).

In recent decades there has been a loss of biodiversity across all types of ecosystems as a result of anthropogenically-induced climate change (IPBES, 2019; IPCC, 2023). This loss extends to vegetation diversity in terrestrial ecosystems (Ellis et al., 2012). Vegetation diversity, referring to the species diversity within the plant-community, holds significance for various aspects including ecosystem resilience and stability, thus, affecting the human society as it has economic (from e.g. food, and regenerative sources, such as trees) and cultural values (Cardinale et al., 2012; IPBES, 2019).

Due to feedbacks within the Earth system, warming in polar latitudes (including subarctic regions) occurs at least four times quicker than the global average (IPCC, 2021). Consequently, the subarctic ecosystems are exposed to a multitude of stress factors (Morison et al., 2023) which are affecting vegetation health and diversity. With increasing temperatures, the treeline is anticipated to shift poleward or along the altitude gradient (Devi et al., 2008; Kharuk et al., 2009; Cudlín et al., 2017). This in turn means that mountain regions are important for observing how vegetation is responding to ongoing climate changes due to their steep climatic gradient, which compresses climatic zones and provides opportunities to test a variety of vegetation responses over a smaller area (Cudlín et al., 2017). Moreover, it has been observed that climate plays a significant role in species distribution, and accordingly, the composition of species in subarctic regions are expected to adjust (Pauli et al., 1996; Greenwood & Jump, 2014). A resulting upward migration of vegetation species is anticipated as they move toward more climactically favorable areas (Pauli et al., 1996).

As an effort to halt the ongoing decline and keep track of changes in biodiversity within Europe, the European Union (EU) collectively decided upon nature directives called Natura 2000 (Kruk et al., 2010). Based on this directive certain sites across Europe are classified as a “Natura 2000 site” to ensure the protection of endangered species and habitats (Kruk et al., 2010). Currently, there are over 27 000 sites across 27 countries within the EU (EEA, 2022) and nearly 4000 Natura 2000 sites in Sweden, one of which located near Abisko (Naturvårdsverket, 2023). The ultimate goal of the sites is to establish long-term sustainability of habitats and ecosystems as well as conserve biodiversity (Van Der Sluis et al., 2016). Because of this, the sites are specially created to prevent activities that could damage habitats or disturb species and if necessary, restore and improve their conservation status (Kruk et al., 2010).

1.2 Spectral Variation Hypothesis

The SVH approach is a recent method gaining attention among environmental researchers (e.g. Rocchini et al 2004; Madonsela et al., 2021; Wallis et al., 2024), implying that the variation of spectral patterns in a remotely sensed image over a specific area is positively correlated to the species diversity within the same area, as originally proposed by Palmer et al. (2000, 2002). This suggests that a higher spectral heterogeneity (spectral variation) signifies a higher number of habitats, consequently suggesting higher species richness and species diversity in the area (Palmer et al., 2000; 2002). Since the SVH is a relatively new suggested method for assessing species diversity there is ongoing exploration of its usage and function (e.g. Fassnacht et al., 2022) with considerations for phenological variabilities such as seasonal leaf direction and maturity which could affect spectral patterns (Campbell et al., 2022; Fassnacht et al., 2022). Furthermore, the timing of maximum spectral reflectance variation varies across plant species and locations (Fassnacht et al., 2022). Additionally, variability in reflectance can stem from differences in individual plant reflectance, especially in datasets with high spatial resolution (Carlson et al., 2007). While the SVH doesn't identify specific species, it offers insights into biodiversity patterns crucial for sustainable environmental management (Boakye, 2023).

Studies evaluating SVH using different parameters and variables have shown varying relationships between spectral heterogeneity and species diversity (Schmidtlein & Fassnacht, 2017). While some studies reported correlations of less than 20% other studies resulted in correlations ranging from 30% to 85% (see review in Schmidtlein & Fassnacht, 2017). Despite the differences in correlation between spectral variation and species diversity, there is increasingly agreed that spectral variation in remotely sensed images can offer valuable insights to vegetation diversity (Madonsela et al., 2021).

1.3 Normalized Difference Vegetation Index

NDVI is a method proposed by Kriegler et al. (1969) that produces a simplified image to assess vegetation by using remotely sensed data. It has, over the years, become a popular and widely used method for assessing vegetation due to its accessibility and simplicity (Huang et al., 2020). NDVI has a wide usage range where it gives a quantitative measure of vegetation greenness making it useful for monitoring vegetation dynamics (Pettorelli et al., 2005), such as growth (Reed et al., 1994), and phenological changes over time (Reed et al., 1994). The method is mostly utilized when evaluating vegetation health (Huang et al., 2020) and could additionally be used to indirectly assess biodiversity as it is positively correlated to species richness (Gould, 2000; Bawa et al., 2002). A higher NDVI is thus positively correlated to a higher biodiversity within the examined area.

1.4 Aim & Research Questions

The main objective of this study is to assess and compare two methods for evaluating vegetation biodiversity through its proxy, species diversity. This is done using remotely sensed multispectral data acquired from the Sentinel-2 satellite. Specifically, it aims to evaluate the application of the spectral variation hypothesis (SVH) against the commonly used normalized difference vegetation index (NDVI) approach, using the seasonal maximum NDVI. The evaluation will examine their ability to distinguish between different habitat types based on the habitats known biodiversity.

Ultimately, this study aims to contribute insights into vegetation diversity assessment in order to help inform land management strategies, conservation efforts, and ecological research practices based on these methods. This study focuses on the diversity at Mt. Nuolja located near Abisko in northern Sweden, using habitat classification from the Natura 2000 dataset and a literature study to gain knowledge about the different habitats.

Towards this aim, the following research questions will be addressed:

1) Is spectral diversity, as calculated using SVH and Sentinel-2 satellite data, well-correlated with alpine grassland biodiversity?
2) How does the choice of Principal Components in the SVH analysis affect the results?
3) Do results from SVH provide a better proxy for alpine grassland biodiversity as compared to using the seasonal NDVI_{max}?

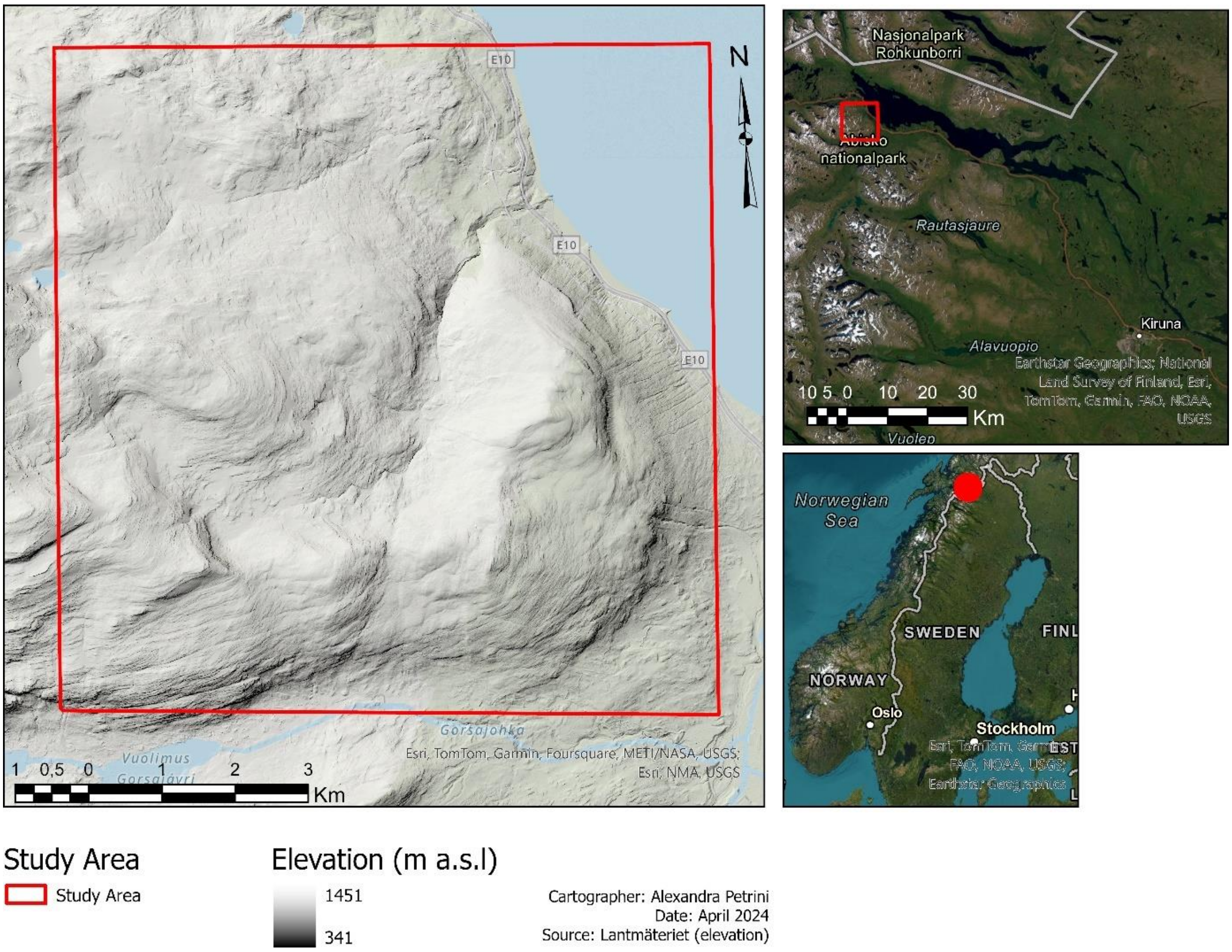
2 Materials & Methods

The analysis consists of four main parts. The first part includes data collection and preprocessing of the data, essential steps to facilitate the subsequent analysis. Parts two and three describe the methodology used to do the SVH and NDVImax analyses, respectively, primarily carried out in a GIS-software. Whereas the last section of each analysis is dedicated to a statistical analysis. The last part is dedicated to the comparison of the different approaches in biodiversity monitoring and assessment with the purpose of seeing if there is a relationship between the methods.

2.1 Study Area

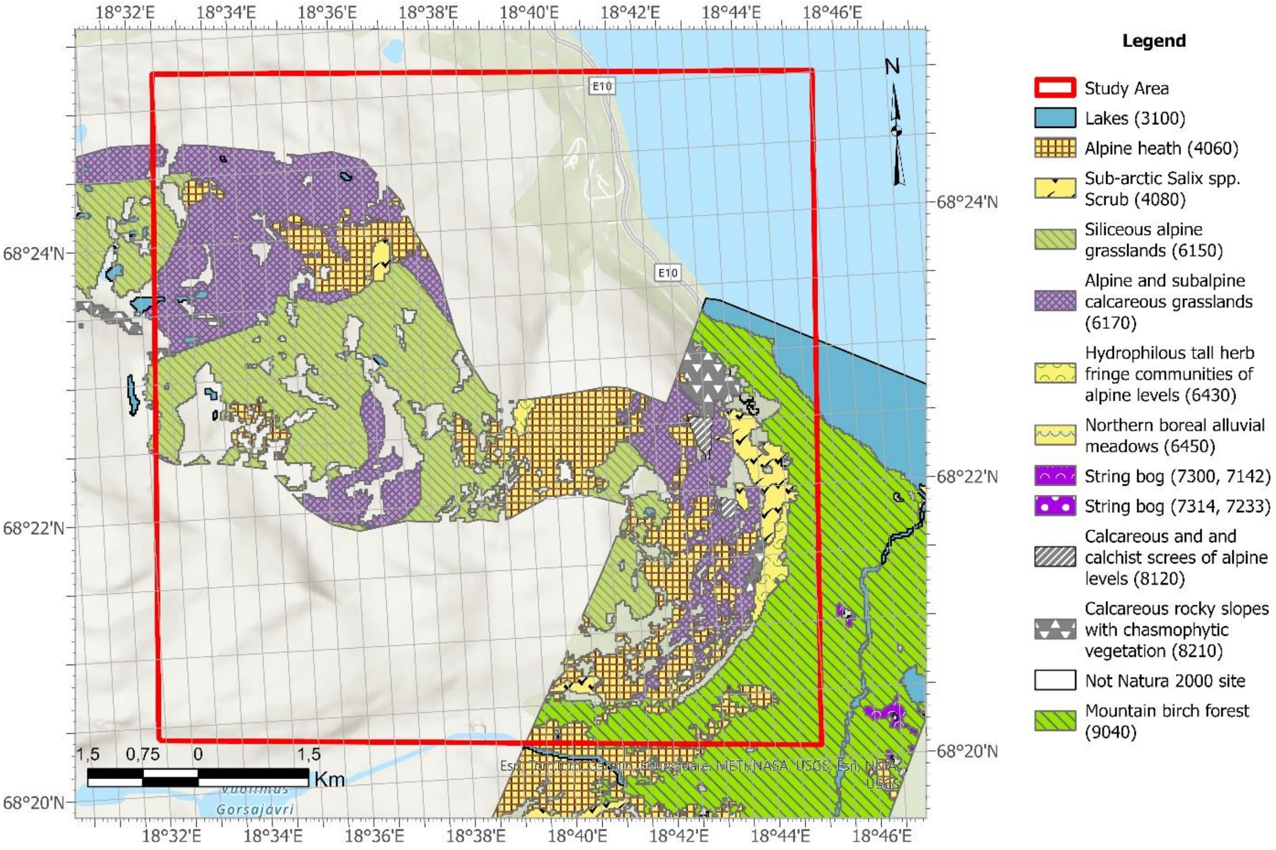
This report focuses on an area of approximately 82 km^2 or 8200 ha, 200 km north of the Arctic circle, in Lapland, Sweden (68.22° N, 18.39° E). The region of interest primarily covers the east-facing slope of Mt. Nuolja as well as parts of Abisko National Park (Fig. 1), it is overlapping with a Natura 2000 site which provides insight into the region's biodiversity. The study area is located in the Sub-arctic climate zone (Dfc) according to the Köppen-Geiger climate classification, which is defined by cold continental weather with cold, short summers and no dry season (Kottek et al., 2006). The highest point in the study area is at 1400 m asl (above sea-level) and the lowest is at 340 m asl (measured in ArcGIS Pro, version 3.2.1).

Abisko National Park and the Nuolja Mountain exhibit a high vegetation diversity, particularly considering the challenging environmental conditions (Länsstyrelsen Norrbotten, n.d; Ecopotential project, n.d.). According to the Natura 2000 habitat sites (EEA, 2022a), the area is predominantly covered by different types of alpine and subarctic grassland habitats. This study utilizes the description covered by Natura 2000 for both habitat and vegetation classifications. Grasslands are habitats of high ecological importance as they cover large parts of the global landmass and are home to many different species, thus having high biodiversity (Gibson, 2009). The study area is mainly covered by alpine siliceous grasslands and subalpine calcareous grasslands on the mountain side along with mountain birch forest covering large parts of the national park (Fig. 2). Calcareous environments, such as these grasslands, are often defined by a species rich flora, contributing significantly to overall biodiversity (Hillier, 1990). These habitats often support exclusive alpine vegetation, adding to their ecological significance (Naturvårdsverket, 2011b). In contrast, siliceous alpine grasslands typically exhibit lower plant diversity due to specific soil and microclimate conditions (Naturvårdsverket, 2011c). The calcareous grassland habitat covers approximately 8 km^2 of the study area while the siliceous covers roughly 9 km^2.



Cartographer: Alexandra Petrini
Date: April 2024
Source: Lantmäteriet (elevation)

Figure 1. Study area with a hillshaded Digital Terrain Model (left) showing the study area in the red square. The insets on the right show the location of the study area. The DTM data are downloaded from Lantmäteriet.



Cartographer: Alexandra Petrini
April 2024
Source: Naturvårdsverket (Natura 2000)

Figure 2. Study area with Natura 2000 classified sites and their respective habitat-form. The habitat codes are in parentheses.

2.2 Data acquisition & Preprocessing

2.2.1 *Multispectral data & Sentinel-2*

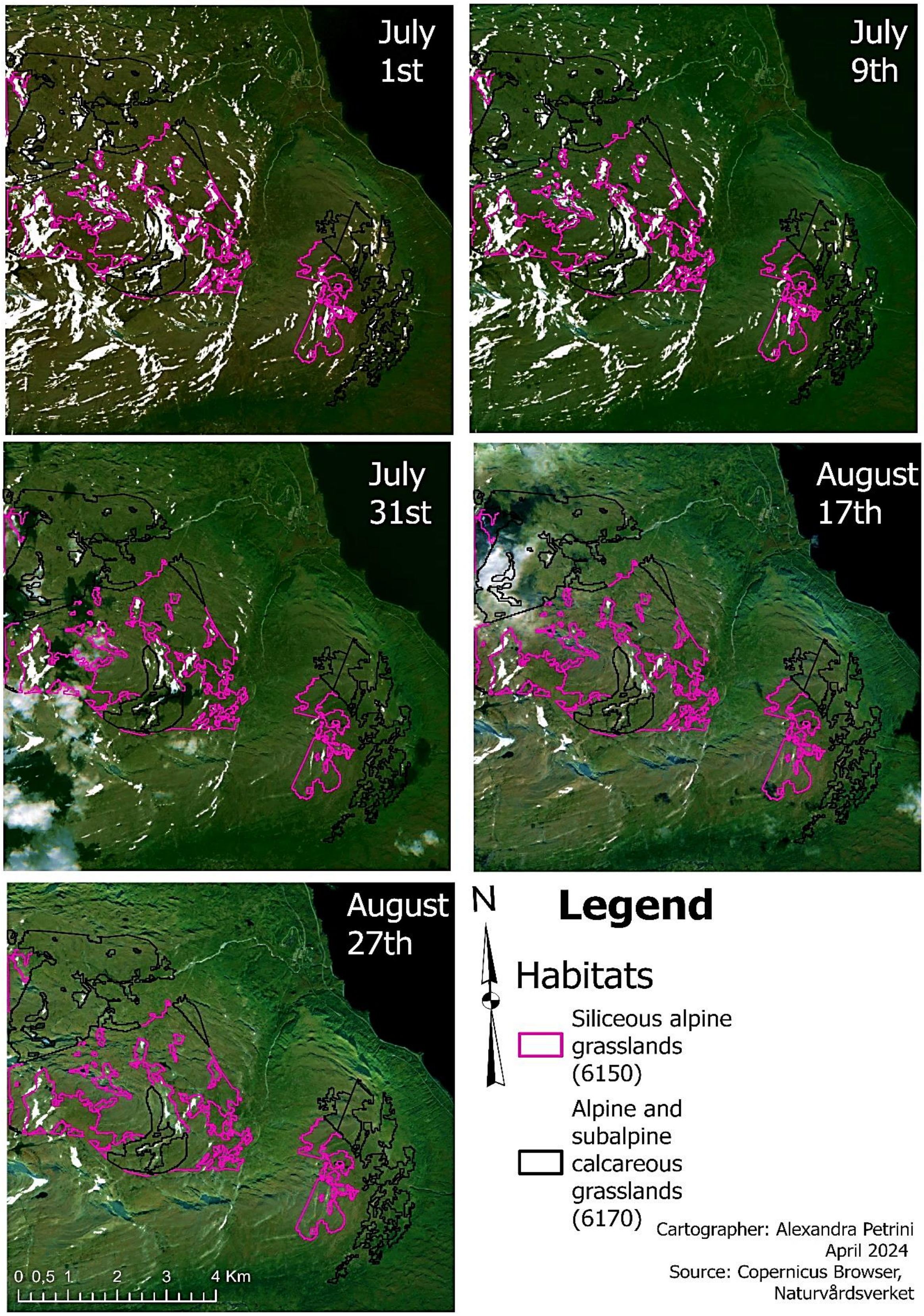
For this study, an initial data analysis was done to investigate the biodiversity and species richness in habitats defined by the Natura 2000 sites downloaded from the EEA Natura 2000 viewer (EEA, 2022a), thereby determining the chosen study area. Multispectral images from the growing season of 2023, which have been corrected for atmospheric effects (L2A), were downloaded from the Copernicus browser (Copernicus, n.d.) with the coordinate system WGS 84 and UTM zone 33. The images were collected by the multispectral instrument (MSI) aboard the Sentinel-2 satellites. Using openly accessible data is a cost-effective and consistent approach for monitoring changes in biodiversity, hence this study utilizes multispectral data from the Sentinel-2 satellites. Multispectral data consists of a combination of several ranges within the electromagnetic spectrum. Each range (or band) corresponds to certain wavelengths which in turn gives specific information about parts of the multispectral image (Xue & Su, 2017). The Sentinel-2 satellites cover 13 bands within the electromagnetic spectrum where the spatial resolution differs between the bands, ranging from 10 m – 60 m (The European Space Agency (ESA), n.d.; Li & Roy, 2017). They have a 290 km x 290 km scene size which divided up into 100 x 100 km tiles. Within the Sentinel-2 mission there are currently two constellations which together have a revisit time of 1 – 2 days at high latitudes (Li & Roy, 2017) with where this study is based.

2.2.2 Image selection

The chosen study period was mainly based on image availability and ground conditions. Images with obstructing cloud cover or extensive snow cover were not considered, as they conceal the vegetation underneath and can affect the accuracy of the analysis (Marcal & Wright, 1997). Similarly, years affected by for example extreme weathers that cause temporary disturbances or stress on the vegetation, such as drought, were also excluded, as these conditions can significantly impact vegetation health and alter the patterns observed in the data (Battisti et al., 2016). By focusing on a period with favorable imaging conditions and stable environmental conditions, the analysis aims to provide more reliable results. Therefore, the study solely used images taken from the growing season of 2023 which began in the beginning of May and ended in the beginning of October resulting in a vegetation period of around 145 days (SMHI, 2022). Suitable images were captured on July 1st, 9th and 31st as well as August 17th and 27th, therefore these images were used for the analysis. Multiple images were used in order to find the NDVImax and see potential changes in spectral variation over the growing period. This approach was applied as there were phenological changes to the vegetation throughout the study period, including the blooming events which do not necessarily take place at the same time over the spatial extent of the image due to variations in altitude within the study area (Deng et al., 2022; Fassnacht et al., 2022).

2.2.3 Preprocessing

For this analysis, the red (Band 4), green (Band 3) and near infrared (NIR, Band 8) bands with a spatial resolution of 10 m were utilized. The bands were imported to ArcGIS Pro (version 3.2.1), reprojected to SWEREF 99 and cropped to the extent of the study area. This was done using the *Clip raster* tool and helped to focus the data on the study area and thereby reduce the data processing time. True color images (Fig. 3) were then created using the red, green, and blue (Band 2) bands in order to do comparisons throughout the analysis.



Cartographer: Alexandra Petrini
April 2024
Source: Copernicus Browser,
Naturvårdsverket

Figure 3. Sentitnel-2 images used in the analysis from the growing season of 2023, collected from Copernicus browser (n.d). The images are shown in true color (RGB). The calcareous grassland habitat is outlined in black and the siliceous grassland habitat in pink, habitat areas are derived from the Natura 2000 data.

2.3 SVH analysis

2.3.1 Principal component analysis & Clustering

The SVH analysis used three bands, red, green and NIR from all five images over the growing season. All bands were combined into a single multiband raster file with all 15 bands by adding all bands into the *Composite bands* tool in the order of green, red, NIR for each date within the study period. The multiband raster file was thereafter used in the geoprocessing tool *Principal components* which performed a principal component analysis (PCA) with the aim to reduce dimensionality of the data. The first principal component (PC) uses all values to explain the largest variation, whereas the second PC utilizes all values the first PC did not use, in order to find the second largest amount of variation in the data. This process goes on until the desired number of components has been reached and thus the respective patterns within the data are visualized in each component. The explained variance is the information each PC retains from the analysis where the PCs contain a certain pattern (variance) found within the data. In this case the expected patterns may come from biodiversity, cloud or snow variations that occur in the data.

Based on the PCA results, two new files were made: one with the first two PCs in a two-layer raster file, and the second with the first four PCs into a four-layer raster file. Therefore, the following parts of this analysis were done twice, once for PCs 1 & 2 and one once for PCs 1 – 4.

Next, the files were used in an *ISO cluster algorithm* (Image analysist ISO cluster) which determines spectral classes in the combined PCs by grouping pixels based on spectral similarity (Esri, n.d.). Thus, the spectral classes have a relationship with spectral diversity (Boakye, 2023). The "maximum number of clusters" option was set to 25 to make sure that all different spectral variations were combined into different clusters thus avoiding that they were combined into one cluster. This was done in order to see which areas were affected by snow, clouds and cloud shadows as well as seeing which areas contained similar spectral signals.

2.3.2 Further analysis of two habitat types

From the Natura 2000 habitat classifications, which was available as a GIS-layer, two dominant habitats were identified in the study area, calcareous and siliceous grasslands. The grassland habitats within the study area were selected using the *Select By Attributes* tool and exported into separate shape (SHP) files, one for each habitat type. Given their known differences in biodiversity, as mentioned in section 2.1, these habitats were used for the next parts of the analysis in order to see if there is a spectral difference between them. Using the *Clip Raster* tool the ISO cluster files were cropped to fit each habitat polygon.

To assess the significance of the spectral differences between the two grassland types, a statistical analysis was conducted on the original 15-band composite file. First, the standard deviation value for each pixel was calculated using the *Cell Statistics* tool. The standard deviation is a measure of how dispersed the values are compared to the mean value for the same pixel, this will become important for the results as it will be used as an indication of the measure of spectral variation. Then, the statistics were used in the *Zonal Statistics* tool. Here, the PCA file for each habitat served as the feature zone data, with the input raster being the respective statistics file and the standard deviation was chosen in the 'statistics type' setting. The resulting files for each habitat type visualizing the standard deviation were then combined into one using *Mosaic to new raster* tool for easier processing in the coming parts of the analysis.

2.3.3 Removing cloud and snow affected areas

As mentioned earlier, clouds, their shadows and snow affect the data analysis, therefore areas that had been visibly affected by these were removed through a masking process. Firstly, a threshold value was chosen by comparing the previous output and the ISO clustering files with the satellite images, and then removing clusters which represented snow, clouds, and cloud shadows. In the *Raster Calculator* the code "DataToBeMasked > threshold" was used, which gave a binary output where all pixels that exceeded the threshold (snow/clouds) were assigned with a value of 1 and the rest 0. The tool *Extract By Attribute* was thereafter used where pixels with a value of 0 were extracted and later used in *Extract By Mask* to ultimately mask out the unwanted data.

For PCs 1 & 2, determining a threshold was challenging as it could be seen earlier that these PCs were not as affected by the clouds as PCs 1 – 4. Thus, larger areas containing data were removed in PCs 1 – 4 while some areas that were cloud covered could be kept in PCs 1 & 2. All clusters that affected the base of Mt. Nuolja were not removed since that region was not affected by either clouds or snow throughout the study period and the removal of these clusters would result in the removal of most data.

2.3.4 Statistical analysis

To statistically compare the two habitats the masked standard deviation files were yet again cropped to fit each habitat using the *Clip Raster* tool and exported as a TIFF-file to extract their data into an excel file.

In ArcMap (version 10.8.2) the information within the raster file was extracted and added to an Excel (version 2403) file where each standard deviation value was accompanied by a count representing the number of pixels containing that value. Subsequently, these counts were converted into percentages, and histograms were constructed. The data was then imported into Python (version 3.9) to generate new CSV files containing a standard deviation value for each pixel, facilitating further analysis. Based on this data, a boxplot was created as well as a two-tailed t-test was conducted in Excel using the *Data Analysis* toolbox to assess the statistical significance of the differences between the two habitat types. T-tests give information about the t-value which measures the difference between the tested groups as well as p-value that gives an indication if the results could occur due to coincidence or not (Francis et al., 2019). For this report significant values are a p-value < 0.05 which means that the resulting t-value most likely did not occur by coincidence (Francis et al., 2019).

2.4 NDVImax

NDVI is based on the fact that chlorophyll absorbs radiation in the red spectrum and strongly reflects NIR radiation. Thus, NDVI is calculated using the red and NIR parts of the electromagnetic spectrum (Eq. 1) where *NIR* and *Red* refer to their respective bands. This results in values ranging from -1 to +1, where the higher NDVI value implies stronger vegetation greenness (Campbell et al., 2022). Normally, areas containing barren rock, snow or water bodies have a low value of 0.1 or less while vegetation has a higher positive value (Jones and Vaughan, 2010; Brown, 2018). Shrublands, grasslands or other areas of sparse vegetation normally result in NDVI values ranging from 0.2 – 0.5 (Brown, 2018). Higher NDVI values are commonly attributed to a dense vegetation cover usually occurring in temperate or tropical forests at their peak growing state (Brown, 2018).

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \qquad \text{(Eq. 1)}$$

The seasonal maximum of NDVI, hereafter referred to as NDVImax, is the highest NDVI value for the area and it is found by looking at the whole growing season (from snow melt to first snowfall). It is calculated by the maximum value composite (MVC) method which compares the NDVI for each image and proceeds to only use the highest value from each pixel (Holben, 1986). This is supposed to reflect the ideal conditions for the vegetation in each pixel by reducing the noise within the image (Holben, 1986) through e.g. minimizing the effects of clouds in the images (Holben, 1986, Marcal & Wright, 1997).

2.4.1 Calculating NDVImax

The first step in the NDVImax analysis was to calculate the NDVI for each date with the *raster calculator* tool using Eq. 1, this was done in ArcGIS Pro. Thereafter the MVC method was applied, using the *raster calculator* once more, rendering a new raster file where each cell contained NDVImax. This was calculated in four steps. Firstly, by comparing each pixel for July 1st and 9th, creating a new raster, and later using the new raster to compare with July 31st, and so on, resulting in a single-band raster file (see Appendix 1 for full code). The results were then checked to make sure that all values were in the correct range.

2.4.2 Statistical analysis

In order to remove affecting factors and focus the data on the habitats, the areas that were snow covered were masked out, here the masking outline used for the SVH analysis PCs 1 – 4 (described in section 2.3.4) was reused, thus removing areas which were affected by clouds too. Similar to section 2.3.4, the areas were also clipped to fit each habitat using the *Clip Raster* tool and exported as a TIFF-file to extract their data into an excel file. The next steps of this statistical analysis cover the making of graphs (histogram and box plots) with the addition of the grouping for the histogram bins which was done in Spyder (described in section 2.3.4).

2.5 Comparison of the two approaches

To compare the methods a stratified random sample was taken on the SVH and NDVImax data. In this case the two strata used were the two different grassland habitats examined in this study. Based on information gathered during the SVH analysis, 1% of the total pixels in each habitat area from PCs 1 – 4 were used as the number of random points (calcareous = 746 points, siliceous = 765 points) that were collected from both the standard deviation data from both parts of the SVH analysis and the respective NDVImax values. This was done in ArcGIS Pro.

The random points were generated by the *Create Random Points* tool in ArcGIS Pro and used in the spatial analyst tool *Sample* to extract information from each. Using the tool *Table to Excel* the tables were exported, thereafter the data from each was plotted against each other in Excel.

To aid in the understanding of the methods' relationship a scatter plot was made, and a linear regression analysis was performed utilizing Excel's toolbox *Data Analysis*, providing information about the correlation between the methods and their respective p-value.

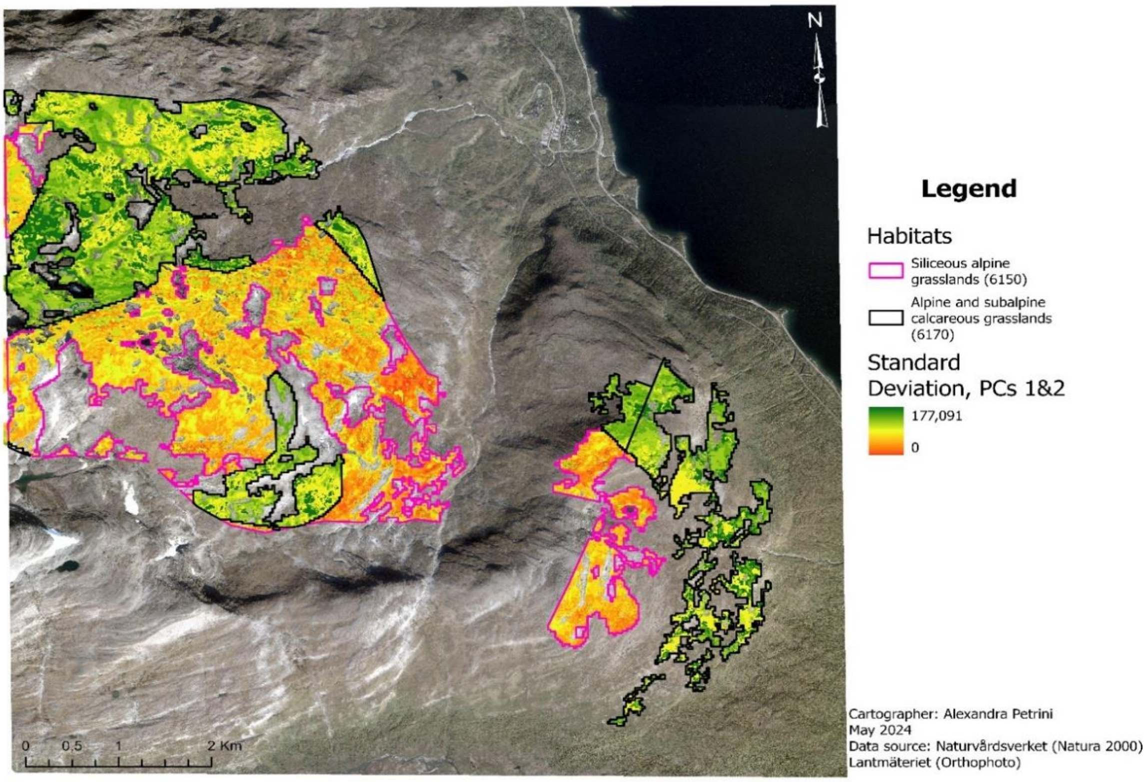
3 Results

3.1 SVH analysis

The PCs that were used in the SVH analysis and their respective variance percentage were PCs 1 – 4, these PCs were used to obtain the end results of the SVH analysis. They had an explained variance of 64.2%, 20.0%, 8.08%, 3.9% respectively. The accumulated explained variance of PCs 1 & 2 was 84.2% and 96.2% for PCs 1 – 4.

The resulting data obtained using the SVH analysis is based on standard deviation values. Figs. 4, 5 and 6 illustrate the standard deviation of PCs 1 & 2, representing the spectral variation within the two examined habitat types, where Fig. 4 visualizes the distribution of standard deviation within each habitat. The calcareous grassland habitat has a standard deviation ranging from 106.8 – 177 while the siliceous ranges from 15.3 – 128.2.

Both habitat types exhibit a variation in standard deviation (Fig. 5), where the calcareous grassland areas have more pixels with a higher standard deviation of spectral values compared to the siliceous grassland areas. Fig. 6 also display that the calcareous grasslands exhibit a higher variation in standard deviation values, with a median of 136. Additionally, according to Fig. 6 the siliceous grassland displays a lower distribution in standard deviation values with a median of 95, compared to the calcareous grassland. This is further supported by the t-test which revealed a substantial difference between the habitat types with significant p-value of < 0.01 and a t-value of 383.5 emphasizing this difference.



Cartographer: Alexandra Petrini
May 2024
Data source: Naturvårdsverket (Natura 2000)
Lantmäteriet (Orthophoto)

Figure 4. Standard deviation in the two grassland habitats using PCs 1 & 2. Displaying higher spectral variation between the analyzed images as green and low as red. The calcareous grassland habitatis outlined in black, and the siliceous grassland habitat in pink.

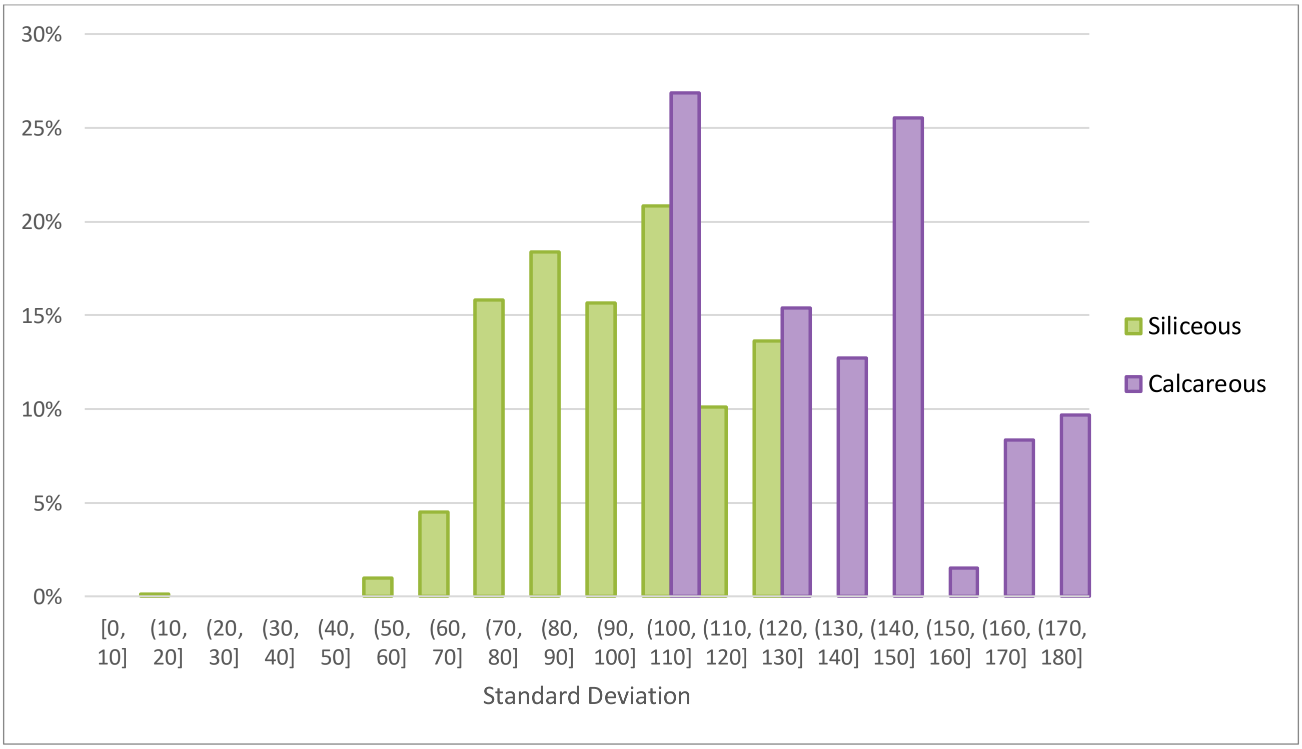


Figure 5. Variation of standard deviation values based on PCs 1 & 2. Calcareous grassland habitat is visualized in purple and siliceous in green.The bars represents an interval of ten standard deviation points where each bar is a visualization of the percentage of the number of pixels within each interval.

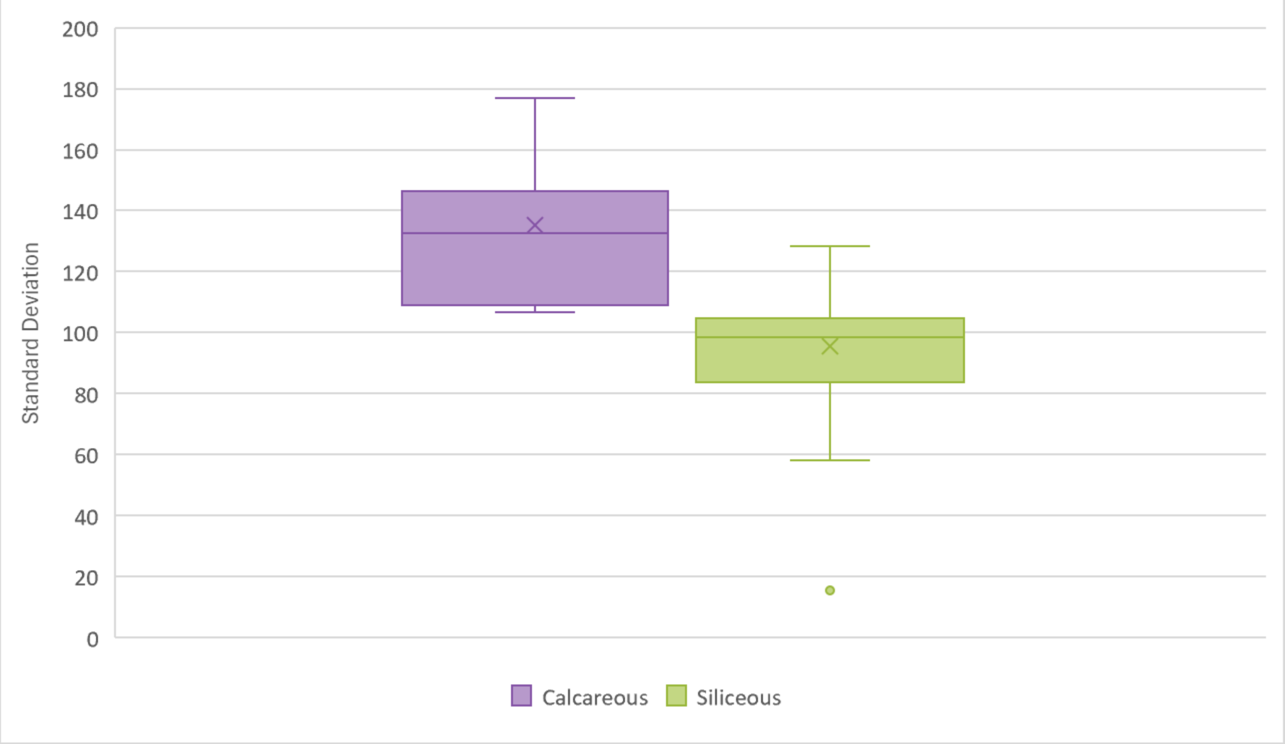
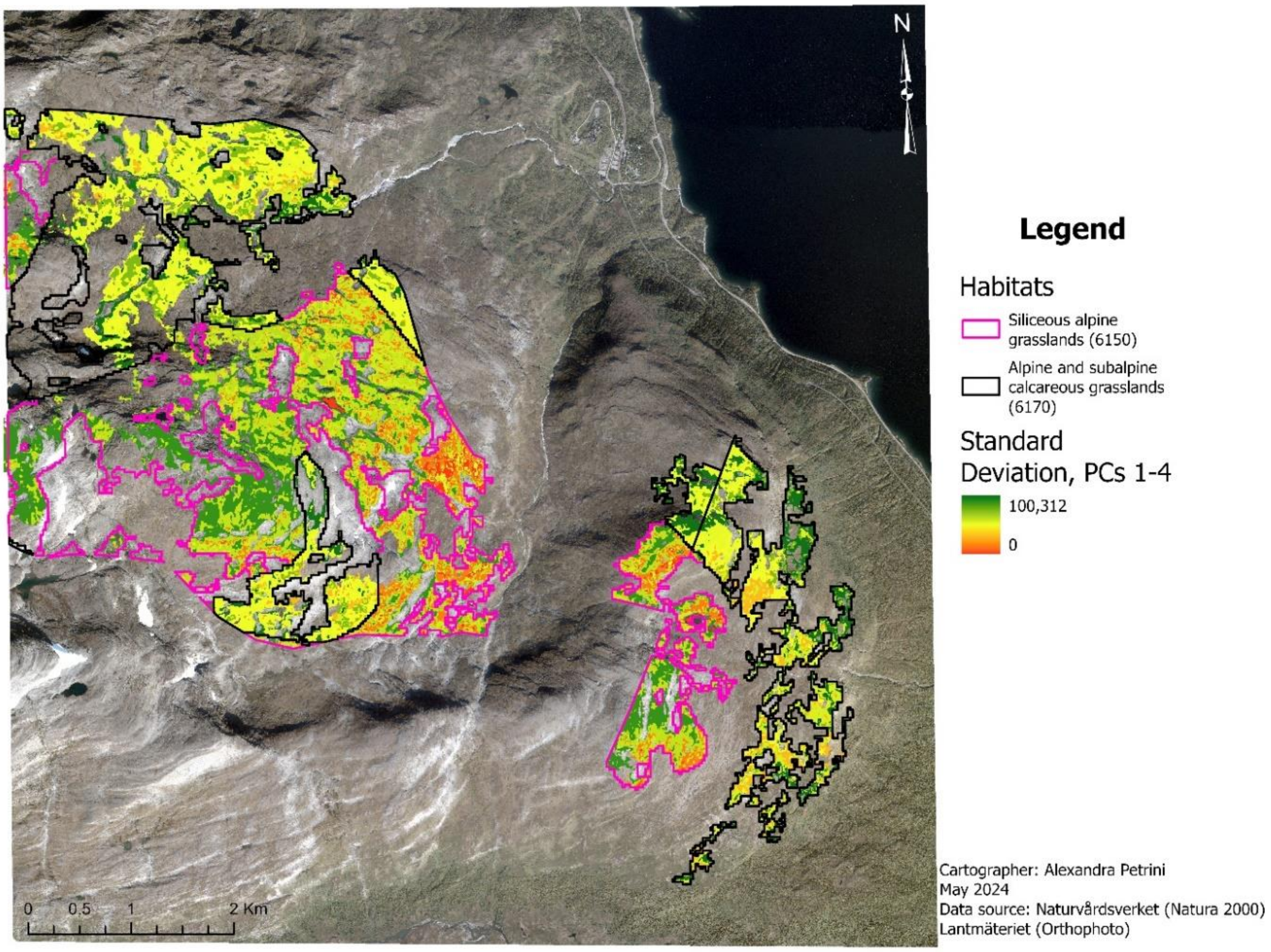


Figure 6. Distribution of standard deviation values for PCs 1 & 2. Calcareous grassland habitat is visualized in purple and siliceous in green.

Likewise, Figs. 7, 8 and 9 visualize the distribution of standard deviation but for PCs 1 – 4. Here the habitat types exhibit a quite different pattern of spectral variability (Fig. 8). The calcareous habitat has the highest standard deviation value between the two habitat types (Fig. 8) with standard deviation values within the range of 38.9 – 100, however the siliceous displays a more even range in standard deviation looking at the distribution (Fig. 9) containing a standard deviation range of 29.9 – 81.5 with the most values located in the higher values and a median of 70. Fig. 9 displays that there is a similar amount of variation between the two habitats when analyzing PCs 1 – 4. This is also confirmed by the t-test that resulted in a significant (p-value < 0.01) t-value of 17.5 which indicates that the tested groups are quite similar.



Cartographer: Alexandra Petrini
May 2024
Data source: Naturvårdsverket (Natura 2000)
Lantmäteriet (Orthophoto)

Figure 7. Standard deviation in the two grassland habitats using PCs 1 – 4. Displaying higher spectral variation between the analyzed images as green and low as red. The calcareous grassland habitat is outlined in black, and the siliceous grassland habitat in pink.

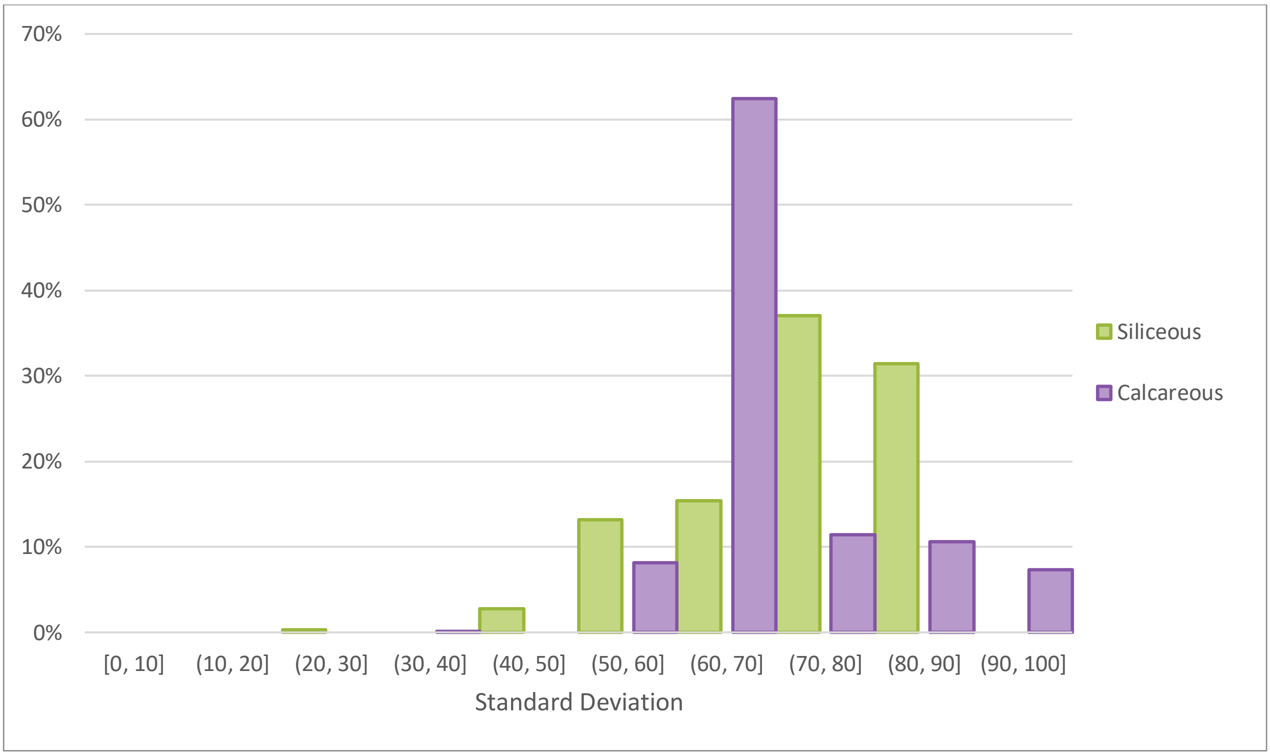


Figure 8. Variation of standard deviation values based on PCs 1 – 4. Calcareous grassland habitat is visualized in purple and siliceous in green. The bars represents an interval of ten standard deviation points where each bar is a visualization of the percentage of the number of pixels within each interval.

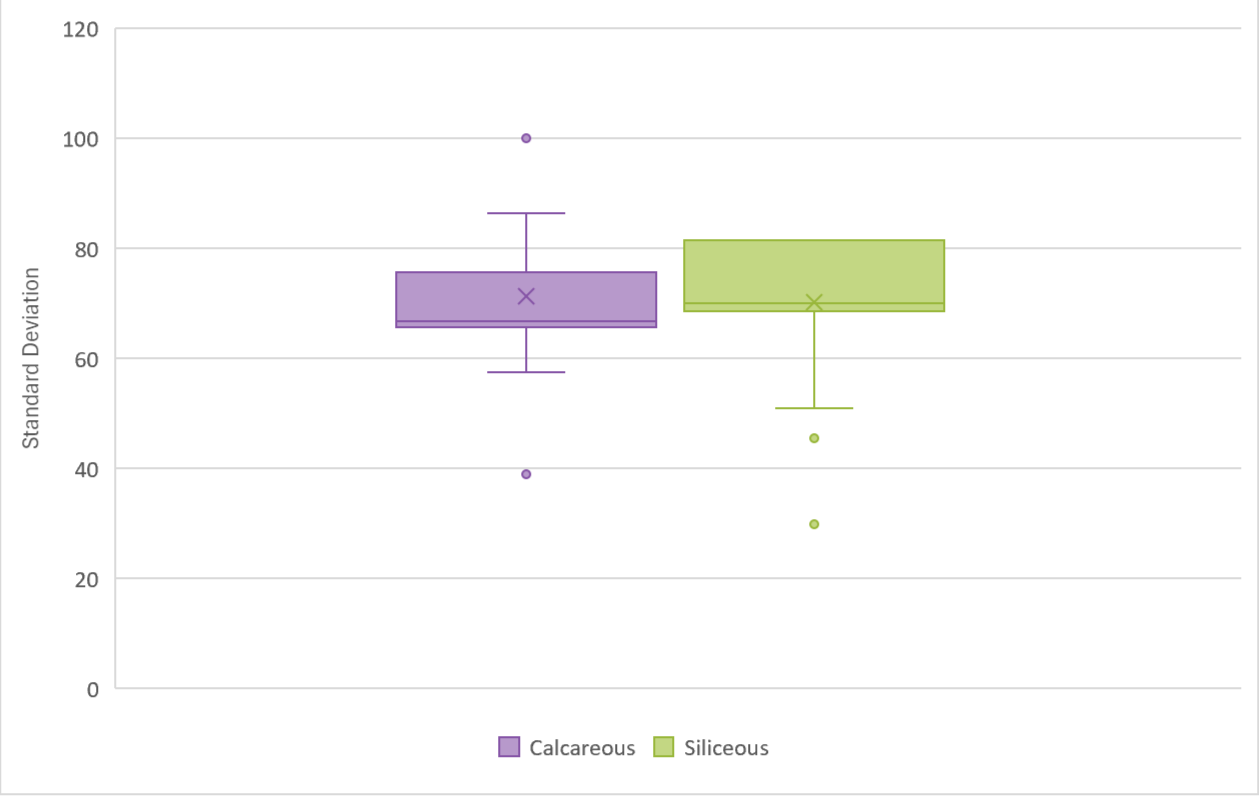


Figure 9. Distribution of standard deviation values using PCs 1 – 4. Calcareous grassland habitat is visualized in purple and siliceous in green.

3.2 NDVImax analysis

The result from the NDVImax analysis is displayed in Fig. 10 showing the variation in vegetation health across both examined habitats for the growing season of 2023 where values at or above 0.2 indicate areas with vegetation (Brown, 2018). It was proven to be a significant difference (p-value < 0.01, t-value 169.5) in NDVImax between the two grassland habitats based on the t-test.

Fig. 11 shows the distribution of NDVImax and combined with Fig. 12 it is evident that the calcareous grassland habitat exhibits overall higher NDVImax with a similar variation in values as the siliceous grasslands. The NDVImax values range from -0.004 to 0.67 and -0.036 to 0.60 for the calcareous and siliceous habitat respectively, where the dominant value is within the 0.3 – 0.4 interval. As there were no pixels containing NDVImax values between -1 to -0.2 in the examined areas, these bins were excluded in the visualization of Fig. 11 in order to make the comparisons between the different histograms clearer. The graph containing all bins is attached in Appendix 2 as Fig. A.

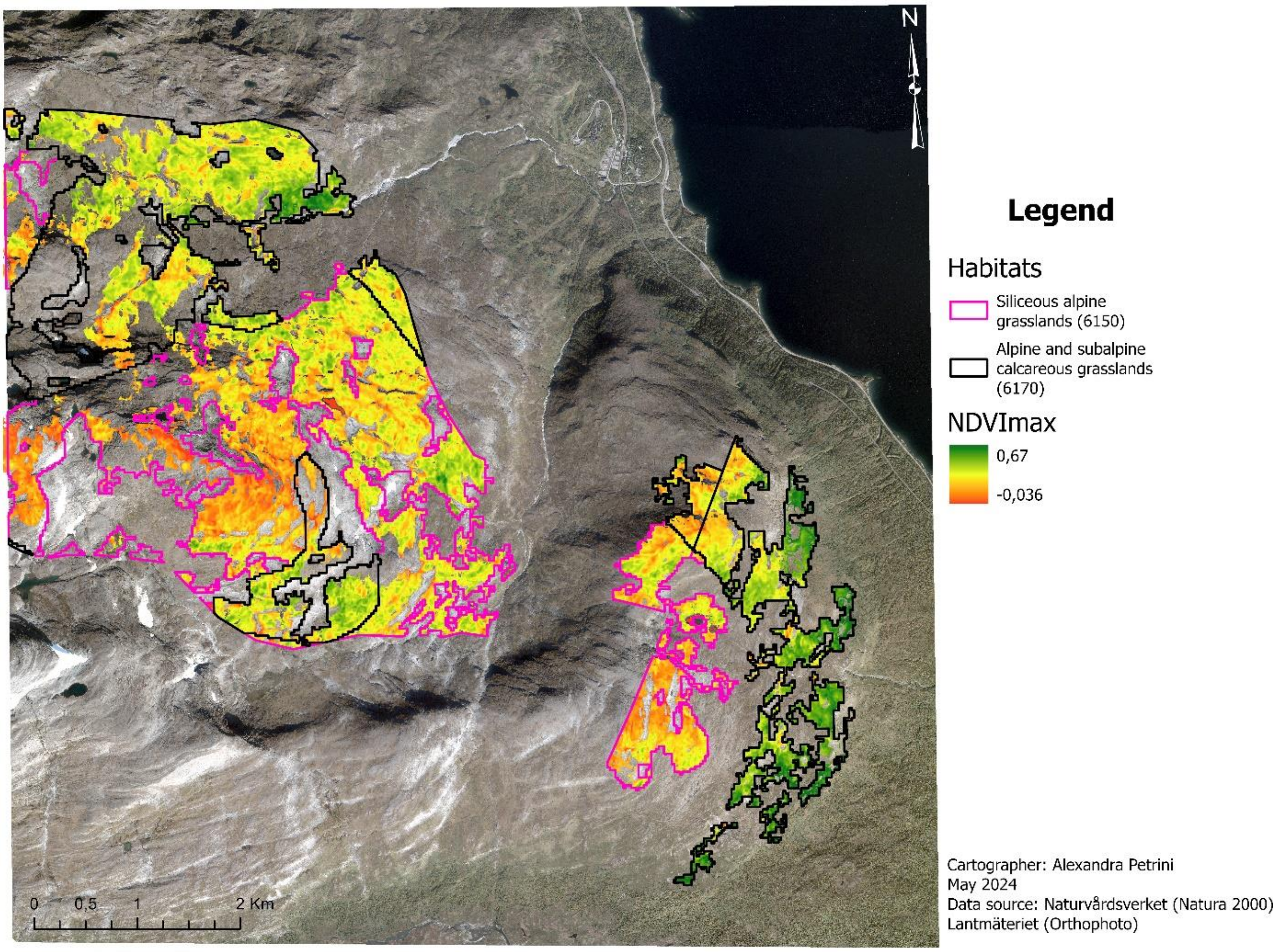


Figure 10. NDVImax in the two examined habitats overlaying an orthophoto (data from Lantmäteriet). Displaying higher NDVI as green and low as red in the calcareous grassland habitat, outlined in black, and the siliceous grassland habitat, outlined in pink. Values at or above 0.2 display areas containing vegetation (Brown, 2018).

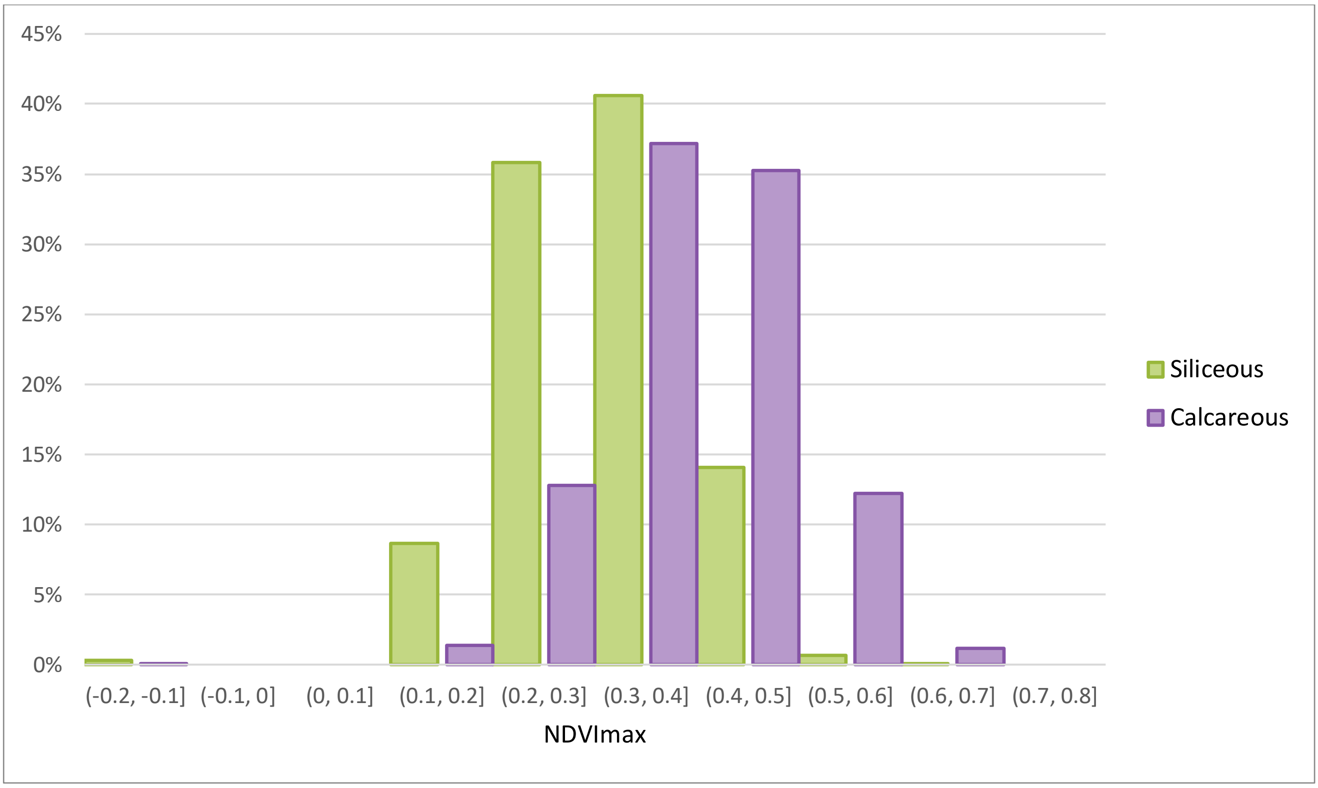


Figure 11. Variation of NDVImax values. Calcareous grassland habitat is visualized in purple and siliceous in green. The bars represents an interval of 0.1 NDVImax values where each bar is a visualization of the percentage of the number of pixels within each interval. Values of ≥ 0.2 indicates points of vegetation (Brown, 2018).

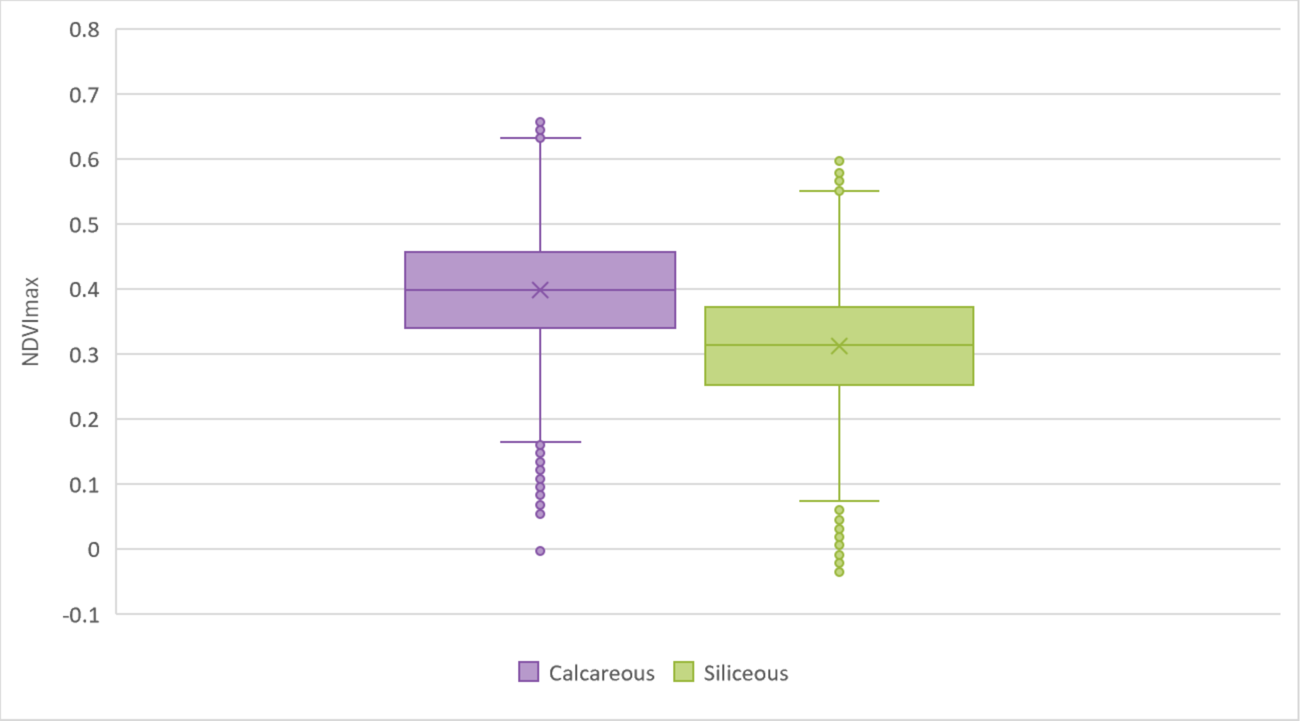


Figure 12. Distribution of NDVImax values for the calcareous and siliceous habitats. Calcareous grassland habitat is visualized in purple and siliceous in green. Values of ≥ 0.2 indicates points of vegetation (Brown, 2018).

3.3 Comparative analysis: SVH vs. NDVImax

The relationship between the two analyzed methods, SVH using PCs 1 & 2 and seasonal NDVImax is visualized in Fig. 13 where the statistical analysis gave a weak correlation (R^2 value = 0.03) with a significant p-value of <0.01 for the siliceous habitat while the calcareous habitat provided an insignificant correlation (R^2 value = 0.0006, p-value > 0.5). Likewise, the SVH PCs 1 – 4 and NDVImax relationship is visualized in Fig. 14. This too gave low correlations (R^2 value = $3.2*10^{-4}$, R^2 = $2.8*10^{-7}$) for the calcareous and siliceous grassland respectively, both with an insignificant p-value of 0.73 and 0.97.

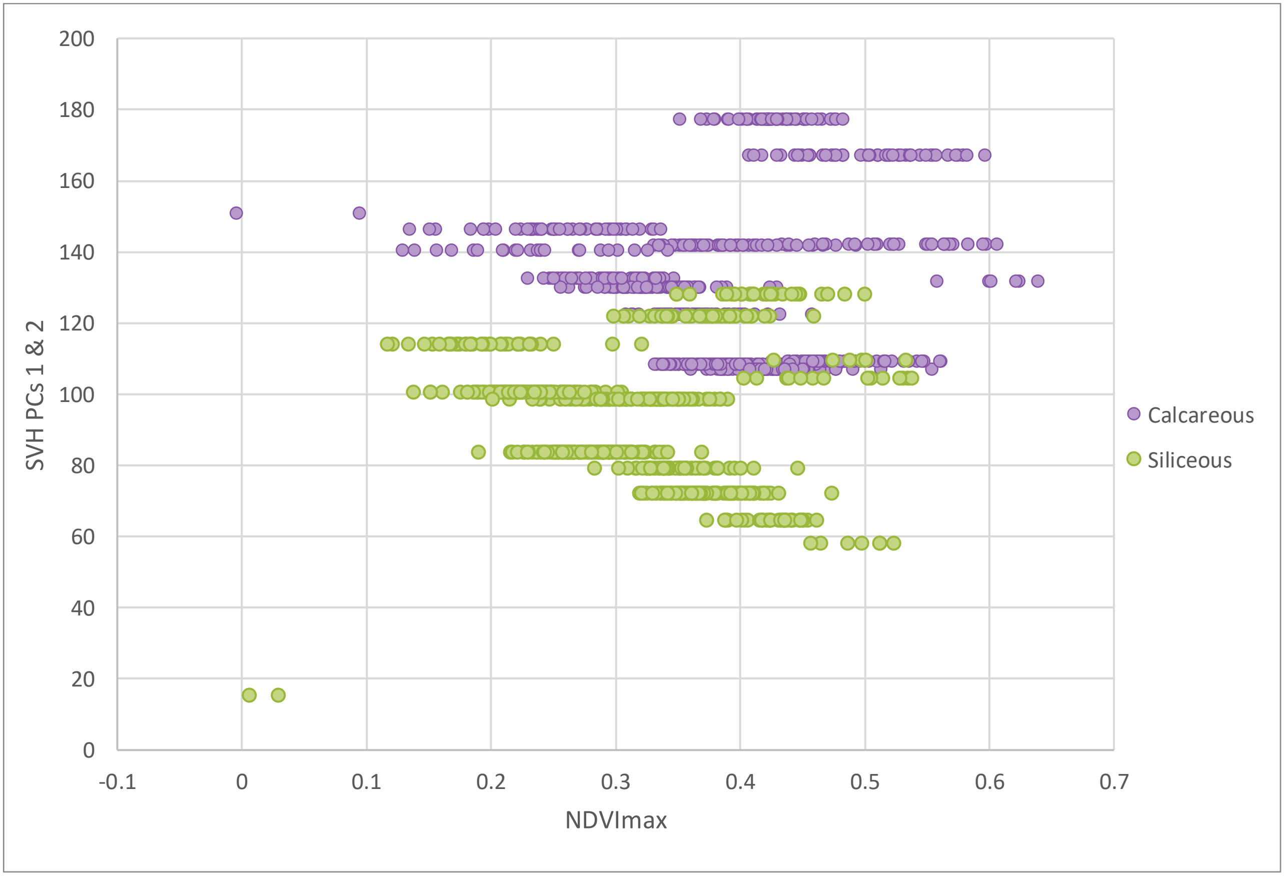


Figure 13. Relationship between NDVmax and the standard deviation for PCs 1 & 2 from the SVH analysis in the siliceous (green) and calcareous (purple) grassland habitat. Each point reflects data from the respective random point generated for both habitats in section 2.5.

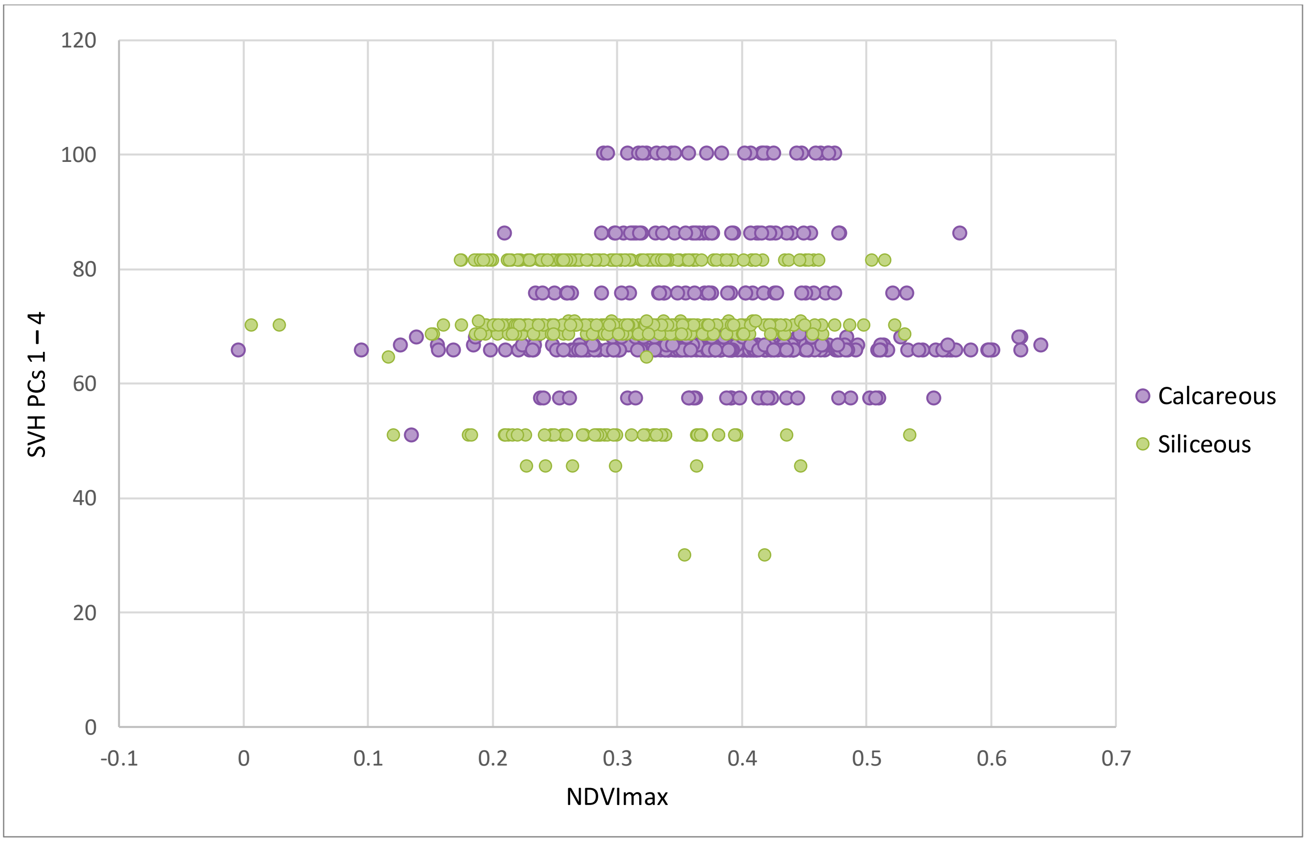


Figure 14. Relationship between NDVmax and the standard deviation for PCs 1 – 4 from the SVH analysis in the siliceous (green) and calcareous (purple) grassland habitat. Each point reflects data from the respective random point generated for both habitats in section 2.5.

4 Discussion

4.1 SVH vs. NDVImax for habitat discrimination

The resulting data obtained using the SVH analysis is the standard deviation values which will be used as a proxy for the spectral variation in this report, as it is a measure of how disperse the values are thus indicating differences in the spectral reflections.

The results clearly demonstrate a significant difference in spectral variation between the calcareous and siliceous areas. This is particularly evident in the analysis conducted on PCs 1 & 2, as well as in the results of the t-tests performed for both parts of the SVH. Despite not being as clear in Fig. 7 compared to Fig. 4, there is a distinct change in spectral variation moving from one habitat type to the other when looking closer at the areas where the habitats meet (e.g. in the southeastern areas).

The spectral variation of the SVH analysis visualized in Fig. 4 and 7, show that there is a clear difference between PCs 1 & 2 and PCs 1 – 4 where the first mentioned display an overall higher spectral variation in both habitat types. Looking at the results of the statistical analysis on PCs 1– 4, specifically Fig. 9, which shows that the siliceous habitats exhibit a higher distribution of spectral variation, the findings differ from those of PCs 1 & 2. Fig. 6 displays a distinct difference between the two habitat types in PCs 1 & 2, where the calcareous grassland exhibits higher spectral variation compared to the siliceous grassland. Consequently, the choice of PCs in the SVH analysis significantly influences the results, as selecting different components yields varied outcomes which e.g. Boakye (2023) also states. Moreover, Figs. 13 & 14 further demonstrate that using different PCs influences the results. For PCs 1 – 4 (Fig. 14) it is more difficult to separate the habitats compared to PCs 1 & 2 (Fig. 13). As the first PCs contained the most information the analysis done on solely PCs 1 & 2 helped to identify areas of higher spectral variation while the analysis done on PCs 1 – 4 reduced the variability captured in the first two PCs by adding more noise to the data.

Even though PCs 1 – 4 had a reduced ability to capture the variability of the data compared to that of PCs 1 & 2, they still indicated that the calcareous grassland had a higher spectral variation. PCs 1 & 2 distinctly displayed this difference in spectral variation (Fig. 4), enabling the differentiation between the two habitats. The statistical analysis resulted in a significant difference between the two grassland habitats, where PCs 1 & 2 proved to have a large difference between the habitats. Hence, both parts of the SVH align in suggesting that the calcareous grassland habitat inhibits a higher spectral variation (Figs. 4 – 9). According to the SVH this would in turn suggest that the species diversity is also higher in these areas compared to the siliceous habitats which is consistent with the known biodiversity in these habitats. This proves that the SVH is applicable in evaluating biodiversity in grassland habitats, which is also supported by the findings of Zhao et al. (2021) and Thornley et al. (2023).

July 31st and August 17th have clouds over the western part of the study area, this affects the analysis as the clouds make it impossible to see the ground underneath and the spectral properties of the data changes slightly due to the cloud shadows. Effects of this would be seen in the NDVI as the NDVImax for those areas could be on cloudy dates and underneath the clouds or in their shadow. Additionally, this essentially affects the SVH analysis in the same manner as the NDVImax as the spectral variations vary depending on a plant’s maturity (Madonsela et al., 2021; Fassnacht et al., 2022). With the SVH analysis it can be seen in PCs 3 & 4 that the clouds are more prominent compared to PCs 1 & 2 as the two later PCs add more noise to the data. Images with clouds were still included in this study as there were solely three dates in which the study area was completely cloud free during the growing season of 2023. Only using those three images would be possible, however, there would be a large gap between July 9th and August 27th which would affect the analysis gravely, especially as the spectral reflections and the NDVI these days could prove to be important. This also provided a good opportunity to compare the effects of the chosen PCs.

Similar to the SVH analysis, the NDVImax analysis also display higher values for the calcareous grassland habitat compared to the siliceous grassland habitat (Figs. 10 – 12), signifying that the calcareous grasslands have healthier and/or more species rich vegetation than the siliceous grassland habitat in this area. It is not as clear a difference between the habitats in the NDVImax visualization (Fig. 10) as in both parts of the SVH analysis, with PCs 1 & 2 displaying the clearest distinction between the habitats.

Even though the methods display similar results showing higher spectral variation and NDVImax in calcareous grassland habitats and vice versa for siliceous grasslands, consistent with known biodiversity patterns, there are notable differences between the two. As Figs. 13 &

14 illustrate, high spectral variation in the SVH analysis does not necessarily correspond to high NDVImax values. Additionally, areas indicating higher spectral variation in PCs 1 – 4 (Fig. 7) are areas where the NDVImax values indicate that there is stressed, or no vegetation (Fig. 10). This is especially notable in the siliceous areas, e.g. at the base of Mt. Nuolja. This may be due to the differences within the methods.

When comparing the suitability of SVH to NDVImax, it is important to note that the differences between the methods can give different results. SVH has the capability to utilize a broader range of spectral information compared to the two bands the NDVI relies on (Rocchini et al., 2010). This can make the SVH method more sensitive to changes in vegetation that may not be captured in the bands of the NDVI analysis (Rocchini et al., 2010) as it uses information from all of the pixels while NDVI uses a single value. For this study, three bands (bands 3, 4, and 8) were used for SVH due to their resolution (10 m). However, other studies, such as those conducted by Rocchini et al. (2004), Madonsela et al. (2021), Boakye (2023), and Wallis et al. (2024), utilized all available spectral bands, thus offering more comprehensive data.

Although all bands were not used, there are studies suggesting that the optimal spectral regions (bands) depend on the species composition in the examined area (Wallis et al., 2024). The same study found that open vegetation, such as grasslands, tend to display high spectral variation in the red band. While this could stem from factors unrelated to species diversity, the red band is also linked to chlorophyll absorption, potentially influencing the relationship between spectral variation and plant diversity (Wallis et al., 2024). Although solely the use of bands with a resolution of 10 m in this study may have resulted in less information, it helped focus the analysis on the specific spectral features present in those bands with the resolution, while also minimizing processing time. This also gave a good comparison between the SVH and NDVImax methods as the red and NIR were used in both methods with an addition of the green band in the SVH displaying how the addition of only one band could make a difference in the results.

All correlation values explaining the relationship between the methods (Figs. 13 & 14) and the habitats were low, and most were insignificant, further proving that the methods work differently and that the SVH approach could give more comprehensive information.

There are controversies surrounding the SVH as a method to assess biodiversity in certain contexts as outlined in e.g. Schmidtlein & Fassnacht (2017), Fassnacht et al. (2022). Many uncertainties connected to the method is the fact that the spectral data is highly dependent on the plant’s phenology (Madonsela et al., 2021), scale effects (Fassnacht et al., 2022), habitat type (Schmidtlein & Fassnacht, 2017; Fassnacht et al., 2022; Wallis et al., 2024) and choice of bands (Fassnacht et al., 2022; Wallis et al., 2024), all of which need to be accounted for when using the method. This study made an effort to account for these uncertainties. Regarding phenology, the spectral variations that are recorded depend on which time of year the study is conducted as well as how mature the plants within the study area are which is further discussed by Fassnacht et al. (2022). Therefore, this study utilized multiple images from the whole growing season, minimizing the uncertainties in spectral variations from an analysis based solely on one image.

Another cause for inconsistency with the SVH as a method to assess species diversity is that it gives different correlation values depending on many various factors mentioned above (Schmidtlein & Fassnacht, 2017). Some of these discrepancies could be due to the different settings and parameters used in the studies (Thornley et al., 2023). Studies have shown that SVH might be better suited for forests (Féret & Asner, 2014; Wallis et al., 2024). However, species diversity assessments done on grassland ecosystems in previous studies show that the SVH appears to hold over this type of landscape (Zhao et al., 2021; Thornley et al., 2023). This suggests that, while SVH may have limitations and variability in its application, it can still be a valuable tool for assessing species diversity in certain habitats. Further research is needed to refine the method and better understand the factors influencing its accuracy and function.

4.2 Future studies

This study finds the use of SVH to distinguish between different types of alpine grasslands promising. In order to further examine the usage of the SVH as a method to assess biodiversity more studies need to be done which e.g. Rocchini et al. (2010); Schmidtlein and Fassnacht (2017); Fassnacht et al. (2022); Boakye et al. (2023); Thornley et al. (2023); Wallis et al. (2024) also states.

A suggestion is to further investigate the SVH in combination with hyperspectral satellite data. Since hyperspectral can detect smaller variations with a wide range of bands it allows for more comprehensive spectral reflectance data, thus more detailed information (Thornley et al., 2023). A recent study conducted by Crofts et al. (2024) found supporting evidence for the use of SVH with hyperspectral data. Similarly, Wallis et al. (2024) demonstrated that the SVH using hyperspectral data is effective for modelling certain traits of species diversity. Additionally, Carlson et al. (2007) found that spectral diversity found through hyperspectral data is positively correlated to species richness. However, all three studies were conducted using aerial hyperspectral data, so exploring the application of hyperspectral data from satellites, with its consistent revisit times, would be an interesting and valuable extension of this research.

Furthermore, using Rao’s Q entropy – a measure of biodiversity established by Rocchini et al. (2017) – with remotely sensed data, preferably hyperspectral satellite data, would be highly beneficial for assessing and monitoring biodiversity in Arctic grasslands. This approach is advantageous as the commonly used Shannon's entropy (e.g., Carlson et al., 2007; Madonsela et al., 2021) has shown some limitations when applied to remotely sensed data (Rocchini et al., 2017). Rao’s Q entropy, however, offers a promising alternative. In a recent study, Pangtey et al. (2023) demonstrated its effectiveness in estimating species diversity using NDVI data from the Sentinel-2 satellite. Extending this approach to hyperspectral satellite data and the use of SVH could provide even more detailed and accurate assessments of biodiversity, given hyperspectral data’s ability to detect subtle spectral variations. This method could significantly enhance our understanding and monitoring of Arctic grassland ecosystems.

5 Conclusion

This study aimed to evaluate the SVH as a method for assessing biodiversity patterns in contrast to the commonly used seasonal NDVImax, with the goal of aiding future biodiversity conservation strategies. Both methods were applied to five Sentinel-2 images from the growing season of 2023, revealing differences in species diversity between subarctic calcareous and siliceous grasslands at Mt. Nuolja in northern Sweden. The study demonstrates that the choice of PCs is of importance for determining spectral diversity, as incorporating additional PCs can introduce noise, diminishing the spectral variability signals and reducing overall information quality.

The SVH method shows potential as a more effective tool for analyzing biodiversity patterns in Arctic grasslands compared to NDVImax. This conclusion is supported by significant p-values, with PCs 1 & 2 demonstrating the highest t-value of 383.5, emphasizing the grasslands difference in spectral variation and thus their species diversity. Additionally, combining SVH and NDVImax methods can provide a more comprehensive understanding of vegetation: SVH can indicate vegetation diversity, while NDVImax can show vegetation vigor and identify vegetated versus non-vegetated areas.

Overall, the necessity of refined spectral analysis techniques to better understand and preserve biodiversity in sensitive ecosystems is important for future biodiversity monitoring. Here, the SVH presents a promising approach for monitoring biodiversity in Arctic grasslands.

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Generative AI tools have been used in this report to give suggestions on how to formulate certain sections, these have, however, been significantly re-written afterwards. Additionally, it has been used as a helping hand during the analysis.

Appendix 1

The NDVImax was found using the raster calculator in four steps using the following code:

i. maxNDVI_1 = Con(NDVI_jul01 > NDVI_jul09, NDVI_jul01, NDVI_jul09)
ii. maxNDVI_2 = Con(maxNDVI_1> NDVI_jul31, maxNDVI_1, NDVI_jul31)
iii. maxNDVI_3 = Con(maxNDVI_2> NDVI_aug17, maxNDVI_2, NDVI_aug17)
iv. maxNDVI_4 = Con(maxNDVI_3> NDVI_aug27, maxNDVI_3, NDVI_aug27)

Appendix 2

The variation of NDVImax values is displayed in Fig. A containing all bins for NDVI-values.

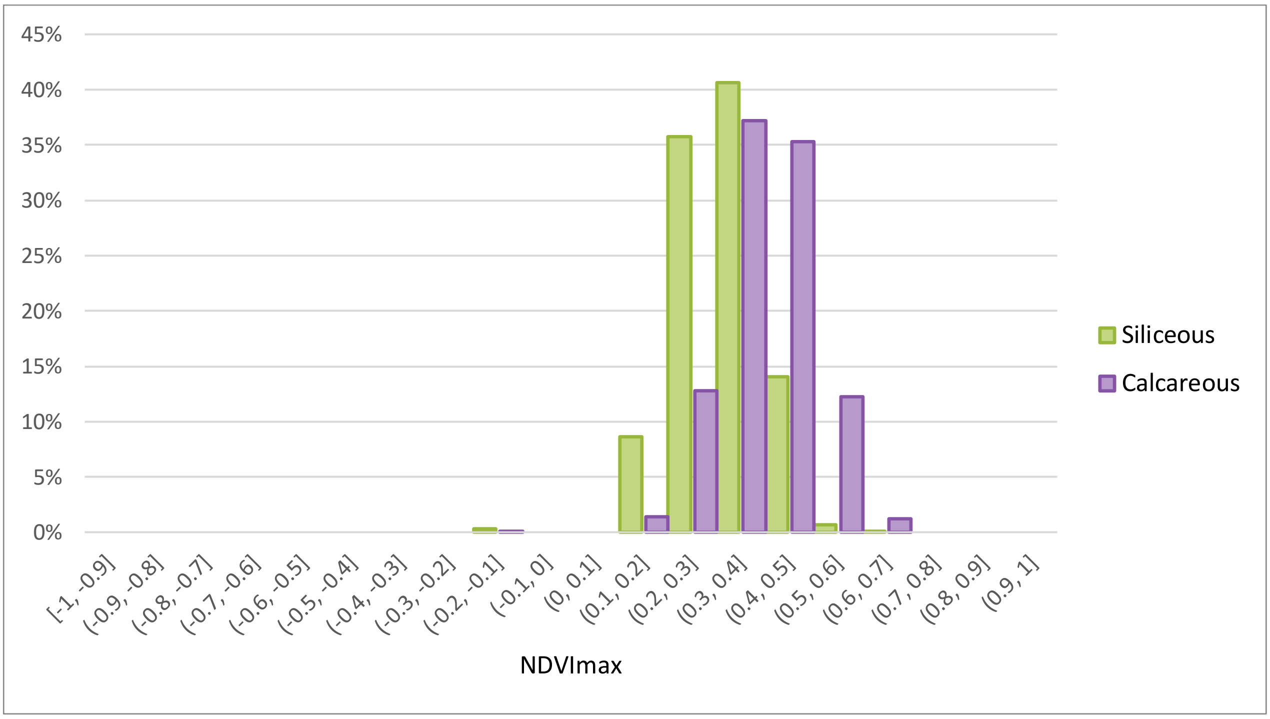

Figure A. Variation of NDVImax values. Calcareous grassland habitat is visualized in purple and siliceous in green. The bars represents an interval of 0.1 NDVImax values where each bar is a visualization of the percentage of the number of pixels within each interval.