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A case study of a natural habitat for Gymnadenia nigra in Vålådalen, Jämtland, using remote sensing and GIS

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Abstract

Since the early 20th century, changes of agricultural practices in Sweden have led to an increased competition from more dominant species in the old forage meadows. As a result, populations of the orchid *Gymnadenia nigra* (L.) Reichb.f. (*G. nigra*), have decreased significantly. It has also been discussed whether the climatic changes have had an impact on *G. nigra* due to a greening in northern latitudes. Today, *G. nigra* is an endangered species, its populations are decreasing and finding possible future habitat for it is therefore of great importance. By using remote sensing techniques, parameters such as Normalized Difference Vegetation Index (NDVI) can be calculated, which is based on the spectral response of vegetation. NDVI is widely used in vegetation studies analyzing biomass productivity and density, whereby it can act as an indicator for a greening or browning of vegetation. Furthermore, by using Geographical Information Systems (GIS) techniques, conditions such as slope, elevation, topographic wetness index (TWI) and aspect can be derived from a Digital Elevation Model (DEM). This report will use the techniques of remote sensing and GIS to 1) analyze the vegetation changes, 2) create a habitat profile based on prevailing conditions of *G. nigra* locales in Vålådalen, Jämtland, Northern Sweden and 3) use this profile to conduct a Multi Criteria Analysis (MCA), based on the Analytical Hierarchy Profile (AHP) to identify possible future habitat in the valley, visualized in a suitability map. It is therefore both an analysis concerning *G. nigra* as well as an evaluation of the method.

I found that the number of flowers increased due to an increase in locales, especially since 2014, in Vålådalen. An increase has also occurred in NDVI, which contradicts the initial expectation that increased NDVI, representing increased competition, would negatively impact *G. nigra*. The results of the climatic impacts on *G. nigra* were somewhat ambiguous, however, the increased mean temperature coincides with the increase in NDVI between 1987 and 2019. It might, therefore, have had a positive impact on NDVI and hence cause a greening in the valley. Finally, the habitat profile created identified a large area suitable as possible future habitat for *G. nigra.* It was divided in three sub-areas: one in the North, one in the West and the largest in the central parts of the valley. The results also showed that existing locales were growing where suitability was high, which was not the case for an area where locales were excluded. Therefore, the method used and area found can be considered as valid.

Keywords: *Gymnadenia nigra*, Vålådalen, habitat, locales, Remote sensing, GIS, NDVI, DEM, MCA, suitability, habitat profile

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I would also like to thank the County Government of Jämtland for allowing me to study the inventoried locales of *Gymnadenia nigra* and Göran Dahl from the Botanical Association of Jämtland who assisted me in answering questions and providing additional information about the locales in Vålådalen.

List of abbreviations

AHP – Analytical Hierarchy Process

DEM – Digital Elevation Model

GDD – Growing Degree Days

GIS – Geographic Information System

MCA – Multi Criteria Analysis

MMU – Minimum Mapping Unit

NDVI – Normalized Difference Vegetation Index

NIR – Near Infrared

RSD – Relative Standard Deviation

SOS – Start of Season

SWI – Saga Wetness Index

TWI – Topographic Wetness Index

WO – Weighted Overlay

Contents

1. INTRODUCTION

According to the IPCC (2019), anthropogenic factors have caused temperatures to increase, especially in Northern latitudes. Due to a warmer climate, a vegetation greening has been observed in large parts of the world during the last three decades (Jia, G., et al., 2019), meaning that vegetation cover and biomass productivity have increased and migrated to higher altitudes (Hedensås, et al., 2012; Kullman, L., 2010). In Northern latitudes, an effect of such greening could lead to an increase in taller vegetation, such as shrubs, which would reduce snow albedo causing temperatures to further increase. As a result, such a positive feedback loop could further increase greening and favor taller and hardier species (Druel, et al., 2019; Loranty, M., & Goetz, S., 2012; Constible, J. M., et al., 2008).

During the 20th century in Scandinavia there was a shift in agricultural practices, from family tradition forage to large scale cultivation. This changed how we use meadows and pasture, mainly by increasing ploughing but also by replacing small-scale forage with large-scale grazing and increasing the use of manure. As a result, this altered the growth conditions for plants where some suffered from overgrazing, others by overgrowing of more dominant species and some of the higher phosphate concentrations due to increased manure (Moen, A., & Øien, D., 2002). For the orchid *Gymnadenia nigra (G. nigra),* these changes led to less favorable conditions in its habitat but also in an increased competition from taller and hardy grass species, causing the population to drastically decline. This is the major reasons to why it is today listed as an endangered species (Naturvårdsverket, 2013., Moen, A., & Øien, D., 2002). Therefore, studies have been conducted in how to preserve the species, e.g. "Aktion Brunkulla" between 1980 – 2005, which analyzed maintenance, distribution, ecology and populations (Björkbäck, F., & Lundqvist, J., 2005) and also the "Åtgärdsprogram för Brunkulla, 2013-2017" by Naturvårdsverket (2013) which further investigated the causes of decline and future scenarios and actions necessary. One of the conclusions by Naturvårdsverket (2013) is that possible impacts of climate change is of minor importance for *G. nigras* survival (Naturvårdsverket, 2013). They do, however, conclude that increased temperatures could lead to locales being overgrown by other species. Overgrowing is also considered as a possible threat for *G. nigras* survival in a study by Moen, A., & Øien, D., (2002), which conducted a site-specific population dynamics research in Sølandet, Norway (Moen, A., & Øien, D., 2002). Still, remote sensing has so far not been used to identify habitat characteristics useful for the species future potential habitats.

G. nigra is the county flower of Jämtland in central Sweden (Fig. 1) and is endemic for Scandinavia. Its habitats are concentrated in the boreal and low alpine regions, i.e. the central and northern parts of Sweden and Norway. However, populations in the southern parts of the boreal regions have been decreasing during the last century (Moen, A., & Øien, D., 2002). It is also a species sensitive to drier conditions, therefore the vicinity to bogs and streams is of importance (Naturvårdsverket, 2013). Further, it prefers the former forage meadows where haymaking and grazing used to limit the competition from more dominant species (Moen, A., & Øien, D., 2002).

In "Aktion Brunkulla", Björkbäck, F., & Lundqvist, J., (2005) suggests that characterizing a *G. nigra* habitat based on ecology is complicated due to large variations in vegetation between different locales, however, low vegetation is still a dominant characteristic. They also conclude that, in contrast to previous research, *G. nigra* is not dependent on calcareous rich soil and that the type of soil can vary greatly. Each habitat should therefore be analyzed by the conditions that prevails in the specific area of interest (Björkbäck, F., & Lundqvist, J., 2005).

Figure 1. Photo of Gymnadenia nigra (Hedrén, M., Lorenz, R., & Ståhlberg, D. 2018).

Remote sensing can be defined as the "...observation of the Earth's land and water surfaces by means of reflected or emitted electromagnetic energy" (Campbell, J., 2011). It is therefore a useful tool within many fields such as ecology, forestry, and geography since data about the landscape can be gathered over larger areas over time, and there is a spatial dimension to the analysis. Additionally, since e.g. satellites can be programmed to pass over the same spot on earth on a regular basis, they provide a temporal dimension to remote sensing (Reese, H., and Olsson, H., 2018). Finally, another important dimension in remote sensing is the spectral dimension, where different objects have spectral signatures defined by the amount radiation emitted, reflected, and absorbed. As an example, chlorophyll in vegetation absorbs more blue and red light, and therefore vegetation appears green to our eyes (Reese, H., and Olsson, H., 2018; Campbell, J., 2011). Since these spectral signatures can be acquired by a sensor mounted on e.g. a satellite, they can later be applied in spatial and temporal analyses and has therefore been proved useful in studying vegetation (Cohen W. & Goward, S., 2004).

By using remote sensing, images also provide spectral responses outside the visible spectrum, such as near infrared (NIR), in which peak reflectance occurs for living vegetation. (Fig. 2) (Campbell, J., 2011).

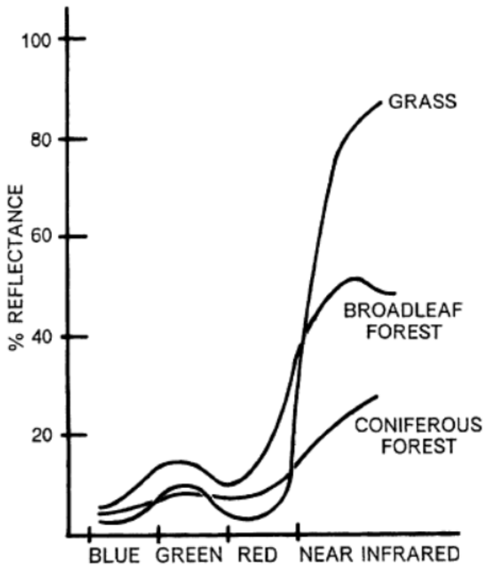

Figure 2. Reflectance from various vegetation in the visible spectrum (Red, Green, Blue) and in the near infrared (Campbell, J., 2011).

Based on the ratio between Red (R) and Near infrared (NIR), reflection of vegetation can be calculated which results in an index defined as Normalized Difference Vegetation Index (NDVI) that ranges between -1 and 1. Since vegetation absorbs red and blue light and reflects near infrared, NDVI will be high for living vegetation and the opposite for non-vegetated surfaces and dead or stressed plants. NDVI is therefore a useful tool when studying e.g. biomass productivity of plants or the density of vegetation (Campbell, J., 2011; Rouse Jr, J. W., et al., 1973; Sweet, S., et al., 2015). Additionally, Digital Elevation Models (DEM) are also common in remote sensing since they provide topographic information about the landscape. By using a DEM, information such as elevation, degree of slope, topographic wetness index (TWI) and aspect can be calculated using a GIS software (Florinsky, I., 2016; Jalayer, F., et al., 2014; Böhner, J., & Selige, T., 2006). These are all valuable inputs for determining suitable habitats for vegetation and have therefore been considered in this report (Store, R., & Kangas, J. 2001).

The aim of this report is to detect changes in the conditions of a *G. nigra* habitat in the area around Vålådalen, Jämtland, since 1987, using remote sensing. It will also search for prevailing conditions of where *G. nigra* thrives. Additionally, it will be investigated whether Geographic Information System (GIS) modelling can identify possible future habitats in other areas. Specific questions:

- Has the Normalized Difference Vegetation Index (NDVI) in Vålådalen increased during the last three decades?
- Can parameters for a suitable habitat be determined based on NDVI, topographic information, vegetation- and soil type, of current *G. nigra* locales?
- Based on the results, are there other areas suitable for *G. nigra* and can they be detected using GIS?

2. Method

The two families *Gymnadenia* and *Nigritella* are closely related (Hedrén, M., et al, 2018) and has both been used for the subspecies *nigra* in previous studies (Moen, A., & Øien, D., 2002; Naturvårdsverket, 2013, Hedrén, M., et al, 2018; Mossberg, B., & Ærenlund Pedersen, H., 2017). However, the Swedish Species Information Centre (SLU (1), 2020) has named it *Gymnadenia* and it will therefore be the name used in this report.

The climate data was prepared using ©Matlab R2020a, in which most of the figures throughout the report was created as well. The GIS software ©ArcMap 10.7.1 was used For *G. nigra* areas, NDVI, DEM elevation derivates, Data value extraction and the Multi Criteria Analysis (MCA). The data analysis was mainly conducted using ©Microsoft Excel, in which most of the tables was created as well.

The report will first investigate the inventoried locales of *G. nigra* in Vålådalen, both over time and between the areas. Second, to identify possible vegetation changes, NDVI calculations will be conducted and investigated in a time-series analysis as well as between the different areas of *G. nigra* locales. This part will also include a two-date change detection based on NDVI calculations in 1987 and 2019. Third, to create parameters for a suitable habitat, NDVI, slope, TWI, elevation, and aspect for all areas will be compared to an area where *G. nigra* locales are excluded. Additionally, the prevailing vegetation cover on to which *G. nigra* grows will also be analyzed. The results will then be used in a Multi Criteria Analysis (MCA), searching for possible future habitats.

2.1 Study area

2.1.1 Vålådalen

Vålådalen is a nature reserve located in the western parts of the county of Jämtland, central Sweden. It is in a valley, with mountains providing moisture through runoff which will eventually end up in lakes North-Northeast of the nature reserve (Fig. 3). Located in the boreal region, its vegetation mainly consists of coniferous forest and shrubs, however with some deciduous trees, e.g. birch, as well. There are three types of soil in the valley: moraine, glaciofluvial sediments and peat (SGU, 2014). The soil is also calcareous rich which, together with the parameters previously mentioned, contribute to Vålådalen being a preferable habitat for *G. nigra* (Naturvårdsverket, 2013).

Figure 3. Overview (left) and location (right) of Vålådalen nature reserve (Lantmäteriet, 2010).

2.1.2 Climate

Vålådalen's climate is defined as Continental Subarctic Climate (Dfc) by the Köppen classification, however with a predicted shift towards Humid Continental Climate (Dfb) in the late 21st century (Beck, H., Zimmermann, N., McVicar, T. *et al.* 2018). Dfc is dominated by a long cold winter season with short, cool summers. Precipitation is overall low with most of it occurring during summer, while in winter, most precipitation is in the form of snow (Encyclopedia Britannica (1), 2016). A shift towards Dfb would mean increased spells of mild weather during winter and overall warmer summers (Encyclopedia Britannica (2), 2016).

2.2 Data

2.2.1 Inventory of *Gymnadenia nigra*

The location and inventory of *G. nigra* was provided by the county government of Jämtland in a point shape file, including number of flowers/locales, each year. This inventory has been conducted by both the County Government of Jämtland and Jämtlands Bothanical Association. The dataset includes inventory since early 1970, however, thorough inventory has been conducted since 1997. The inventory has also been conducted on various time of the year, so there might be errors in the dataset due to this reason. Finally, since *G. nigra* is an endangered species, preserving its existing locales is important. Therefore, the location of existing locales is classified (County Government of Jämtland, 2020) and they will either be included without any base map, or not included at all.

2.2.2 Landsat program and images used

The US Landsat program has had satellites in operation since 1972, it is therefore useful in studying changes of vegetation cover on a long-term basis. It also contains several bands of the solar electromagnetic spectrum useful in vegetation studies, such as the NIR (Cohen W. & Goward, S., 2004). Additionally, it produces images of the same spot on Earth every 16th day over a large area, providing all three important dimensions: spatial, temporal, and spectral.

The most prolonged program was Landsat 5, operating between 1984 – 2011, containing eight bands between 15 – 30 m resolution. Today, Landsat 8 is in operation, it contains eleven bands between 15 – 100 m resolution (Table 1) and with an improved scanner allowing for images with a higher radiometric resolution (Reese, H., and Olsson, H., 2018).

Table 1. An overview of all satellites in the Landsat program (Reese, H., and Olsson, H., 2018; USGS, 2020).

Satellite	Launched	Decomissioned	Main sensor	Bands and Pixel sizes
Landsat 1	1972	1978	MSS	4 bands with 80 m pixels
Landsat 2	1975	1982	MSS	
Landsat 3	1978	1983	MSS	
Landsat 4	1982	2001	TM	6 bands with 30 m pixels + one 15 m panchromatic + one thermal band
Landsat 5	1984	2013	TM	
Landsat 6	1993	1993	ETM	
Landsat 7	1999	2003	ETM+	
Landsat 8	2013	Still in operation	OLI	8 bands with 30 m pixels + one 15 m panchromatic + two thermal bands with 100 m pixels

In this report, a time series of the past three decades has been investigated using satellite images from the Landsat program 5 and 8, which were obtained from United States Geological Survey's (USGS) EarthExplorer website. Both Landsat 5 and 8 programs have 30m resolution for the bands used in this report, however the Landsat 8 has a higher radiometric resolution than Landsat 5 (Table 2).

Table 2. Wavelength ranges and resolution of the different bands in the Landsat programs 5 & 8 (USGS, 2020).

Band	Landsat 5 Wavelength (µm)	Landsat 8 Wavelength (µm)	Resolution (m)
Blue	0.45 – 0.52	0.45 – 0.51	30
Green	0.52 – 0.60	0.53 – 0.59	30
Red	0.63 – 0.69	0.64 - 0.67	30
Near Infrared (NIR)	0.76 – 0.90	0.85 – 0.88	30

Since peak greenness usually occurs in the shift between July and August (Walther, S. et al, 2016), images taken between the 20th of July – 7th of August were the initial search criteria. However, the Landsat images are only taken every 16th day and since the images needs to exclude cloud cover, only five images (1987, 1995, 2007, 2018 and 2019) were found. Therefore, Growing Degree Days (GDD) was included, which is a method used to determine whether the growing season has started or not (Eq. 1) (Fu, Y., et al, 2014).

Equation 1.

$$SOS = \sum_{t135}^{GDD} (T_{mean} - T_{base})\ if\ T_{mean} > T_{base}$$

Where t135 are the temperatures post the 15th of May (day 135), Tmean the daily mean temperature and Tbase the temperature needed for plant growth (Fu, Y., et al, 2014; Henry, G., & Molau, U., 1997). Further, in the region where Vålådalen is located, T_{base} has been set to 5°C by the International Tundra Experiment (ITEX) (Henry, G., & Molau, U., 1997). Additionally, in the study by Fu, Y., et al, (2014), they conclude that in the northern hemisphere, an accumulated GDD of 85.2°C indicates the start of growing season in boreal needleleaf forest, and will therefore be used as a threshold for SOS. As a result of including the input of GDD, the years of 1997, 2003 and 2015, with images taken on the 9th, 10th and 11th of July, respectively could be included in the analysis (Table 3).

Table 3. Year and date for SOS based on an accumulated GDD of 85.2°C for each of the Landsat images used for NDVI (SMHI, 2020; USGS, 2020).

Year	SOS	Image	Landsat
1987	23-jun	21-jul	5
1995	08-jun	27-jul	5
1997	12-jun	09-jul	5
2003	04-jun	10-jul	5
2007	04-jun	06-aug	5
2015	28-jun	11-jul	8
2018	26-maj	26-jul	8
2019	06-jun	29-jul	8

2.2.3 Vegetation cover, soil type and derivates from DEM

The inputs of vegetation and derivatives from DEM such as slope, TWI, elevation, and aspect has also been considered in the analysis. These have been collected from Lantmäteriet and the Geological Survey of Sweden (SGU) through the University of Agricultures (SLU) Geodata Extraction Tool.

The actuality for vegetation data were between 1980 – 1998 and has a Minimum Mapping Unit (MMU) of three ha. The photos used have been taken during vegetation season, i.e. June, July, and August or in the beginning of September. It has initially been mapped using manual interpretation in stereo aerial photos, with a complimenting in-field confirmation to increase the quality of the dataset. The vegetation data also included an accuracy for each vegetation cover, based on the experience in each mapping group, and has been concluded as Medium for deciduous forest and High for remaining parameters used in this report. (Lantmäteriet, 2008).

Unfortunately, the resolution of the soil type data was too coarse and was therefore excluded in the MCA. It was, however, still used in the report to analyze prevailing soil type on to which existing locales have been found.

Finally, the DEM has a resolution of 2m and was created using laser scanning in a nationwide coverage project in 2010 (Lantmäteriet, 2019).

2.2.4 Climate

The climate data such as precipitation and temperature have been collected from the Swedish Meteorological and Hydrological Institute (SMHI). Temperature data included mean daily temperature and precipitation included monthly averages, both ranging between 1963 – 2019 from Höglekaredalen, which is located 40 km east of Vålådalen, however with similar climate and on similar altitude (SMHI, 2020).

2.3 Data preparation

2.3.1 Temperature and precipitation

For temperature and precipitation, annual averages were calculated and used in a time series analysis between 1963 – 2019. Further, monthly averages were used and calculated for a seasonal analysis, divided into two time periods, 1963 – 1986 and 1987 – 2019, for comparing climate past and prior to the period of analysis.

2.3.2 *Gymnadenia nigra* areas

Step 1 in preparing *G. nigra* areas included a visual analysis of existing locales. In *step 2*, existing *G. nigra* locales were divided up by areas of clustered locales, onto which a buffer of 100 m surrounding each point was added, resulting in a NW, North, NE, East, SSE and South area of locales. In *step 3,* to include areas where no *G. nigra* locale existed in the analysis, a buffer was created ranging between 100 – 300 m away from the buffered points of locales. Finally, in *step 4,* 600 randomly distributed points were created in this area using Create Random Points tool. The amount was based on the number of *G. nigra* points/buffered area, i.e. there were around 300 *G. nigra* points buffered by 100 m and 600 points with no *G. nigra* buffered by 200 m (Fig. 4).

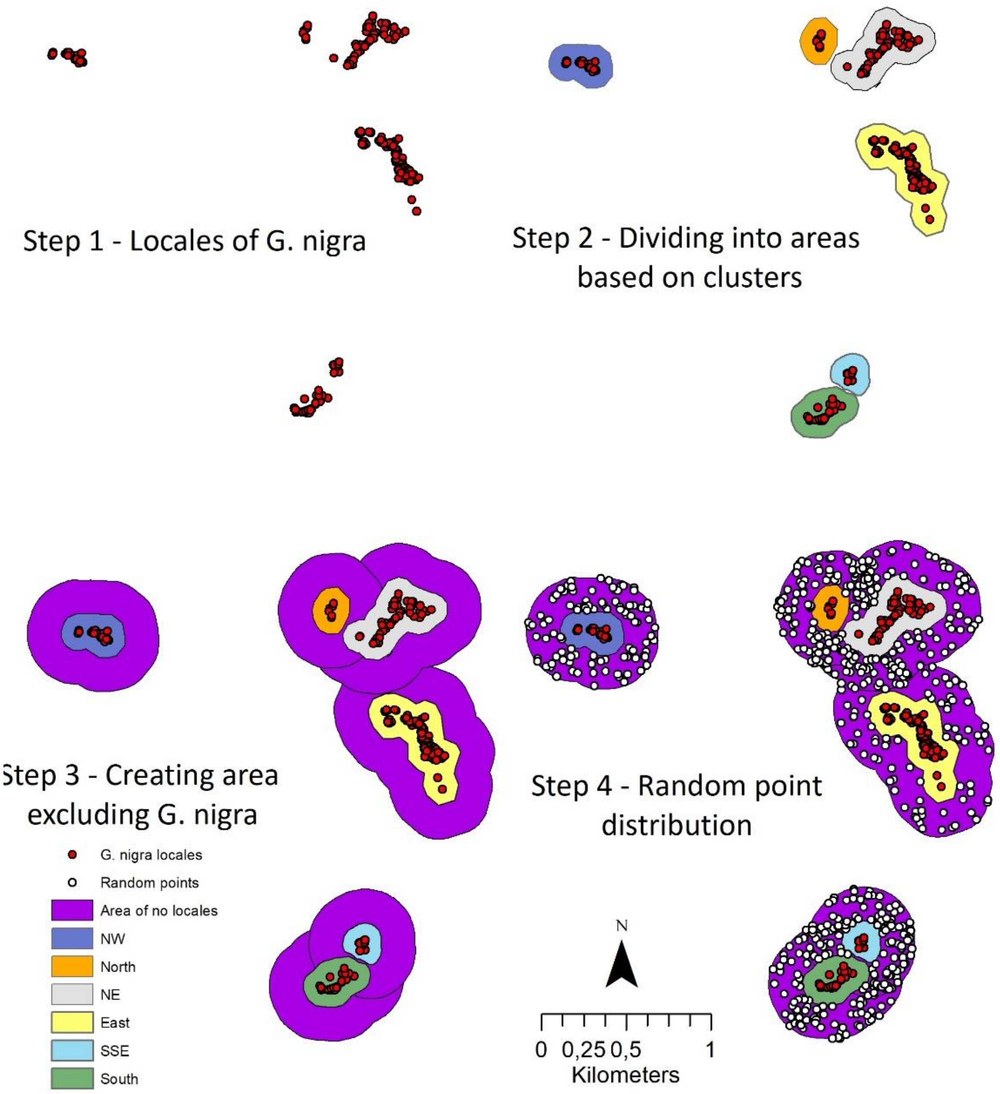

Figure 4. Workflow of defining and dividing the different areas (County Government of Jämtland, 2020).

The division of *G. nigra* resulted with two minor areas, the Northern and SSE, with 2% and 4% of the total locales, respectively. There were also two medium areas, NW and South, with 14% and 12% respectively, one intermediate area, NE, with 25% and the largest area, East, which included 42% of the total locales (Table 4).

Table 4. Number, and percent, of locales/area (County Government of Jämtland, 2020).

Area	Nr of locales	% of all areas
East	125	42
NE	74	25
NW	42	14
South	36	12
SSE	13	4
North	6	2
All areas	297	-

2.4.3 NDVI creation

The calculations for NDVI were conducted using Raster Calculator (Ec. 2), based on the Landsat images collected.

Equation 2. Calculations for NDVI, based on the ratio between the NIR and Red wavelengths, resulting in a value between -1 and 1.

$$NDVI = \frac{NIR - R}{NIR + R}$$

The Landsat 8 (2015, 2018 and 2019) images included some negative valued pixels and were therefore reclassified to 0, since no reflection is negative, and were then used for NDVI calculations. The NDVI ranges between -1 and 1, where living vegetation will result in higher values.

2.3.4 DEM derivates

Based on the DEM, slope, aspect, and elevation were calculated. Further, the TWI was calculated based on slope, which has been proved to be a valid method for hydrological factors (R. Sørensen, U. Zinko, J. Seibert, 2005). It usually ranges between -3 and 30 where a higher value indicates an area where water is more likely to accumulate (Ballerine, C., 2017). The TWI was calculated in the open source program © Saga and will, therefore, further be defined as Saga Wetness Index (SWI).

2.3.5 Data value extraction

NDVI, slope, elevation, aspect, SWI, values were extracted for each point of including and excluding *G. nigra* locale, using Sample. This resulted in several area-based sample files: “NW”, “North”, “NE”, “East”, “SSE”, “South”, “All areas” and “Area excluding *G. nigra*” Since the files containing vegetation and soil type in vector format, they first had to be transformed into raster files using Feature to Raster tool, before conducting a Sample, since sample demands the input of raster values.

2.4 Data analysis

2.4.1 *Gymnadenia nigra*

The total count of *G. nigra* flowers during the entire time-period were also divided up between the areas NW, North, NE, East, SSE, South and one for All areas (Fig. 4). For each area, the count of flowers/year was summarized and analyzed together with the years where NDVI was available. Therefore, in this analysis, two years of inventoried flowers were excluded, 1975 and 1976, together with NDVI in 1987.

2.4.2 Inputs

For NDVI, slope, elevation, aspect and SWI mean, standard deviation, relative standard deviation (RSD) and confidence interval (CI) was calculated. Standard deviation was used to calculate RSD and CI, while RSD itself was used for the relative weighting between each input. The mean +/- CI was used to investigate the statistical significance in relation to the areas both including and excluding the presence of *G. nigra*, between each input.

2.5 Multi Criteria Analysis

The Multi Criteria Analysis (MCA) followed five steps based on the article *"Implementation of the analytical hierarchy process (AHP) with VBA in ArcGIS"* by Oswald, M. (2004). The steps have been adjusted to fit this report and with the addition of Relative Standard Deviation (RSD) to determine the relative preference between each input.

1. Identifying possible inputs for the MCA
2. Classification of each input
3. Creating a preference matrix for the possible inputs
4. Calculations for each inputs weight
5. Conducting the MCA based on previous steps

Identifying possible inputs for the MCA – Besides vegetation cover, if the mean for NDVI, slope, elevation, aspect or SWI in the area including *G. nigra* were statistically significant different from the area excluding *G. nigra*, it was used as an input in WO.

Classification of each input – The reclassification was conducted to assign more preferred parameters higher weight, with the most preferable parameter assigned 10 and then in falling order. Mean +/- CI was considered as the most preferable parameter, after that the 25^{th} and 75^{th} percentile distribution range, followed by the outer range and, finally, with the outliers as the lowest preferred parameter (Table 5). Vegetation, however, were weighted based on the most frequently occurring type the locales were located on.

Table 5. Template for the input reclassification procedure.

Class and weight	Input values	Parameter
10	A – A	Mean +/-CI
9	B – B	25th percentile - CI
8	C – C	CI - 75th percentile
7	D – D	Lower range - 25th percentile
6	E – E	75th percentile - Higher range
5	F – F	Higher range - Highest outlier
4	G - G	Lowest outlier - Lower range
0/Restricted	H – H	Lowest value - Lowest outlier
0/Restricted	I - I	Highest outlier - Highest value

Creating a preference matrix for the possible inputs - Each possible input's weight ratio (i.e. relative preference) had to be determined. Therefore, each datasets Relative Standard Deviation (RSD) was calculated, based on which they were given a scaled value of importance (Table 6). However, since vegetation cover being discrete values, its RSD could not be calculated. Therefore, its scaled value will be based on the interpretation from its results, i.e. how likely the results were.

Table 6. Scale value definition for each possible input (Oswald, M., 2004)

Intensity of importance	Description
1	Equal importance
3	Moderate importance of one factor over another
5	Strong or essential importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values
Reciprocals	Values for inverse comparison

Calculations for each inputs weight – The preference matrix was created by dividing each input's scaled value with each other (Eq. 3) a preference matrix was created. The AHP tool then calculated the weight for each input, based on the eigenvectors and eigenvalues from the preference matrix, returning a value between 0 and 1 which was then calculated into percent (Oswald, M., 2004).

Equation 3. Calculations between each input's scale value to determine their preference value.

$$If\ \frac{Input_x}{Input_y} = 1, equal\ importance$$

$$If\ \frac{Input_x}{Input_y} > 1, Input_x\ has\ greater\ importance$$

$$If\ \frac{Input_x}{Input_y} < 1, Input_x\ has\ less\ importance$$

Conducting the MCA based on previous steps - Each input's weighted percent were then used in the WO tool as their weighted ratio. In the end, this resulted in a map of suitability, ranging between 1 and 10, with 10 being the most suitable.

Finally, since the location of existing locales is classified, their location could not be included graphically in the final MCA result. However, the suitability value for each point both including and excluding locales were extracted by Sample. Their mean +/- CI and distribution was then calculated and plotted for a comparison analysis.

3. Results

3.1 Changes in climate

The annual mean temperature has increased significantly since 1963. With the exception in 2010, the annual mean temperatures have not reached below 0°C since late 1980s. The region has also experienced an increase in precipitation until 2012 when it started to decrease, however still with higher minimums during the 21st century than during the late 20th century (Fig. 5).

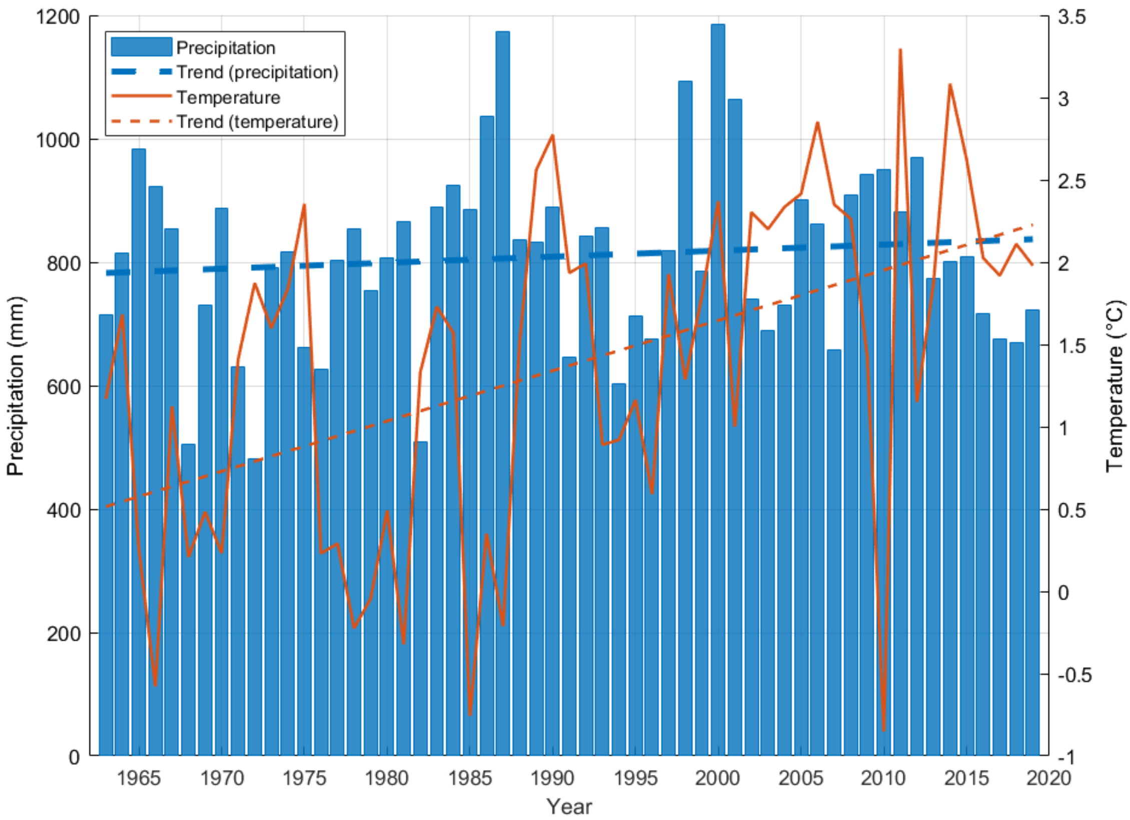

Figure 5. Cumulative annual precipitation and mean annual temperature between 1963 – 2019, including their trend calculations (SMHI, 2020).

Changes are also detectable when comparing seasonal climate between the period prior the analysis, 1963 – 1986, with the period of analysis, 1987 – 2018. During the period of analysis, temperature has increased in all months except May, June, and October. For precipitation, an increased has also occurred, especially in summer and late winter. Further, main precipitation in spring has shifted from April to May, while precipitation during autumn has rather decreased (Fig. 6).

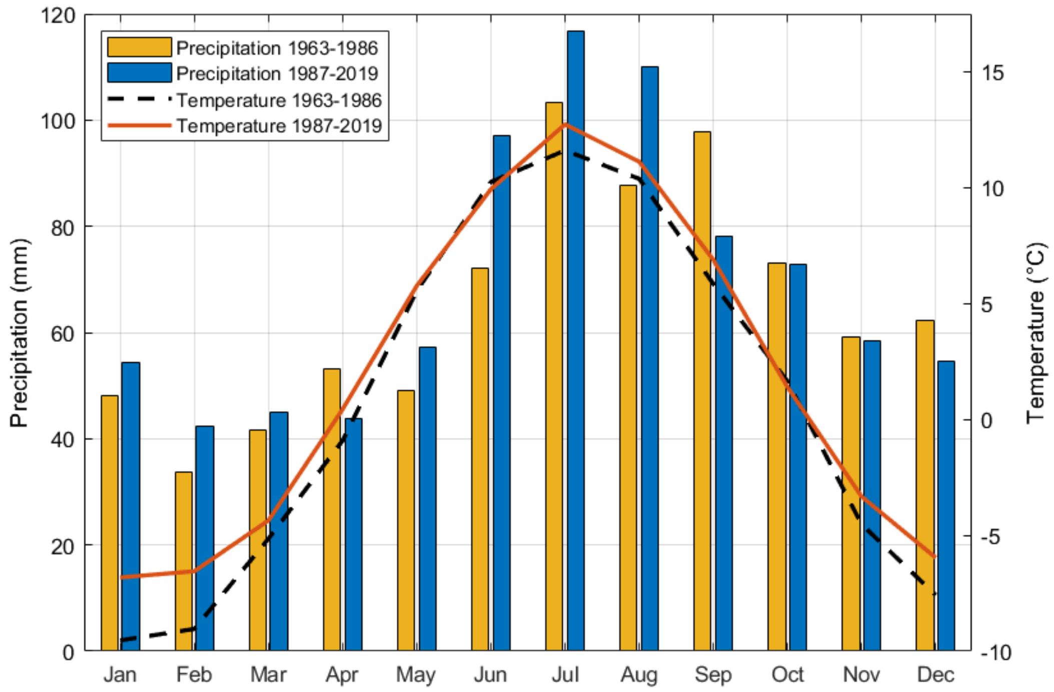

Figure 6. Seasonal analysis, comparing the monthly averages of precipitation and temperature, between the period before (1963 – 1986) and the period of analysis (1987-2019) (SMHI, 2020).

3.2 *Gymnadenia nigra*

The trend of total count of flowers resulted in a value of 14,08 for the slope of regression between 1994 and 2019 (Fig. 7). However, between 1994 and 2015, the trend was rather static (0,67 for the slope of regression) and it is mainly since then the increase have occurred (Fig. 8). Further, by looking at each area individually, NE is the only area containing a significant number of flowers until 2014, peaking in 2019 with 539 flowers. There is also an exception during the years of increase, 2018, when the count of flowers suddenly drops again (Fig. 9 & 10).

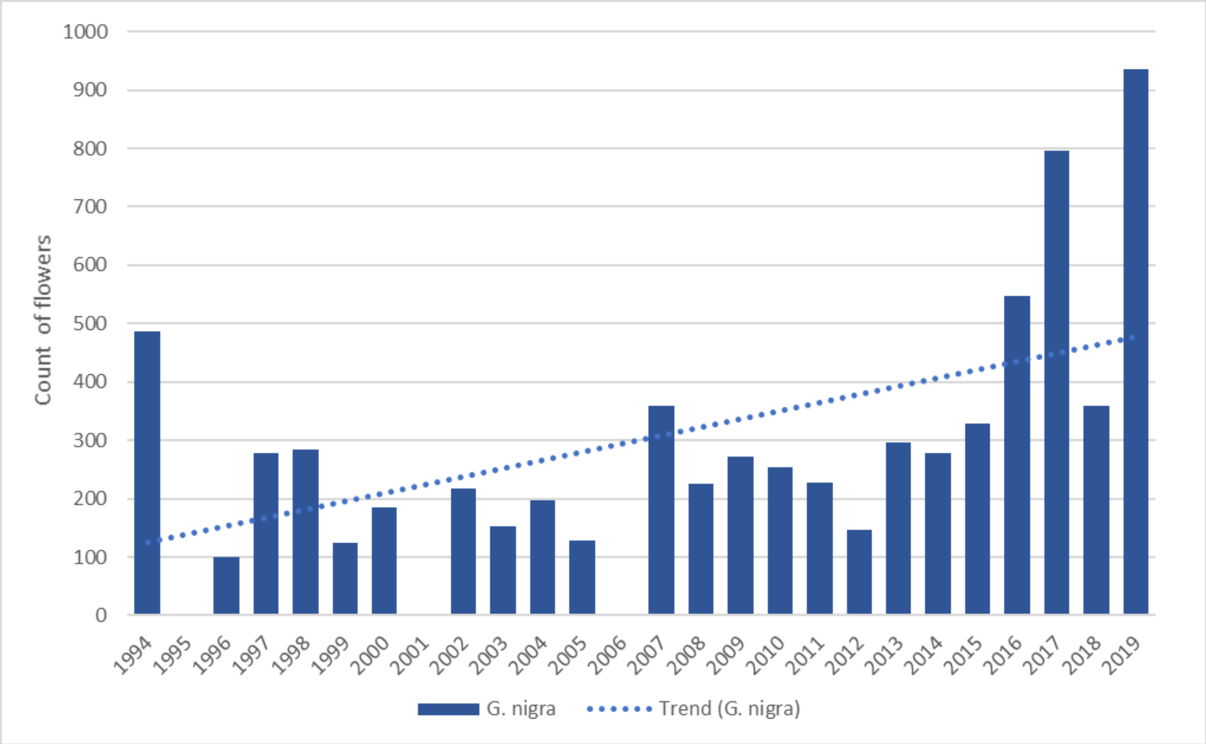

Figure 7. Number of flowers/years, including a calculation for its trend (County Government of Jämtland, 2020).

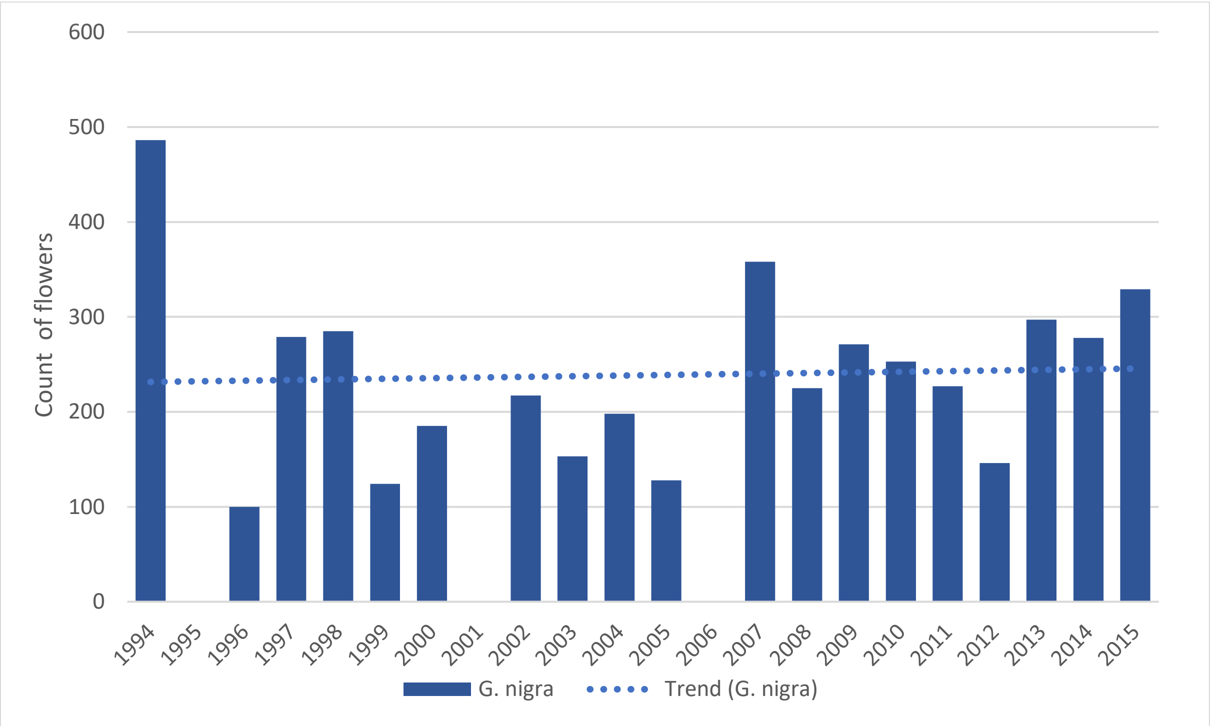

Figure 8. Number of flowers/years between 1994 and 2015, including a calculation for its trend (County Government of Jämtland, 2020).

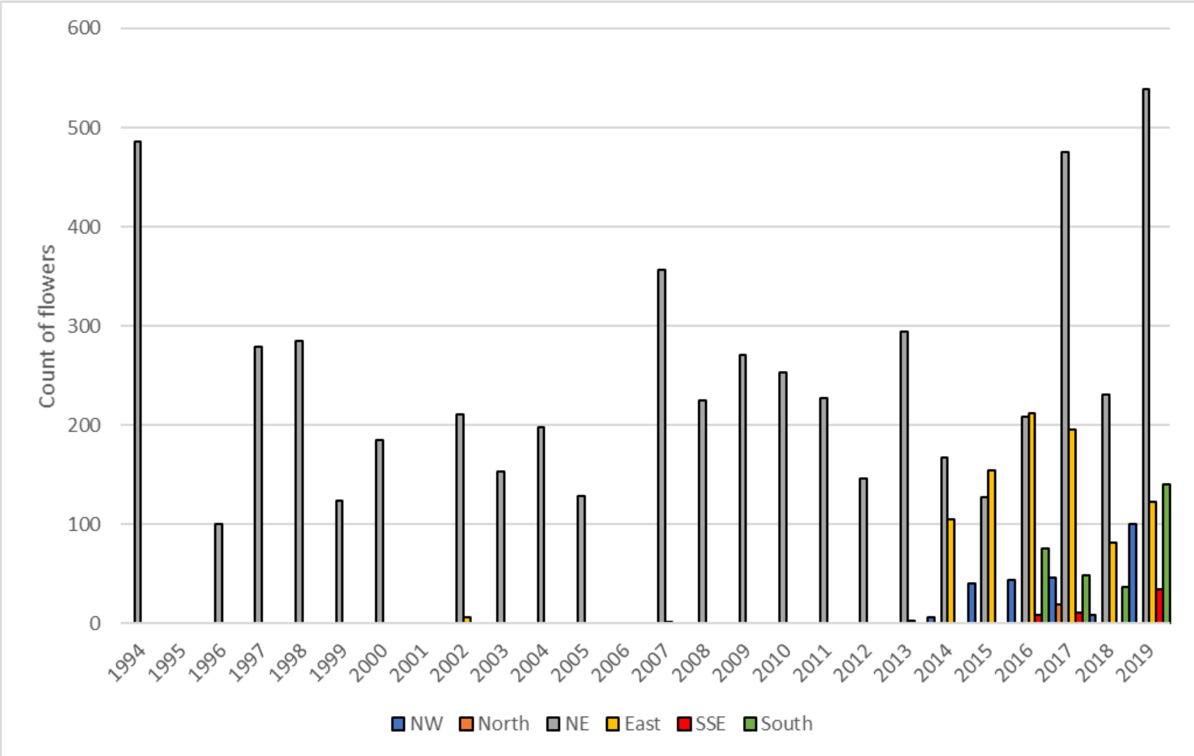

Figure 9. Number of flowers for each area since 1994 (County Government of Jämtland, 2020).

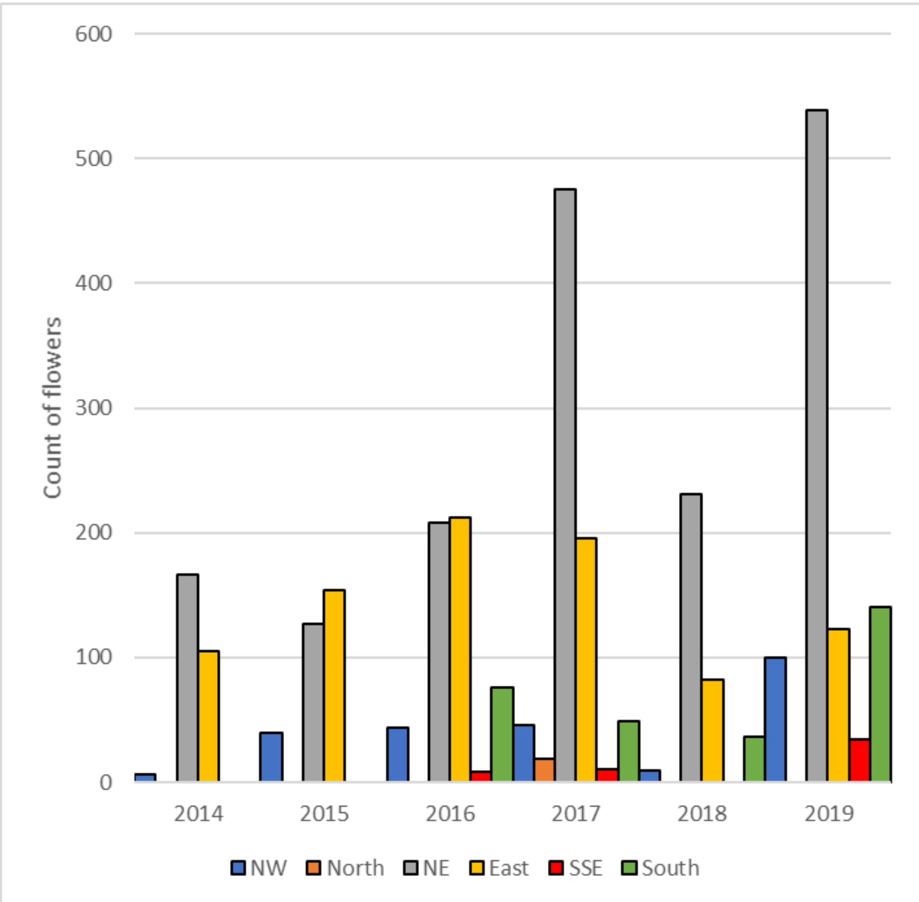

Figure 10. Number of flowers for each area since 2014 (County Government of Jämtland, 2020).

3.3 Normalized Difference Vegetation Index

3.3.1 Two-date change detection

The NDVI difference between 1987 and 2019 indicates that a greening has occurred in Vålådalen during the period of analysis, mostly in the Southwestern and Southeastern parts of the valley. Due to some cloud cover in 2019, there are a cluster of low NDVI in the southern parts, as a result they are detectable as a decrease in the difference between 1987 and 2019 (Fig. 11).

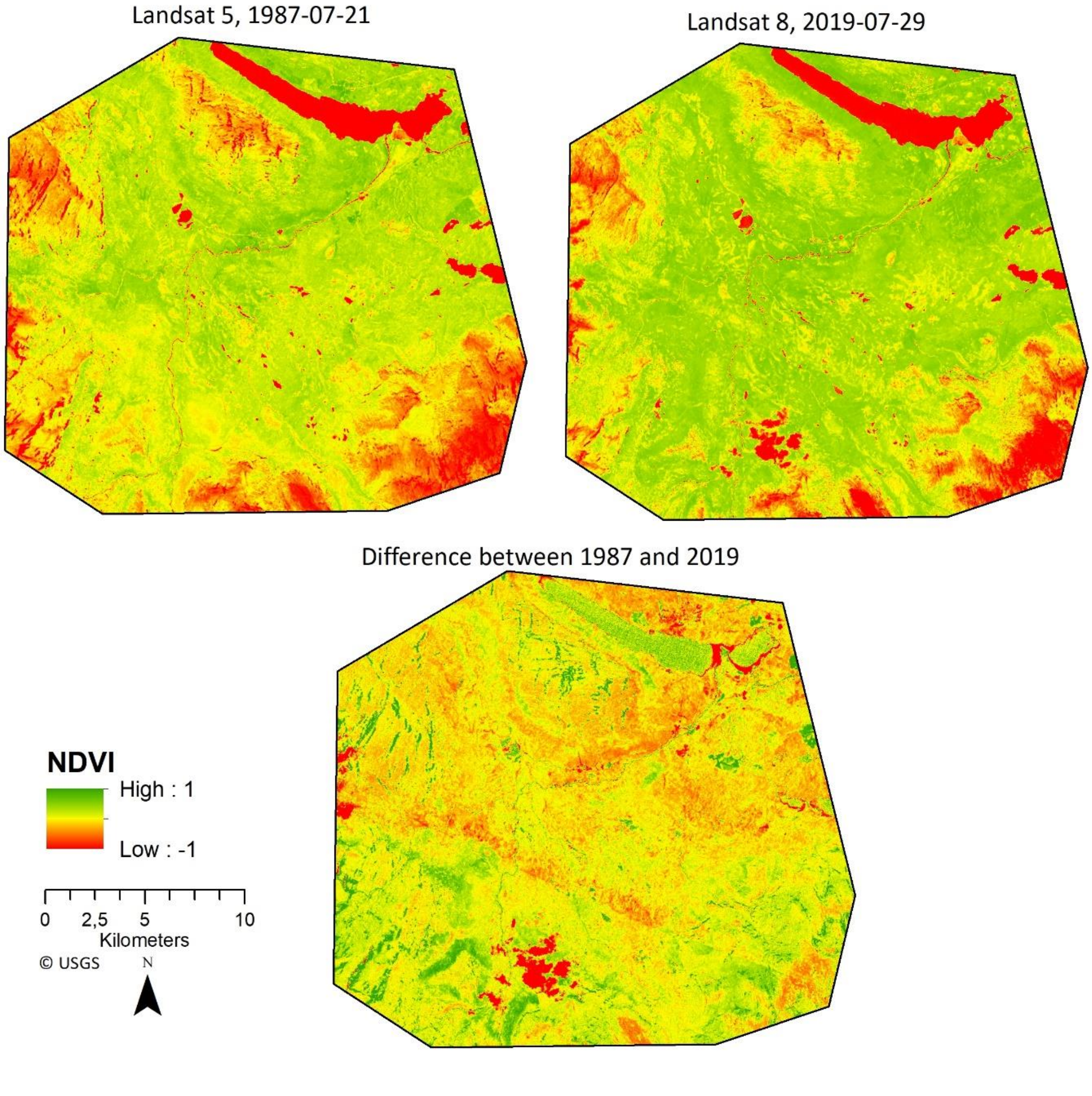

Figure 11. NDVI in Vålådalen for 1987 (top left) and 2019 (top right), including the difference between the two (bottom) (USGS, 2020).

3.3.2 Calculations for each Landsat image

The NDVI trend of all Landsat images resulted in a value of 0.16 for the slope of regression since 1994, this trend also coincides well with the positive trend of *G. nigra* flowers (Fig. 12).

Between 1987 and 2019, the mean NDVI in the area including *G. nigra* has increased from 0.48 to 0.76, with an exception in 1995, where the lowest NDVI (0.32) during the time-period was found. The area excluding *G. nigra* followed the same pattern, however with slightly higher NDVI in 2015 (Fig. 13). The mean +/- CI, however, resulted in a statistically non-significant difference between the area including *G. nigra* and the area excluding *G. nigra*, and NDVI will therefore not be used in the MCA.

There were several statistically significant increases in the area including *G. nigra*, the greatest occurred between 2003 and 2007 with an increase in NDVI from 0.49 to 0.70, and the latest between 2018 and 2019. In the area excluding *G. nigra*, the greatest change also occurred between 2003 and 2007. However, in the area excluding *G. nigra*, the next, and last, significant increase occurred between 2007 and 2015 (Fig 14).

Between the different areas, the Northern area had the highest NDVI values during the entire time-period, while two areas (SSE and NW) had below average. The remaining areas fluctuated around the overall average, with NE slightly higher (Appendix 1).

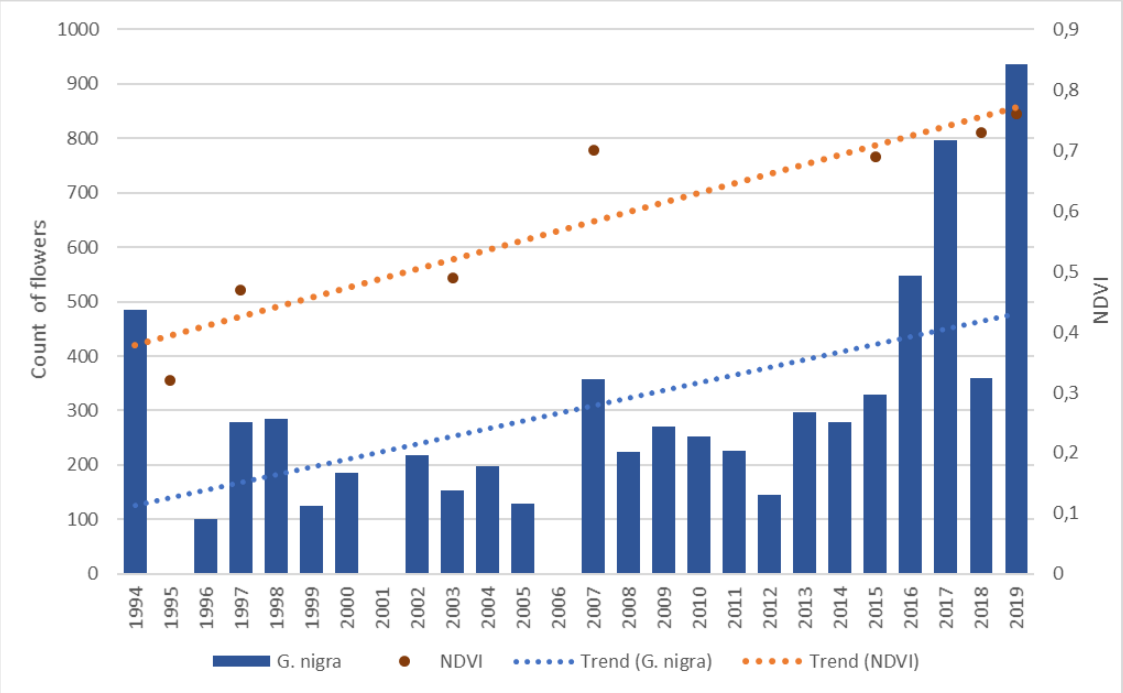

Figure 12. Number of flowers in all areas, with the inclusion of NDVI and calculations of trend for both inputs (County Government of Jämtland, 2020; USGS, 2020).

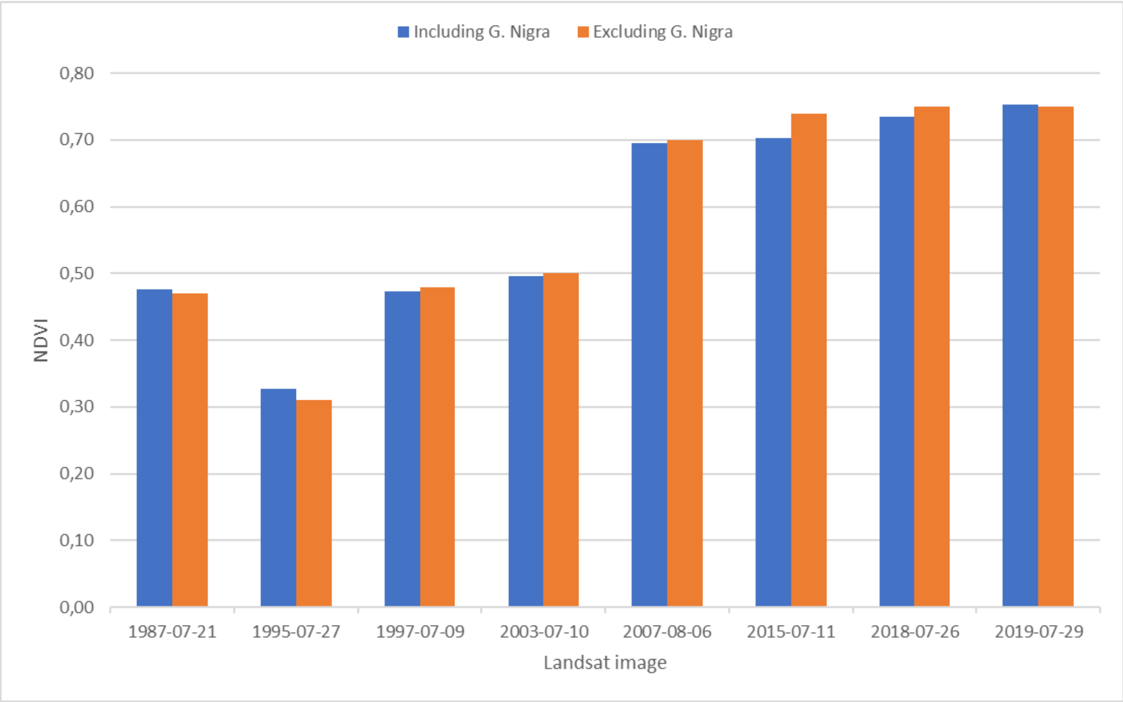

Figure 13. Mean NDVI in the areas including and excluding G. nigra. (USGS, 2020; County Governemtn of Jämtland, 2020)).

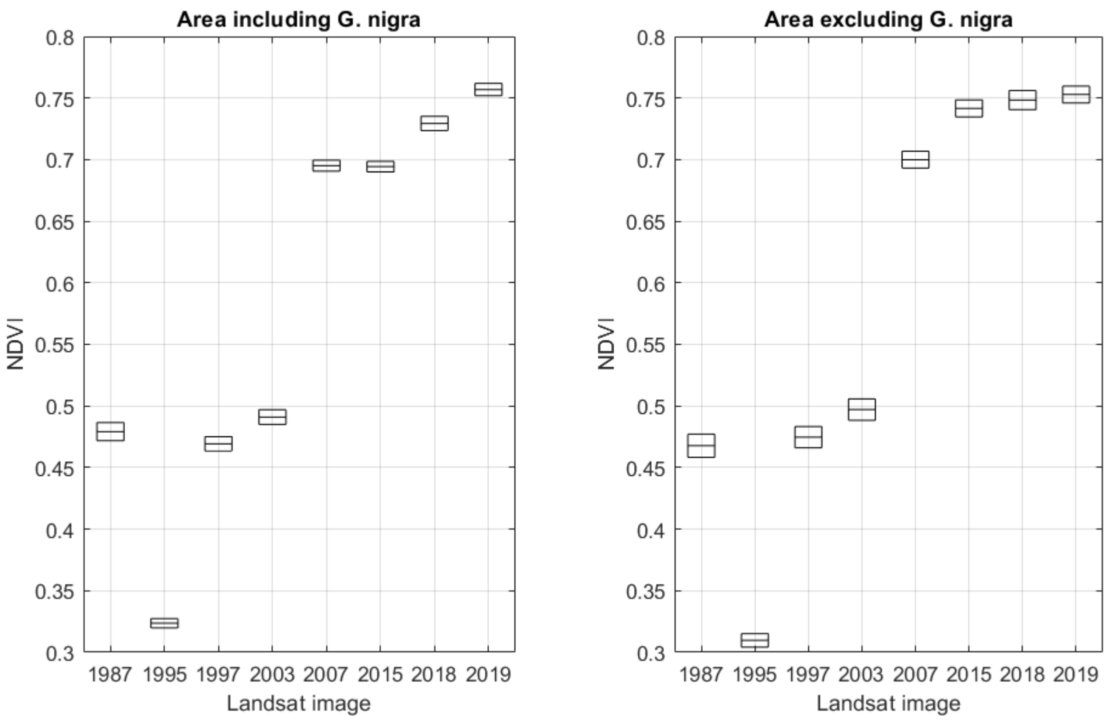

Figure 14. Mean +/- Cl (boxes) for the area including (left) and excluding (right) G. nigra for each year of the NDVI calculations (USGS, 2020; County Government of Jämtland, 2020).

3.3.3 Distribution

The range of NDVI values in the area including *G. nigra* varied from year to year, however, in 2019 there is a clear distinction from 2018 concerning the 25th – 75th percentile and with a more compact distribution. 1987 and 2018 resulted in the widest distribution range, while 1995 and 2015 resulted in the narrowest. The mean annual temperature has increased in the area, which is also the case for the NDVI (Fig. 15). The distribution of each individual area all followed a similar pattern (Appendix 2 - 7).

The area excluding *G. nigra* resulted in a lot of outliers below the 25th percentile, however with similar distribution (i.e. wideness between the 25th and 75th percentile) from year to year (Fig. 16).

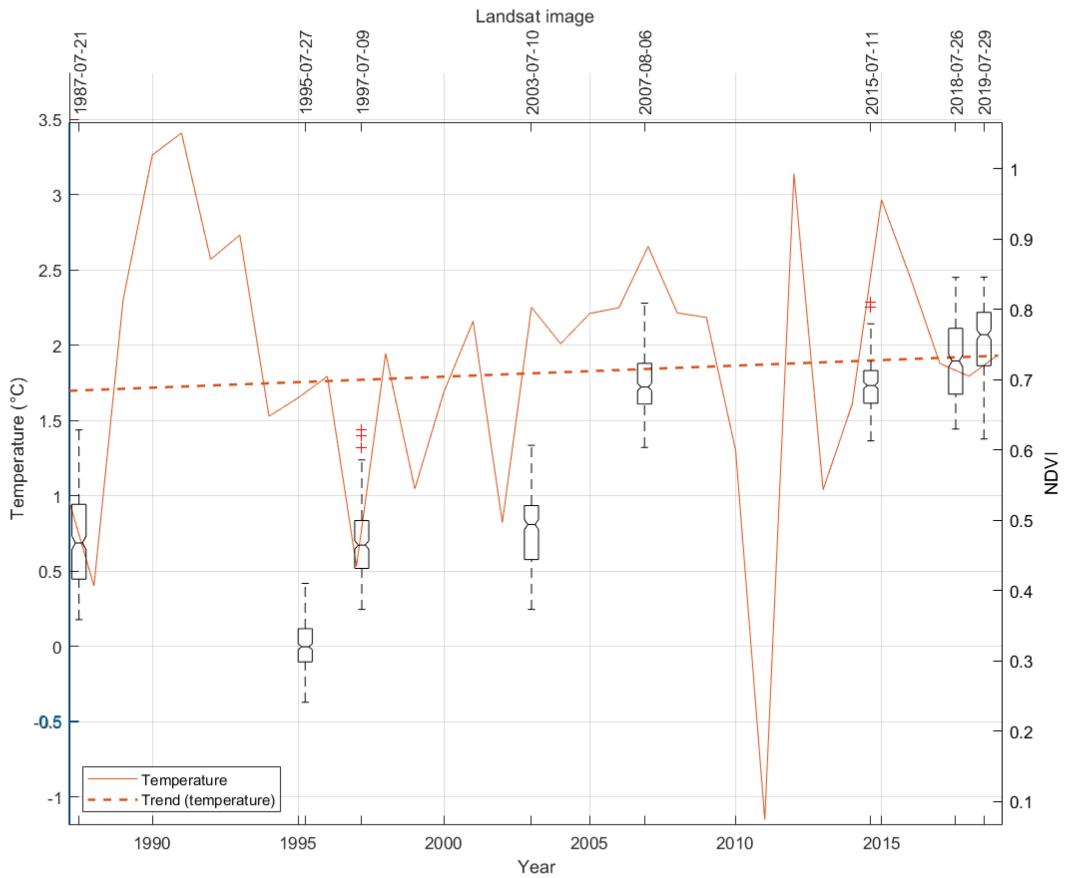

Figure 15. Boxplot showing distribution of NDVI in all areas including G. nigra, with mean annual temperature and its trend calculation. Lower – higher range (--), outliers (red cross) (USGS, 2020; SMHI, 2020; County Government of Jämtland, 2020)).

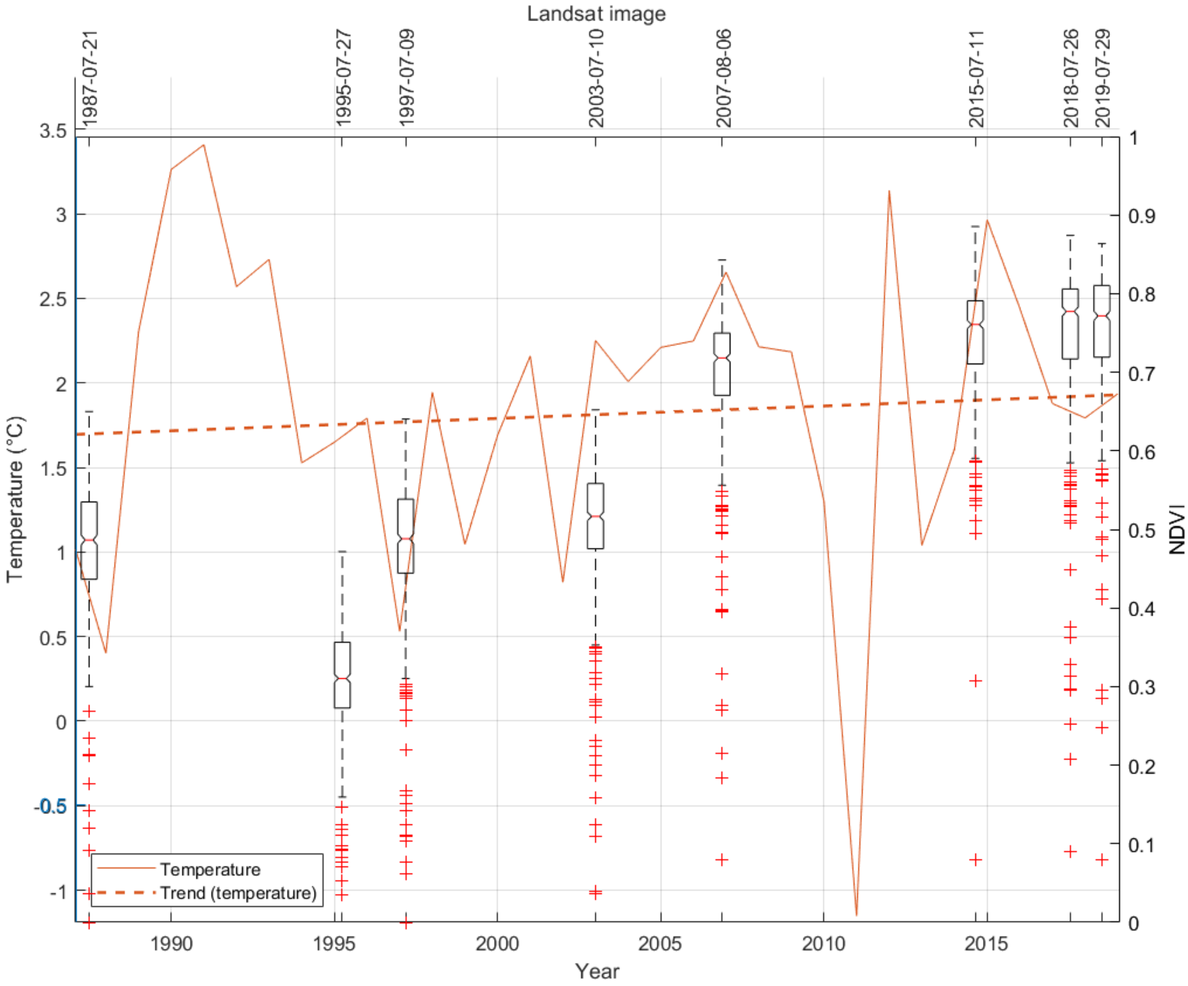

Figure 16. Boxplot showing distribution of NDVI in the area excluding G. nigra, with mean annual temperature and its trend calculation. Lower – higher range (--), outliers (red cross) (USGS, 2020; SMHI, 2020).

3.4 Derivates from DEM

3.4.1 Slope

The analysis of slope characteristics in the area including *G. nigra* resulted in a large range of values, between 0.22° and 8.93°, and with several high valued outliers. The gap between the 25th and 75th percentile, however, was quite narrow with values of 1.20 and 4.34° respectively with the 50th percentile at 2.60°. The area excluding *G. nigra* resulted in a range between 0 and 20.02°, with outliers stretching above 35° and with a wide range between the 25th and 75th percentile. The mean +/- CI resulted in a statistically significant difference between the areas including *G. nigra* and the area excluding *G. nigra* and will therefore be used in the MCA (Fig. 17). The distribution in each area followed a similar pattern with compact distribution below 5° with the exceptions of North and NE.

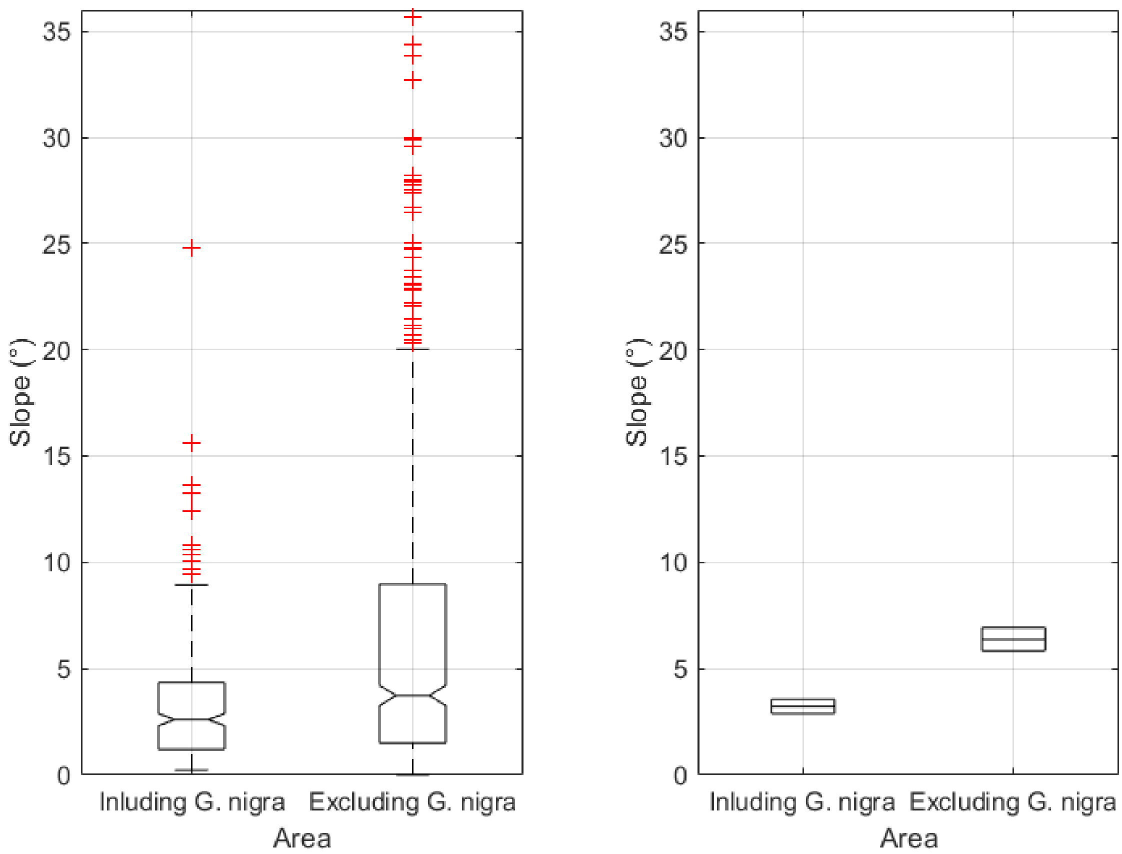

Figure 17. Boxplot showing distribution of slope (left) and mean +/- CI (right) in both the area including and the area excluding G. nigra. The distribution also includes the outer range (- -) and outliers (red cross) (Lantmäteriet, 2019; County Government of Jämtland, 2020).

3.4.2 Saga Wetness Index

The analysis of SWI in the area including *G. nigra* resulted in large fluctuations, ranging between 3.22 and 9.92. On the other hand, it resulted in a compact distribution between the 25th and 75th percentile, with values of 5.41 and 7.22, respectively. The area excluding *G. nigra* resulted in even higher fluctuation, ranging between 0.91 and 11.96 and a much wider distribution between the 25th and 75th percentile. The mean +/- CI resulted in a statistically significant difference between the area including *G. nigra* and the area excluding *G. nigra* and was therefore used in the MCA (Fig. 18).

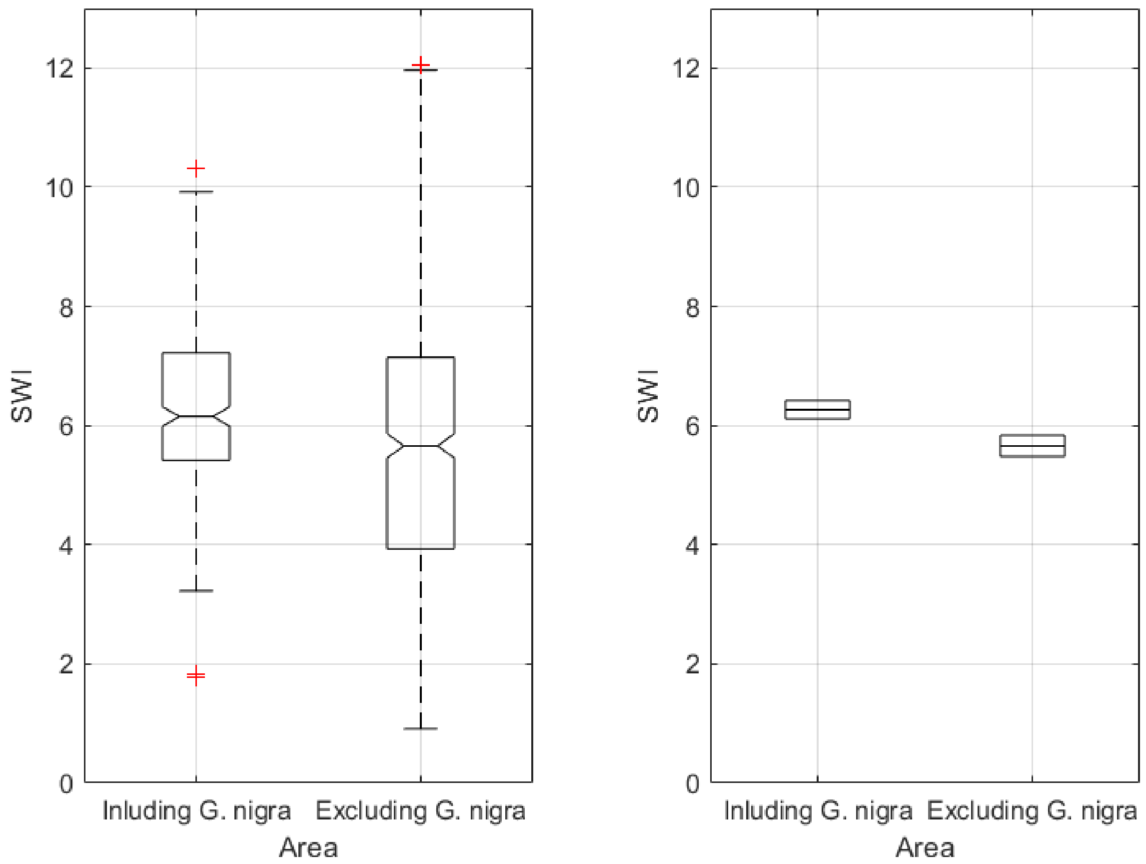

Figure 18. Boxplot showing distribution of SWI (left) and mean +/- CI (right) in both the area including and the area excluding G. nigra. The distribution also includes the outer range (- -) and outliers (red cross) (Lantmäteriet, 2019; County Government of Jämtland, 2020).

3.4.3 Elevation

The elevation analysis for the area including *G. nigra* locales resulted in a compact distribution between 614 and 632 meters, with a five-meter range between the 25th and 75th percentile (621 – 626 meters). In contrast, the area excluding *G. nigra* had a large variation in its overall distribution, ranging between 613 and 659 meters, and between 622 and 637 meters for the 25th and 75th percentile, respectively. The mean +/- CI resulted in a statistically significant difference between the area including *G. nigra* and the area excluding *G. nigra* and it will therefore be used in the MCA (Fig. 19).

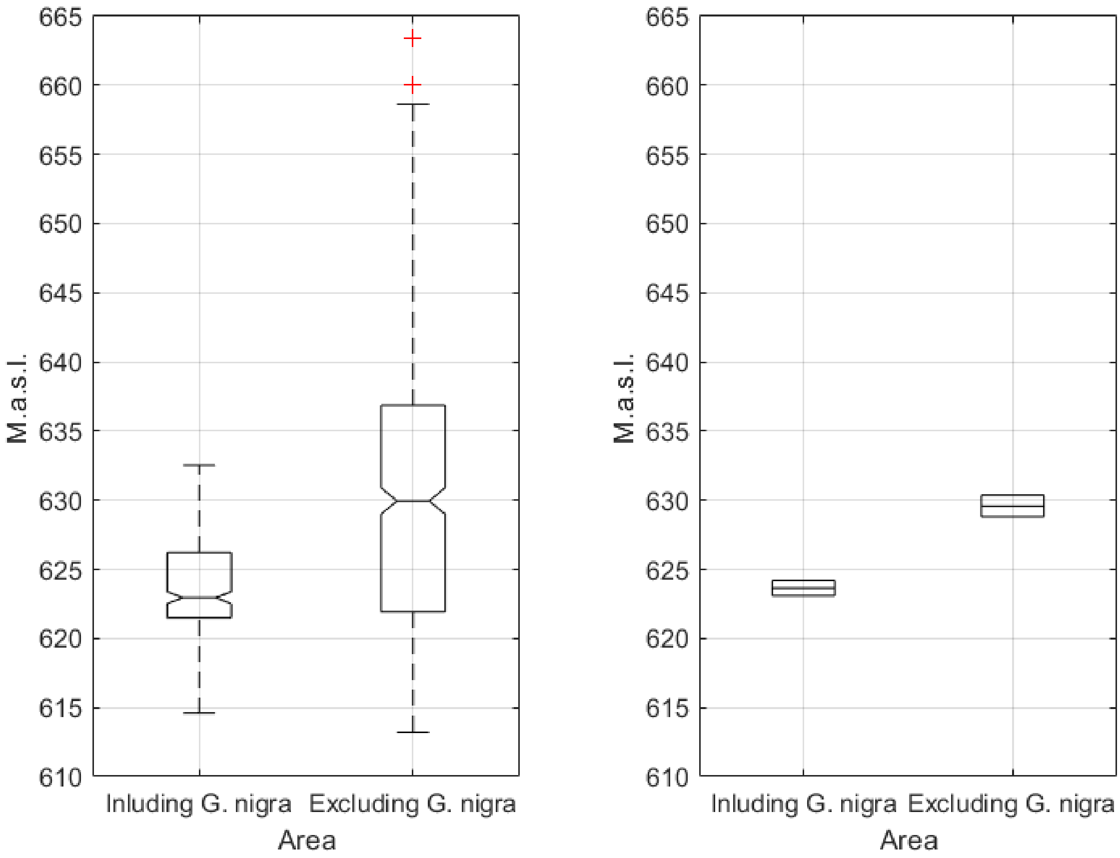

Figure 19. Boxplot showing distribution of elevation (left) and mean +/- CI (right) in both the area including and the area excluding G. nigra. The distribution also includes the outer range (- -) and outliers (red cross) (Lantmäteriet, 2019; County Government of Jämtland, 2020).

3.4.4 Aspect

The results from the analysis of slope aspect indicate that, in Vålådalen, *G. nigra* has grown on slopes facing all directions. The same conclusion can also be made for the area excluding *G. nigra*. The mean +/- CI resulted in no statistically significant difference between the area including *G. nigra* and the area excluding *G. nigra* and will therefore not be used in the MCA (Fig. 20).

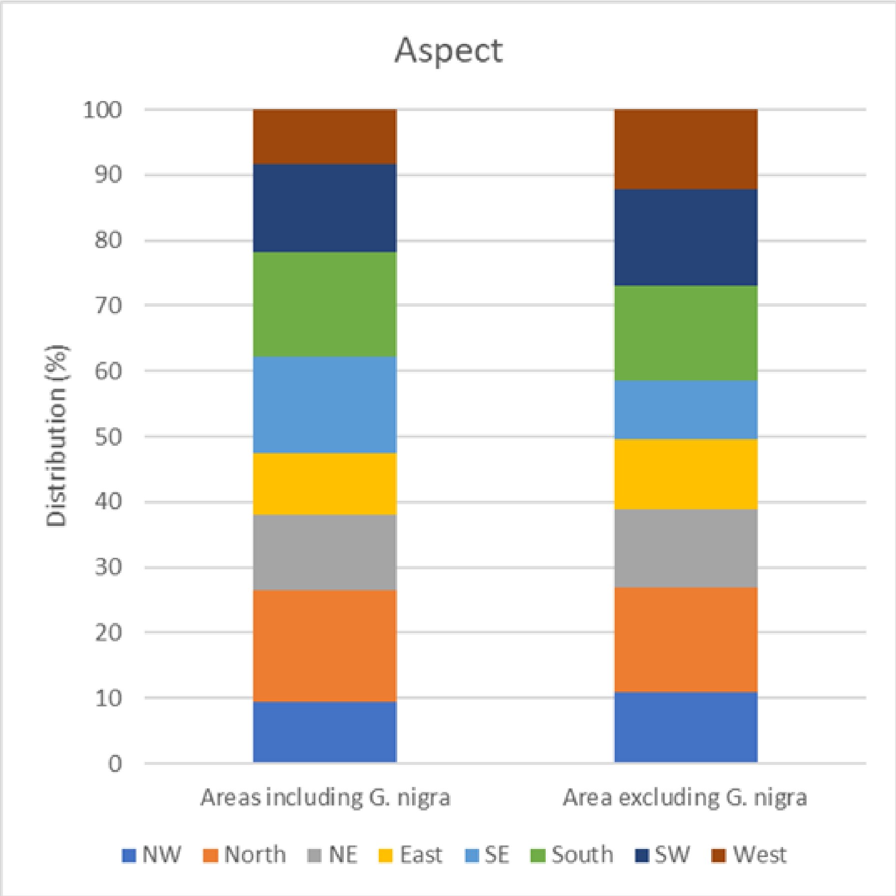

Figure 20. Distribution of each direction for both the area including and excluding G. nigra (Lantmäteriet, 2019; County Government of Jämtland, 2020).

3.5 Vegetation and soil

Results from vegetation show that most of the existing locales are growing on short alpine meadow or on dry - mesic heath. Out of 297 locales, 135 were growing on short alpine meadow, 101 on dry - mesic heath, 16 on mire, 14 on dry – mesic deciduous, 8 on lichen-rich deciduous and the remaining 7 in coniferous forest.

The dataset containing soil type was too course to be used in the MCA and resulted in all locales growing on glaciofluvial sediment.

3.6 Multi Criteria Analysis

3.6.1 Weighting of inputs

The variables which had a significant difference regarding *G. nigra* occurrence versus absence were included as an input in the MCA, namely: slope, SWI, elevation and vegetation. Based on slope and SWI, seven parameters each were assigned weights while for elevation, five parameters were assigned weights. All three also had three parameters which needed to be restricted, since no locales included those values (Table 7 - 9). Finally, vegetation resulted in six classes (Table 10).

Table 7 WO input arguments for slope, based on its distribution result (Fig. 17).

Class and weight	Slope (°)	Parameter
10	2,89 - 3,55	Mean +/-CI
9	1,20 - 2,89	25th percentile - CI
8	3,55 - 4,34	CI - 75th percentile
7	0,22 - 1,20	Lower range - 25th percentile
6	4,34 - 8,93	75th percentile - Higher range
5	8,93 - 15,61	Higher range - Compact Outliers
4	15,61 - 24,78	Compact outliers - Extreme outlier
Restricted	0 - 0,22	Lowest slope - Lower range
Restricted	24,78 - 83,86	Extreme outlier - Highest slope

Table 8. WO input arguments for SWI, based on its distribution result (Fig. 18).

Class and weight	SWI	Parameter
10	6,11 - 6,42	Mean +/-CI
9	5,41 - 6,11	25th percentile - CI
8	6,42 - 7,22	CI - 75th percentile
7	3,23 - 5,41	Lower range - 25th percentile
6	7,22 - 9,93	75th percentile - Higher range
5	9,93 - 10.30	Higher range - Highest outlier
4	1,77 - 3,23	Lowest outlier - Lower range
Restricted	10,30 - 16,09	Highest outlier - Highest SWI
Restricted	-0,37 - 1,77	Lowest SWI - Lowest outlier

Table 9. WO input arguments for elevation, based on its distribution (Fig. 19).

Class and weight	Elevation (m.a.s.l.)	Parameter
10	623,1 - 624,2	Mean +/-CI
9	621,5 - 623,1	25th percentile - CI
8	624,21 - 626,2	CI - 75th percentile
7	626,2 - 632,5	75th percentile - Higher range
6	614,6 - 621,5	Lower range - 25th percentile
Restricted	569,0 - 614,6	Lowest elevation - Lower range
Restricted	632,5 - 1050,0	Higher range - Highest elevation

Table 10. WO input arguments for vegetation, based on the frequency of locales on each type.

Class and weight	Vegetation	Amount
10	Alpine vegetation (low)	135
9	Dry – mesic heath	101
8	Mire	16
7	Dry - mesic deciduous	14
6	Lichen-rich deciduous	8
5	Coniferous	7

3.6.2 Preference matrix

The RSD for elevation was extremely low and it was therefore assigned the highest scaled value, nine. SWI also resulted in a low RSD and was therefore assigned the second highest scale value, seven. Slope resulted in relatively high RSD and was therefore assigned a lower value of three. A high number of locales were, according to the vegetation data set, growing on heath. This was considered not likely since heath consist of more dominant species and could rather be due to an error in the data set (Lantmäteriet, 2008), Therefore, it was assigned the lowest scale value of one (Table 11). The results from the preference matrix assigned elevation the highest weighted percent, followed by SWI, Slope and finally vegetation (Table 12).

Table 11. RSD calculations and assigned scale values for each input used in the MCA.

Input	RSD	Ratio = RSD / Total RSD	%	Scaled value
Elevation	0,008	0,007	0,7	9
SWI	0,212	0,190	19,0	7
Slope	0,896	0,803	80,3	3
Vegetation	-	-	-	1
Sum	1,116	1	100	-

Table 12. Preference matrix for each input used in the MCA, including their relative weighting percent.

Input	Elevation	SWI	Slope	Vegetation	Weighting (%)
Elevation	1	1,29	3	9	50
SWI	0,14	1	2,33	7	28
Slope	0,33	0,43	1	3	16
Vegetation	0,11	0,14	0,33	1	5

3.6.3 Multi Criteria Analysis results

The MCA results with highest suitability for possible future habitats were mainly concentrated in the Central to Northern part of the valley, consisting of three sub-areas where highest suitability was concentrated. There were also two narrow bands with modest suitability stretching towards the East (Fig. 21). The three sub-areas of highest suitability were each large enough to represent a possible future habitat. One area is in the North stretching from Southwest to Northeast (Fig. 22), one is in the western parts stretching Northwest to Southeast (Fig. 23) and, finally, the largest area located in the Central part of the valley (Fig. 24).

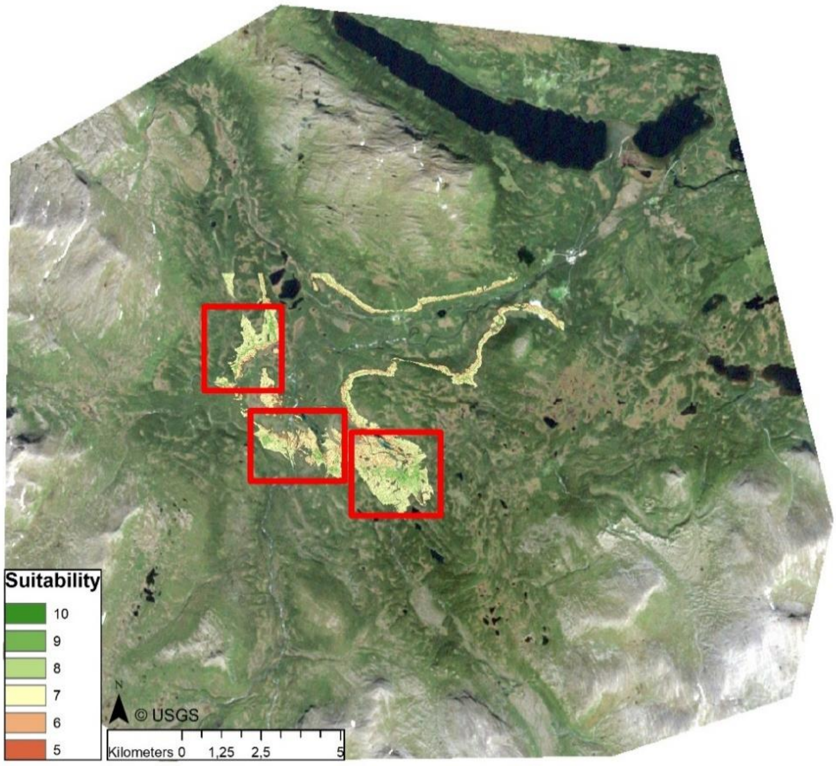

Figure 21. The overall extension for possible future habitats, including the three sub-areas (red boxes), based on the results from the MCA (USGS, 2020).

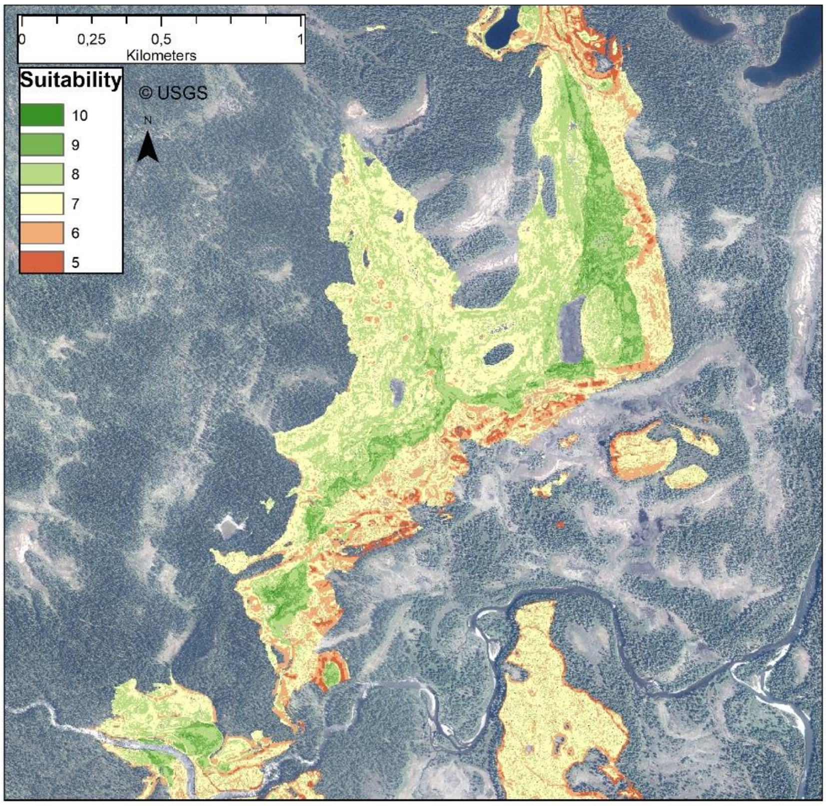

Figure 22. The NW sub-area of possible future habitat, based on the MCA results (USGS, 2020).

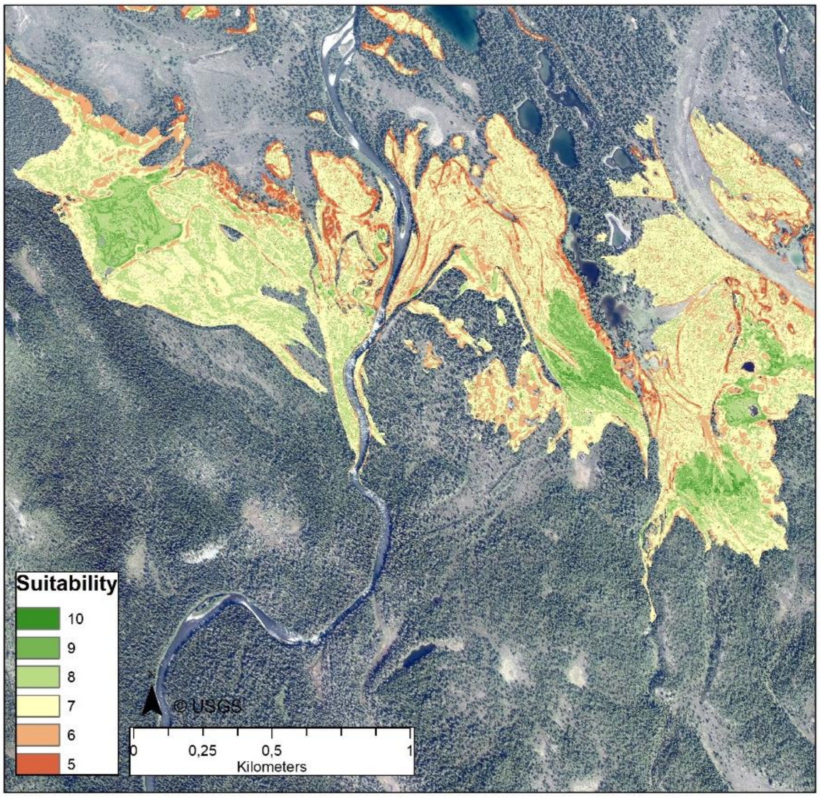

Figure 23. The Western sub-area of possible future habitat, based on the MCA results (USGS, 2020).

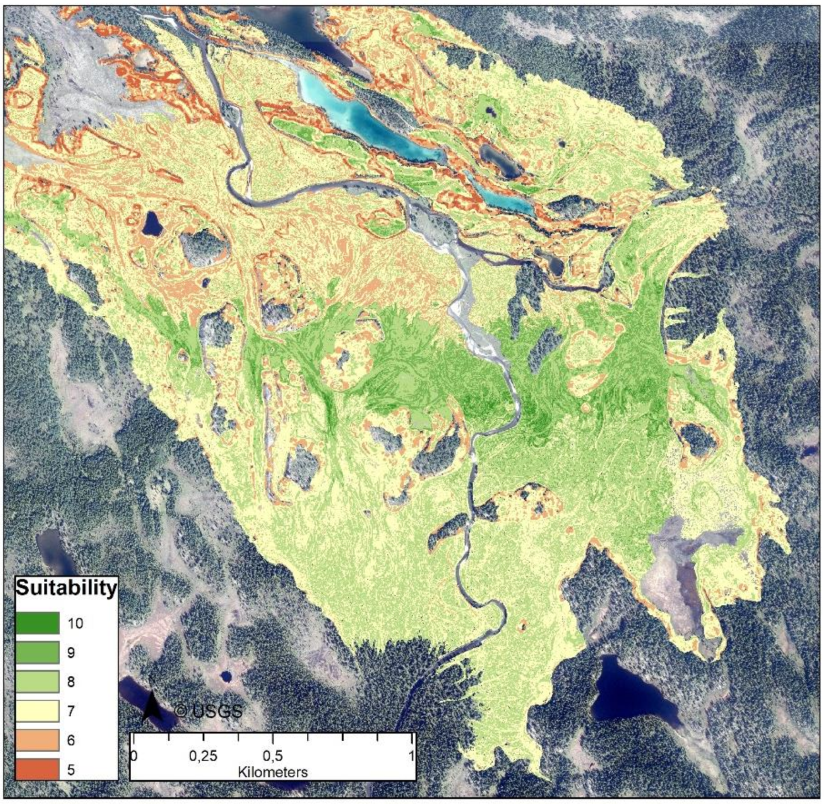

Figure 24. The central sub-area of possible future habitat, based on the MCA results (USGS, 2020).

The comparison between extracted suitability values from the MCA results, between points including and excluding *G. nigra* locales resulted in a statistically significant difference (Fig. 25). There is also a great difference in their distribution, where zero suitability was the most common result concerning points excluding locales and seven the most common suitability for points including locales (Fig. 26).

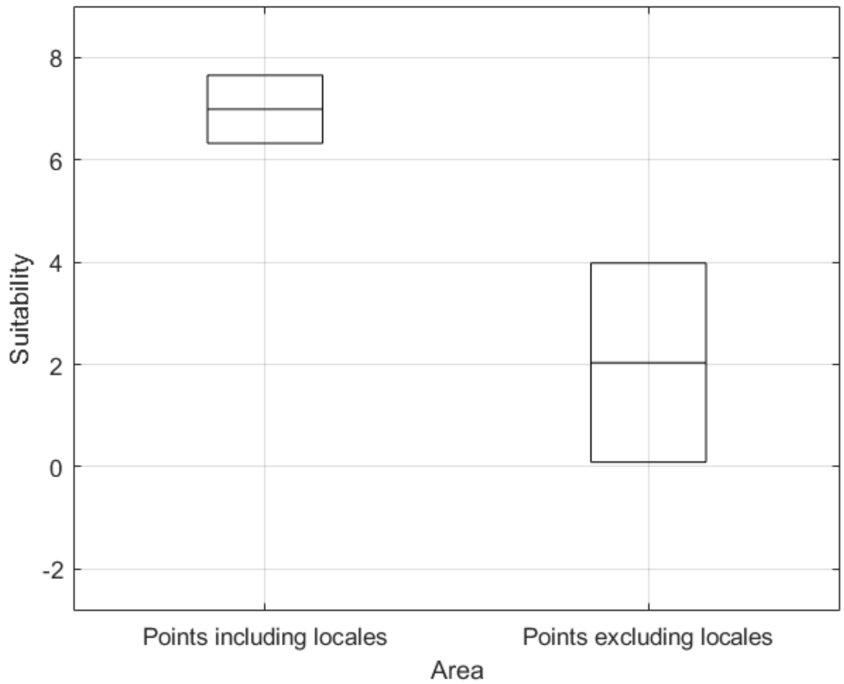

Figure 25. Mean +/- CI (boxes) for suitability between points including and excluding locales.

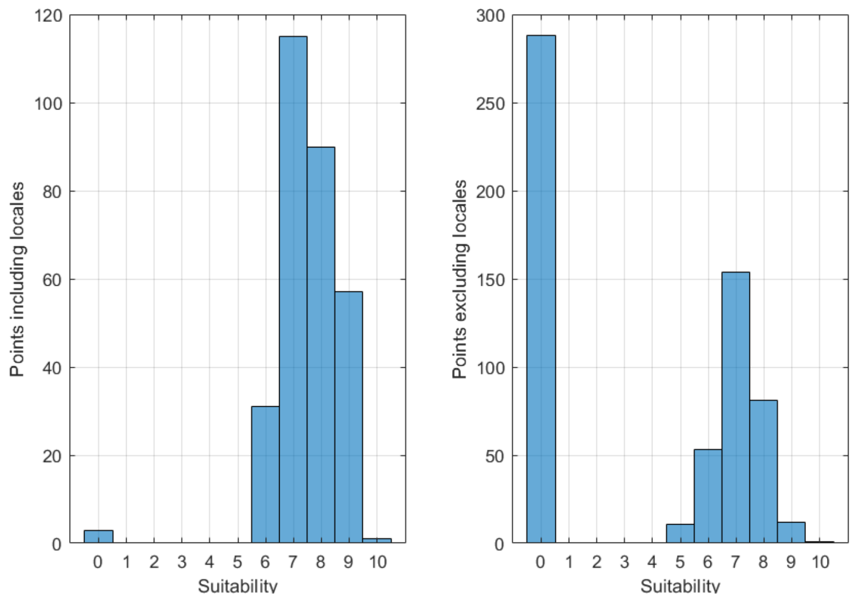

Figure 26. Distribution of suitability compared between points including (left) and excluding (right) locales.

4. Discussion

4.1 *Gymnadenia nigra* and NDVI

By dividing up the habitat based on clusters of inventoried flowers, i.e. NW, North, NE, East, SSE and South, several locales in the area could be detected. This division resulted in the finding that, prior to 2014, mainly one of these areas contained *G. nigra* flowers (NE). This could potentially mean that the reason for the increased number of flowers is an increase in locales. In other words, the number of flowers in a specific area might not have experienced a significant increase, it is rather that the *G. nigra* has found new locations for growth. According to G. Dahl (personal communication, 30-04-20) from the Botanical Association of Jämtland, they have also found several new sub-locales since 2014 . He further comments that the species seems to thrive in Vålådalen when compared to other lowland locales, which can also be concluded based on the results from this report.

As it turned out, NDVI appears to have increased significantly in the area between 1987 to 2019, however, there is no indication that it has decreased the number of flowers in total, since they have rather increased as well. This is a quite interesting result which contradicts the initial expectations. Since the positive trend of NDVI indicates that an increase in biomass productivity has occurred, this was expected to represent an increase in the competition from other species (Druel, et al., 2019) and, as a result, eventually affect the *G. nigra* habitat negatively, decreasing the number of flowers. Therefore, to analyze if the resulting increase of NDVI was of a magnitude enough to cause an impact, the results were compared with a study by Olthof, I., et al. (2008), which used NDVI in an analysis concerning vegetation greening and competition in Canada. Their results show that a positive trend in NDVI, with values between 0.005 – 0.010 for the slope of the regression (depending on which vegetation type), has occurred between 1986 – 2006. They further conclude that this has led to an increased greening in Northern latitudes, which has especially favored shrubs and vascular plants. Finally, they connect this to an increased competition that has caused weakly competitive vegetation types, such as lichens, to decrease (Olthof, I., et al., 2008). Since the NDVI results from Vålådalen resulted in a positive trend with a value of 0.016 for the slope of the regression, the results from Olthof, I., et al. (2008) can confirm that this increase in NDVI should have caused a greening in the valley and thereby an increased competition. However, since their results show that the greening has favored both shrubs and vascular plants and only causes competition for lichens (Olthof, I., et al., 2008), it can mean that the increased greening that has occurred in Vålådalen, so far, is what causes the flower to spread to new locales and thereby increasing the total number of flowers. It should, however, be emphasized that in the present study on Vålådalen, the NDVI resulted in a statistically non-significant difference from the area excluding *G. nigra* and it is therefore not possible to conclude that NDVI have had any impact concerning specifically *G. nigra* in the area. It should rather be concluded that the increased NDVI values have affected the entire plant community in the valley. In addition, it should be noted that this study has used only a single image date per year, which should represent peak greenness. However, to get a full picture of peak greenness, several images representing the growing season would be required. This is a step that can be taken in future work. Finally, there might also be a lag effect concerning the impact on *G. nigra* by increasing NDVI and that a continuous analysis on an annual basis would be of interest to see if, or when, the number of flowers will start to decrease.

4.2 Climatic impacts

During the period of analysis, annual mean temperature in Vålådalen has experienced a positive trend that coincides with NDVI. Other studies have shown similar results (Olthof, I., et al. 2008) and since a warmer climate favors vegetation greening (Jia, G., et al., 2019), these results were expected. Since the NDVI analysis resulted in not affecting *G. nigra* negatively, it cannot, however, be concluded that a vegetation greening, due to a warmer climate, has had a negative impact on *G. nigra*. In 2018, however, the number of flowers suddenly dropped drastically, and this could be explained by the extreme drought which occurred in Sweden this year (Jordbruksverket, 2019), rather than an effect of a long-term greening (Moen, A., & Øien, D., 2002).

The seasonal cycle during 1987 - 2019 showed an increase in precipitation, especially during late spring and early summer. An increase during this period could have a positive effect on *G. nigra* flowers according to Naturvårdsverket (2013), causing them to increase and might therefore be an important parameter for the increasing number of flowers. It has, on the contrary, been concluded that increased winter precipitation has a negatively correlated effect on *G. nigra* (Moen, A., & Øien, D., 2002). Therefore, to draw any major conclusion about the impact on *G. nigra* due to climatic changes is still complicated and further research is needed. A potential approach to do this would be to record annual *in situ* measurement of temperature and moisture in an area where known *G. nigra* flowers have grown for a longer period. Then, the effect that present and previous years' climate might have had on the flowers could be analyzed and compared to older climate data in the region.

4.3 Suitability profile

The results from slope, SWI and elevation were all statistically significant different from the area excluding *G. nigra* and could, together with vegetation, be used in determining a habitat profile for *G. nigra* in Vålådalen. *G. nigra* seems to thrive on an elevation between 621 to 626 meters in Vålådalen, which also proved to be the most important factor in the MCA. By studying the location of existing locales in relation to elevation (i.e., DEM or a hillshade model of the DEM) it seems that they grow in a canyon, consisting of streams following a meander pattern. An explanation might be that there are other parameters prevailing that should be considered, such as the soil type in that area. The soil dataset was unfortunately of too coarse a scale as compared to the other inputs to be used in the MCA. It did, on the other hand, show that all existing locales grow on glaciofluvial sediment (SGU, 2014). This means that the canyon they seem to grow in might be a result of the last glacial period, which has provided calcareous-rich glaciofluvial sediment that favors *G. nigra* (Borgström, I., 1981; Naturvårdsverket, 2013). The input of soil has been concluded to be important as a parameter for where *G. nigra* thrives (Naturvårdsverket, 2013). This seems, on the other hand, to be a debated issue and other research suggest that calcareous rich soil is of minor importance for *G. nigra* (Björkbäck, F., & Lundqvist, J., 2005). In Vålådalen, however, it seems that soil, and geomorphological features for that matter, are of importance.

The second most important parameter proved to be SWI, however, the SWI values were not very high (7 with maximum possible value of 30). Other research has shown that flatter areas should result in higher values of SWI (> 10) since it represents the capability for water to accumulate (Birsrat, E., & Berhanu, B., 2018). It has, on the other hand, also been concluded that SWI values are highly impacted by the resolution of the DEM which, in turn, will affect the size of the upslope area. This means that with a lower grid cell resolution DEM, the mean in upslope area increases and thereby the SWI values (Sørensen, R., & Seibert, J., 2007). Since the DEM in this research had a high grid cell resolution of 2 m, the values of SWI might therefore be somewhat lower where it indicates that the soil may be moist. This would also coincide with previous research, specified in *G. nigra* habitats in Sweden, that concludes the species to be sensitive to drier conditions (Naturvårdsverket, 2013).

Finally, *G. nigra* locales were found growing on alpine meadows with low vegetation or on dry – mesic heath. The result of many *G. nigra* locales growing on heath was quite surprising, since heath contains compact and tall species such as Betula Nana and other hardier species (Lantmäteriet, 2008). This could be explained by the fact that the vegetation data set has a

Minimum Mapping Unit (MMU) of three ha, therefore, any information about vegetation types smaller than this area will be generalized into the majority vegetation type (Fassnacht, K., S., et al., 2006). This can be misleading, especially if using such small areas as studied in this report, where *G. nigra* locations were derived from a point file based on GPS points. So, even though the accuracy for heath has been concluded as being "high" (Lantmäteriet, 2008), the three ha MMU might have excluded smaller patches of vegetation cover on which *G. nigra* might grow. The large number of flowers growing on short alpine meadows, on the other hand, was quite expected since it contains short herb-species and grass (Lantmäteriet, 2008), hence having lower competition from more dominant species (Moen, A., & Øien, D., 2002).

4.4 Multi Criteria Analysis

One major area including three large sub-areas with higher suitability could be detected using MCA, based on the habitat profile created from the results. All three sub-areas were situated in the lower part of the valley, close to smaller lakes and streams. They were also quite large in relation to the current distribution of locales and with a high suitability (dominated by values between 7 – 9). Furthermore, by comparing the MCA suitability values extracted for points including locales with points excluding locales, a statistically significant difference between the two was found. Therefore, it could be concluded that the result of the MCA, by using GIS and remote sensing techniques, is valid. Still, the results were based on continuous input data derived from a DEM, together with discrete data of vegetation. Therefore, there was a difference in the data format used where information of vegetation followed crisp boundaries, as opposed to the continuous nature for DEM derivatives. Instead, if all inputs were initially to be reclassified into the same data format, they might thereby fit each other better and possibly increase the accuracy of the results. This problem was confronted in a study by Store, R., & Kangas, J. (2001) concerning habitat suitability using GIS based multi-criteria analysis, where they discretized all continuous data before used in the suitability analysis. This, however, might have generalized the values from e.g. elevation and, as a result, could have led to not discovering its importance. Instead, by using a more spatially detailed vegetation data, the results from this report would still retain their importance while the quality of the results would improve further. Additionally, instead of using the AHP method to weigh their inputs, they used the so-called HERO heuristic optimization to overcome the limits of the AHP, which only uses a few classes based on each input's distribution. Instead HERO uses the sub-priority function, which creates a continuous data set of priority based on the input's distribution, maximizing the use of all information in each input data (Store, R., & Kangas, J., 2001; Helles, F., et al., 2001).

4.5 Errors and future research

Since the Landsat satellite collects images every 16th day, there were some problems finding useful data for this type of research since the time-period of interest (i.e., peak greenness) only concerned a three-week window. Another problem was that the images needed also had to exclude cloud cover, which, in mountainous areas, can be problematic (Nyland, E., et al., 2018). For this report, the use of GDD as an indicator of potential peak greenness was used to broaden the potential time period of useful satellite data, however, this led to a wider timespan concerning the date for each image each year. Although Landsat has a long revisit time (i.e., 16 days), it is very useful since consistent data characteristics (e.g., pixel size 30 m, same wavelengths) have been collected since 1984. For future research however, the use of Sentinel 2 satellite images might be of interest since they collect images every third day (Reese, H., and Olsson, H. 2018) in Sweden, increasing the possibility to collect images on dates closer to peak greenness. There are also other techniques suggested to overcome the issue of available images on a specific date, one of which is the dense stacking methodology (Nyland, E., et al., 2018). By including all the images available during the time of year to be analyzed, despite cloud cover, it was suggested that areas disturbed by clouds might be covered by other imagery. So, by increasing the dataset, the issue of lacking imagery due to disturbances might therefore be solved (Nyland, E., et al., 2018).

Besides following up the development of NDVI and number of flowers on an annual basis, the results should be considered as a first draft and that a complimenting field study would further increase the accuracy and quality of the results. A field study could for example confirm or dismiss the result of such a large number of flowers growing on heath. As a result, this could improve the use of vegetation data in the MCA, allowing it to have a heavier weighting than used in this report. In the study by Store R., & Kangas J., (2001), the 6870-ha large Kivalo forest in northern Finland was analyzed in habitat suitability for different species. By comparing the results based on data from field inventory with data created from spatial analysis tools, such as soil moisture and aspect, using a GIS software, they concluded that the quality of their results was highly dependent on the quality of the input data used. The field inventory data still included errors, but much less than the spatial analysis data and, therefore, by using inventory data, the quality of the results would increase (Store, R., & Kangas, J., 2001).

Finally, this study also excluded an accuracy assessment for the MCA results due to a narrow dataset of locales, as they were all used to improve the quality of the input in the MCA. If a complimenting field study could be conducted, not only could the input data quality increase but the MCA results could also be analyzed in a proper accuracy assessment to see if the results were accurate enough or if other conditions or parameters prevailed in the area.

Another possible error due to the quality of the datasets arose in the NDVI results. Since the NDVI calculations were conducted from satellite images with a 30 m grid cell resolution, while the areas where existing locales are located were quite small, it led to a quite generalized result concerning NDVI for each individual locale. Furthermore, the areas excluding *G. nigra* were a minimum of only 100 m away from existing locales (300 m maximum), which could explain the fact that there was little difference between the areas including *G. nigra* with areas excluding it. This rather conservative buffer used to create "exclusion areas" to compare with areas where *G. nigra* was growing was done to purposefully so that the analysis would not consider areas where *G. nigra* would obviously not grow, i.e., rock faces or water. Instead, we analyzed areas relatively near to known *G. nigra* observations, that did not have reported flowers. All parameters, except aspect, resulted in a statistically significant difference from the area excluding *G. nigra*, and they were all derived from a 2 m resolution DEM.

It should also be emphasized that neither soil or geomorphological features were included in the MCA, and that both parameters were only discussed briefly concerning their possible impact on existing locales. There might also be other important parameters, such as wind patterns spreading seeds (Naturvårdsverket, 2013) or fungus needed for germination (Moen, A., & Øien, D., 2002), as reasons for why the locales only cover such small areas. So, since the area indicated as suitable for possible future habitat from the MCA results was quite large, including more parameters such as those named above might help answer the question as to why *G. nigra* does not grow there today. Additionally, since no *in situ* confirmation could be conducted for the results, the question also arises if there are flowers growing in the area found today that has not yet been discovered.

Finally, other research includes the expertise from various fields in determining the weights within each data input to the MCA and their scaled values in relation to each other (Marinoni, O., 2004; Store, R., & Kangas, J., 2001; Recanatesi, F., et al., 2014). In this report, the weighting for each input has been based on its distribution and the scaled value has been based on the RSD between each input. Therefore, further analysis with other weighting techniques would be of interest in further increasing the accuracy of the results (Fassnacht, K., S., et al., 2006), such as the HERO technique mentioned above (Store, R., & Kangas, J., 2001). Despite the limitations of this study and the potential improvements named here, this study could act as a first output in establishing a valid method for analyzing the habitat conditions for *G. nigra* with the aid of remote sensing and GIS.

5. Concluding remarks

Based on the method used in this study, the total number of *G. nigra* flowers have increased from 486 to 936 during the past three decades (1994 - 2019), mainly due to an increase of new locales. The NDVI as indicated from Landsat images has also increased between 1987 and 2019. The initial expected effect of decreasing number of flowers and locales with increased NDVI could not be concluded and increased NDVI instead appears to have had a positive effect on *G. nigra*.

No conclusions about the effect of changes in Vålådalen's seasonal climate could be made. However, the increased mean annual temperature could have led to the increasing NDVI, which can be interpreted as a greening in the valley. To determine whether this greening will have a negative impact on *G. nigra* in the future, further research on an annual basis would be needed.

A habitat profile for *G. nigra* could be created based on the inputs of slope, elevation, SWI and vegetation cover. Among the inputs, elevation was the most important factor followed by SWI, slope and vegetation, in that order. Furthermore, based on the profile created, one large area suitable as potential future habitat could be detected. In this area, three sub-areas dominated by suitability values between 7 - 9 were identified as potential suitable habitats: one in the North, one in the West and the largest in the central parts of the valley. The results of the MCA where known *G. nigra* existed was statistically significantly different from the results of nearby areas which had no reported *G. nigra* locales, which supports the idea that the use of GIS and remote sensing was a valid method for this kind of analysis. Still, further research is needed, especially with a complimenting field study that can confirm or dismiss possible results. Such a compliment could further improve the quality of the inputs used in the MCA and thereby also the results.

6. References

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6.2 Data

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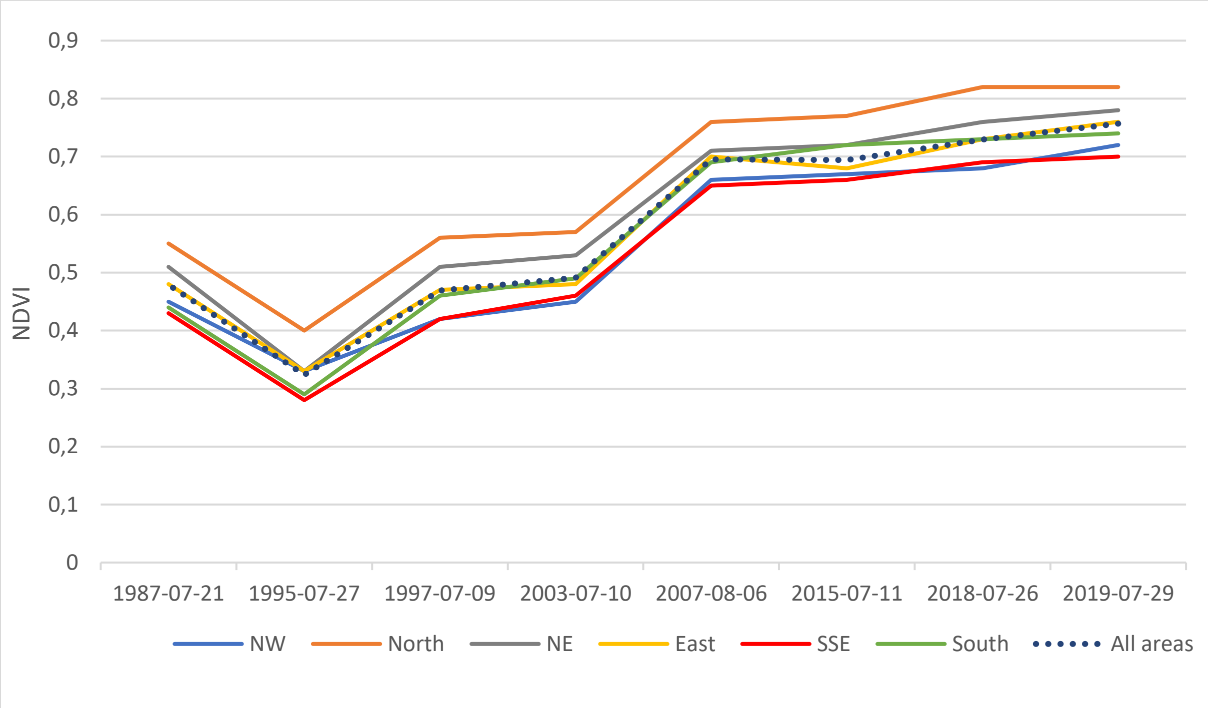
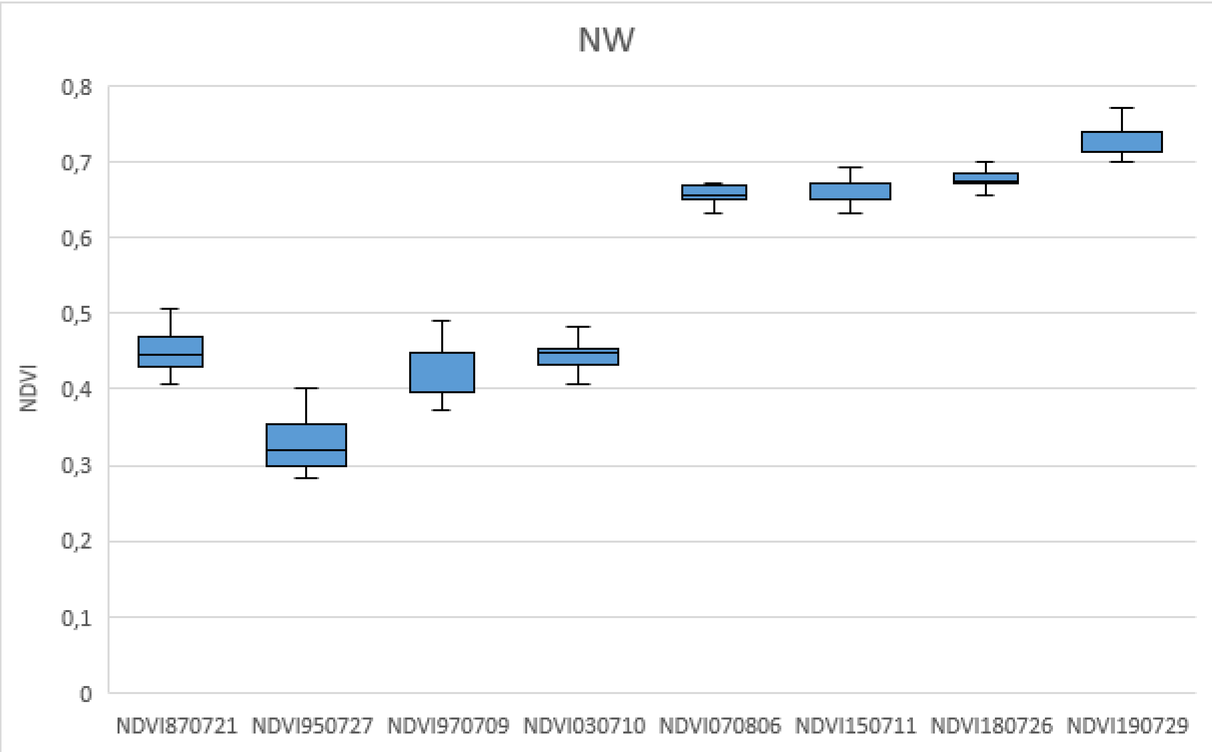
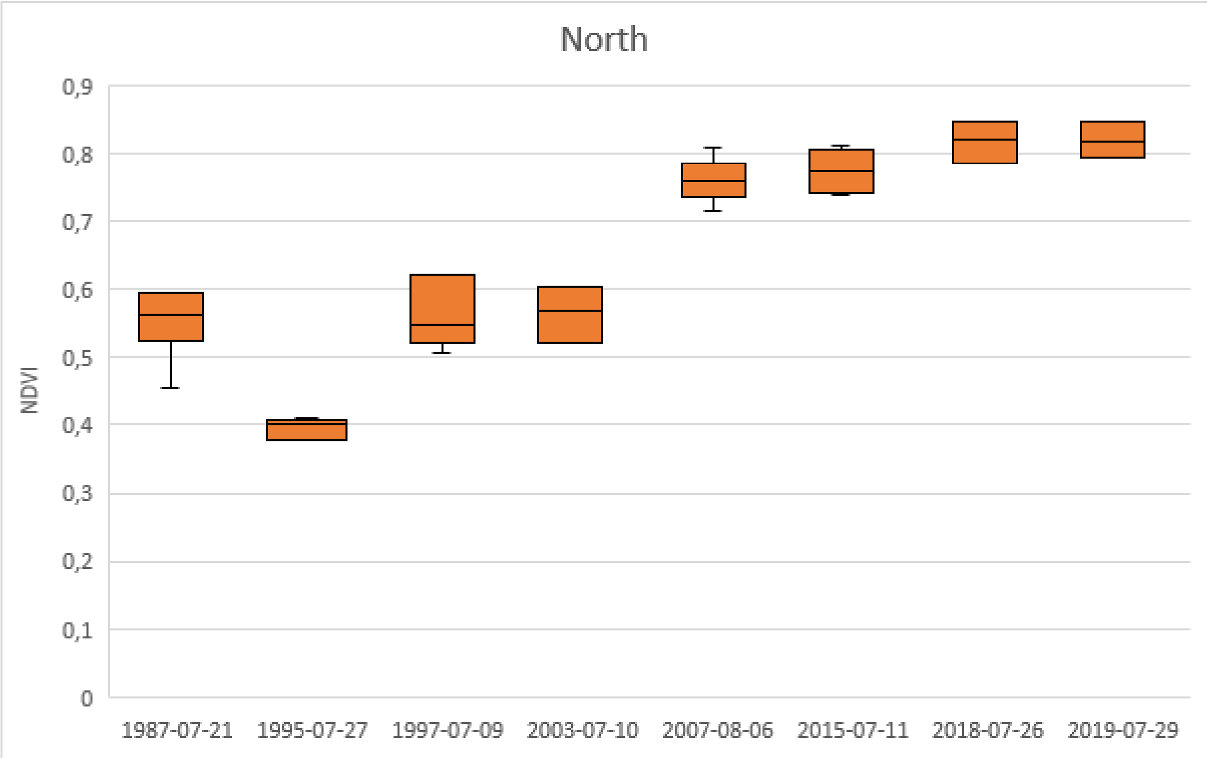
7. Appendix



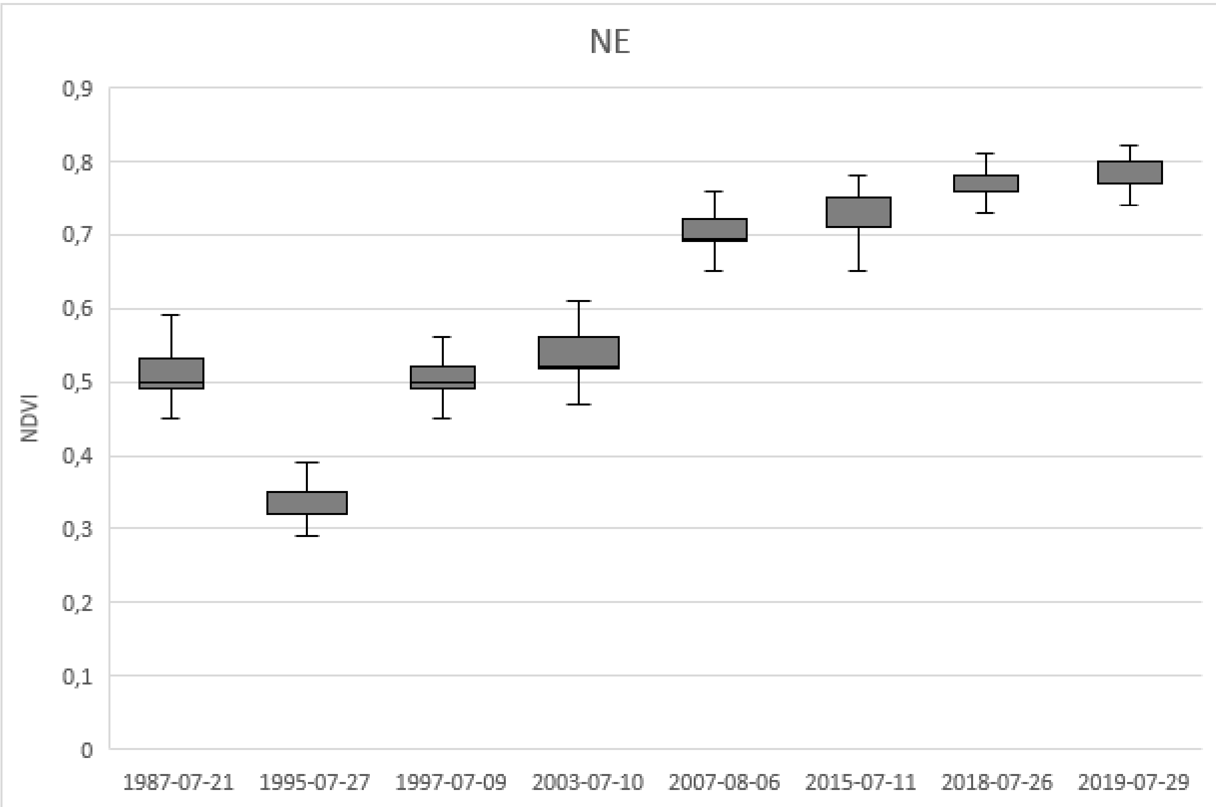
Appendix 1. Timeseries analysis of NDVI in all areas (USGS, 2020)



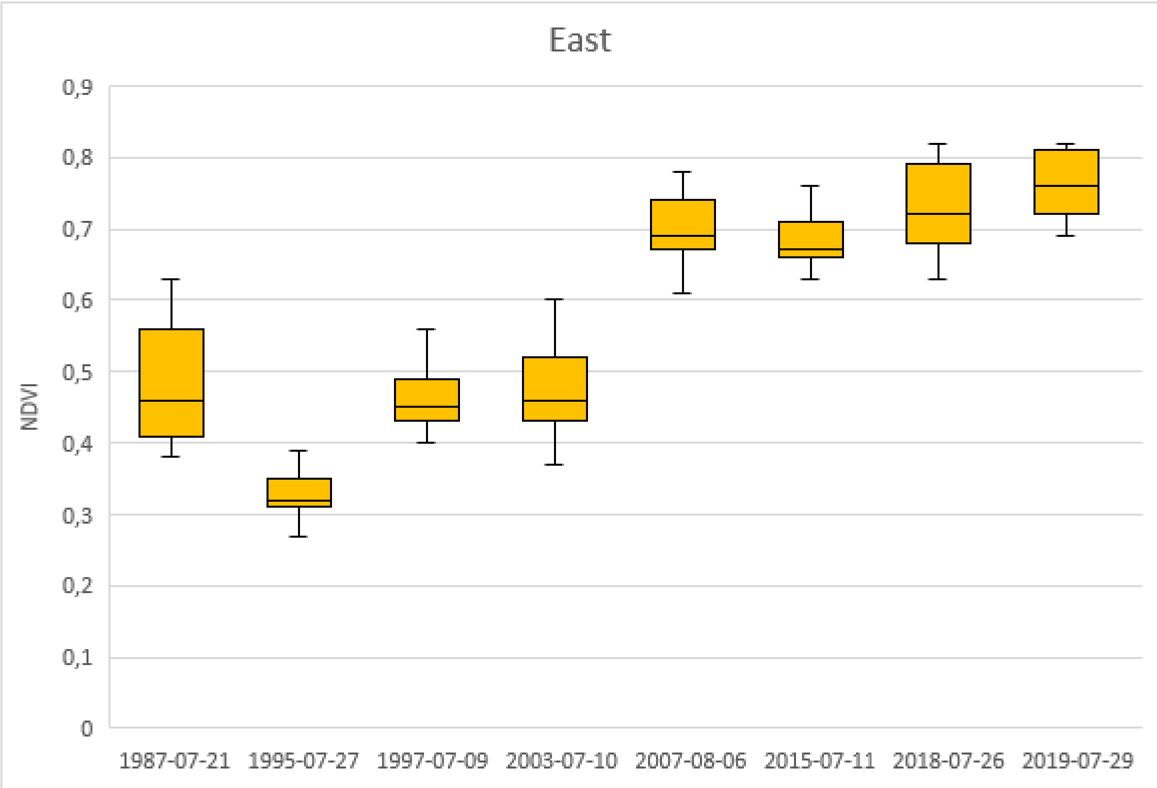
Appendix 2. Distribution of NDVI in the Northwestern area (USGS, 2020).



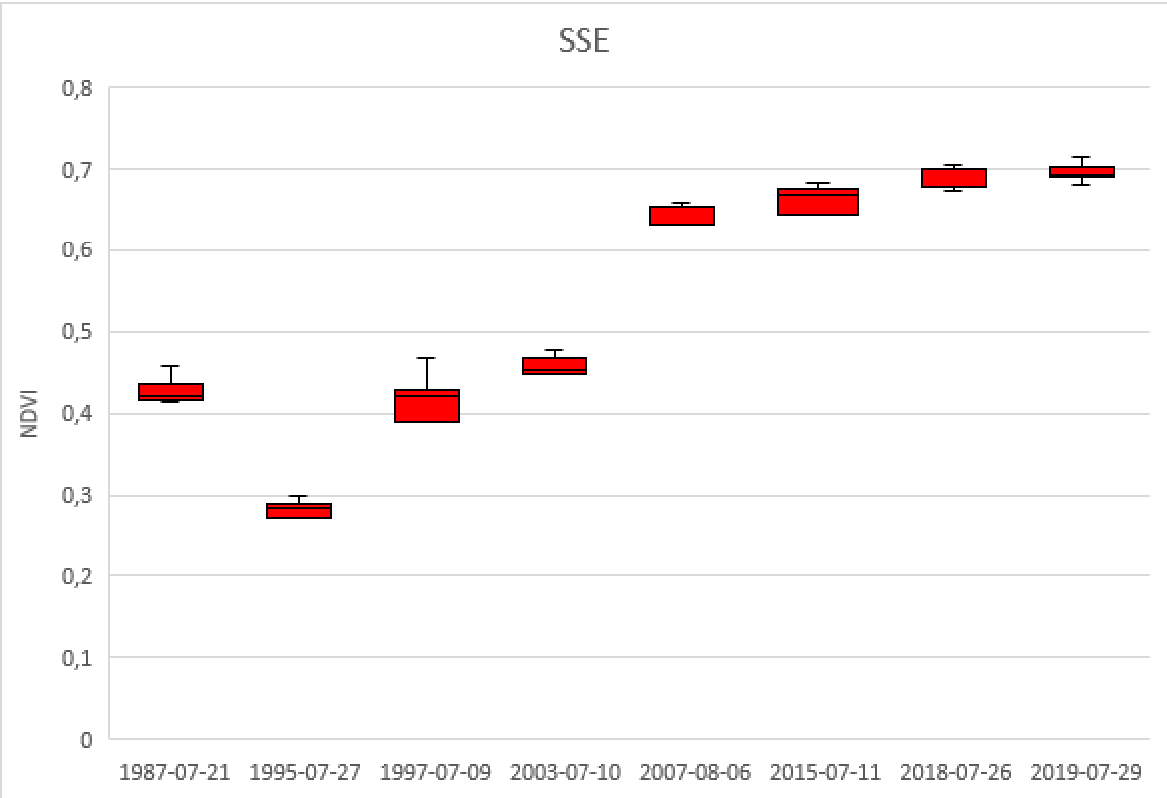
Appendix 3. Distribution of NDVI in the Northern area (USGS, 2020).



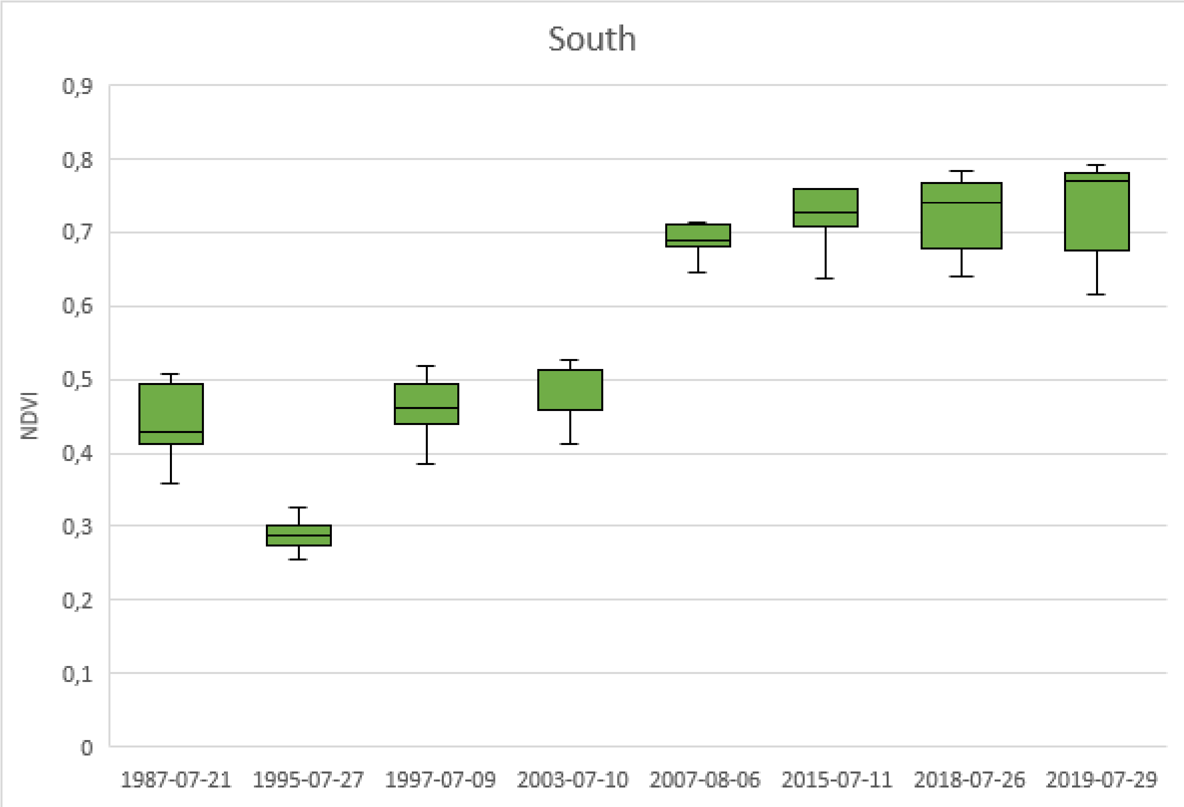
Appendix 4. Distribution of NDVI in the Northeastern area (USGS, 2020).



Appendix 5. Distribution of NDVI in the Eastern area (USGS, 2020).



Appendix 6. Distribution of NDVI in the Southsoutheastern area (USGS, 2020).



Appendix 7. Distribution of NDVI in the Southern area (USGS, 2020).