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Limestone Quarry Restoration - Evaluation plan of restoration methods for Alvar establishment on northern Gotland

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Abstract

Alvars are globally rare habitats with rich and distinctive vegetation-communities. Alvars are found on limestone bedrock which is also subject to quarrying for cement production. The increasing global need for cement results in either expanding existing quarries or the opening of new ones. Current legislation requires the restoration of limestone quarries after they are closed for quarrying and there are visions of using alvar as the target habitat of such restoration.

The purpose of this thesis is to provide a plan of evaluation for a restoration project carried out by Cementa AB on northern Gotland. The test sites of the project are situated in the Western quarry of Slite cement production plant.

The evaluation plan was formed by reviewing existing literature in the field of limestone quarry restoration and analysis of alvar characteristics. Biotic and abiotic variables were included in the evaluation plan based on studies of the composition of plant species on alvar and patterns in the levels of soil nutrients when comparing to other habitats. Sampling frequency was based on the method of existing national monitoring programmes in combination with the time-plan for the Western quarry.

All studies about limestone quarry restoration were from North America, but since alvar communities across continents share similar conditions, and sometimes even support the same plant species and community types, they are suitable for an initial comparison. However, additional studies conducted outside America, preferably as close to Sweden as possible, would strengthen the results.

Key words: *Limestone quarry, alvar, restoration, evaluation plan, ANOVA, environmental monitoring*

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Contents

1. INTRODUCTION

Alvars are north-temperate habitats rich in flora and fauna, spread across flat and relatively open areas overlaying calcareous bedrock (Schaefer and Larson 1997). Patterns of topography, cracks and crevices caused by weathering and erosion vary greatly due to different geological bedrock types from the periods Devon, Silur and Ordovicium, situated beneath alvar sites (Reschke et al. 1999). The varying patterns of topography give the alvar a distinct look of inconsistent soil patches with sparse vegetation consisting mainly of endangered and endemic plant communities of cryptogams, herbs and shrubs (Larson et al. 2006). The cryptogamic crusts are a mixed composition of cyanobacteria, lichens, mosses and fungi which, by its stabilizing function binds organic fractions to the mineral fractions of the dissolved limestone matrix underlaying the thin soil column (Stark et al. 2004). Because of local weathering processes and climatic conditions, alvars across the world host a wide variety of plant communities (Reschke et al. 1999). The habitats of alvars experience overlapping weather-extremes of periodic drought and flooding (Larson et al. 2007), which during winter periods give rise to a freeze-thaw phenomenon, leaving elements of ripped vegetation covers. During warm summer periods the same areas experience extreme temperatures and drought stress (Jacobson 2011).

The habitats of alvars are sparsely spread across the world, thus declared globally imperilled. On the European continent they occur in the Baltic region of Sweden, Estonia and in West Russia (Schaefer and Larson 1997). The alvar of the Baltic region resemble steppes that are found in eastern Europe and Asia (Reschke et al. 1999) and exist in Sweden under the names of ‘Nordic alvar’ and ‘Precambrian calcareous flatrocks’ (Jacobson 2011). Across the Atlantic alvars have been studied in the Great Lakes region of North America, with a majority of the habitat occurring south of the contact line of the Canadian Shield (Reschke et al. 1999).

Increasing rates of limestone quarrying have led to the destruction of terrestrial ecosystem such as alvars, and it is nowadays important to develop restoration plans of limestone quarries in order to re-establish habitats that supports the unique flora of alvar (Larson et al. 2006). It has been suggested that restoration of limestone quarries has a higher chance of success if the restoration targets something that it closely resembles in nature (Larson et al. 2007).

Up towards present day there seems to be little to no documentation of successful restoration of habitats favourable for alvars in limestone quarries. Some of the suggested limitations of this are a general lack of literature on hard rock landscape restoration coupled with the absence of clear restoration targets (Larson et al. 2006). An on-going project of limestone quarry-restoration, with the aim of alvar restoration, is conducted by Cementa AB Slite in the municipality of Gotland in Sweden.

1.1 Aim

The aim of this thesis is to compose an evaluation plan for the methods used in a limestone quarry restoration project of the Western quarry of Cementa on Gotland, where the targeted nature type is alvar. The evaluation plan will be based on an analysis of literature in the field of alvar nature and limestone quarry restoration.

1.2 Outline of Report

The background of this thesis presents a brief introduction to alvar and limestone quarrying on Gotland, Sweden, followed by a thorough review of the restoration-project in the Western quarry. The method describes the process of a literature review based on scientific studies. The result part of the thesis presents the findings of the literature review and are followed up by an evaluation plan for the project. The discussion debates the choice of variables and inventory strategy, as well limitations and possible developments of the study, leading to a final chapter with conclusions.

2. BACKGROUND

2.1 Alvar on Gotland

Located off the east coast of southern Sweden lies the elongated, rhomboidal shaped, island of Gotland. The main island stretches 117 km in N-S direction and 45 km in the W-E direction and together with a number of surrounding minor islands, its total surface sums up to 3160 km^2. The bedrock of Gotland dates back to the middle of the Palaeozoic era, some 400-500 million years ago, consisting mainly of limestone and marlstone. This composition has led to an absence of rivers and a few brooks carry water only parts of the year (Manten 1971). The permeable limestone areas of Gotland give rise to areas with scattered vegetation called alvar, with a unique vegetation. Surface depressions are inundated in winter which give rise to lake vegetation that gradually, at its periphery, passes into xerophilous, drought resistant, vegetation (Manten 1971). In contrast the whole alvar can dry up in the summer. The alternation of environmental conditions is reflected in the various occurrence of species from one year to another. Temperature fluctuations in autumn and spring, from below and above zero, cause frost upheaval of soils that prohibits the establishment of deep-rooted perennials (Manten 1971).

2.2 Limestone quarrying on Gotland

Quarrying of limestone on Gotland dates all the way back to the fifth century but saw the rise of its modern form during the early stages of the 20th century, with the establishment of the cement production plant in Slite (Ahlberg and Udd 2009). Today Cementa, in Slite, accounts for more than 75 percent of the Swedish cement production with a yearly volume of 2.5 million tonnes (Cementa AB 2020). The company Cementa AB is owned by Heidelberg Cement, the second largest cement producer in the world (Heidelberg cementgroup 2020). As part of Heidelberg Cement, the plant in Slite derives its environmental policy from the concerns sustainability commitments. One of these are named "Reducing our Environmental Footprint" which aim to include biodiversity enhancement recommendations at the extraction sites (Heidelberg cementgroup n.d.).

Two quarries are today connected to the production plant in Slite: Western quarry, located west of the production plant, and File Hajdar, located roughly 3km from the west quarry in west direction (Figure 1).

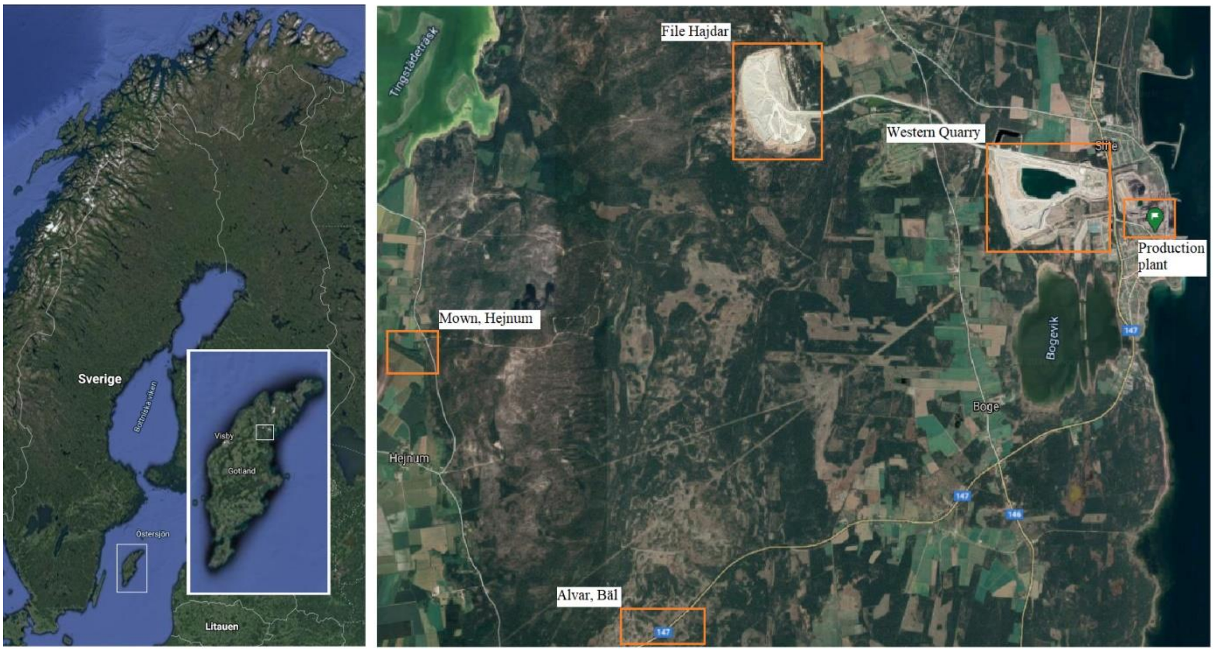

Figure 1. Location of quarry sites, Western Quarry and File Hajdar in relation to the production plant of Cementa AB. The location of the mown in Hejnum and the alvar in Bäl, from which hay was collected, are indicated. Google Maps. Slite, Gotland, Sweden. Map data retrieved April 27, 2020 from shorturl.at/mIW19 (©2020 Google). Screenshot and graphics by author.

2.2.1 Western Quarry

As the name implies the Western quarry is located west of the cement production plant (Figure 1) with a height above the sea of about 0 meters (Figure 2). The quarry makes up a total area of 94 hectares and reaches a depth of approximately 50 meters from the surface to its deepest parts which are currently being water filled (Cementa AB 2017). The geology of the western quarry is almost exclusively made out of marlstone, an impure version of limestone with a greater mix of clay minerals (Cementa AB 2017).

2.2.2 File Hajdar Quarry

The quarry of File Hajdar is located approximately 3 km northwest of the Western quarry (Figure 1) and stretches over an area of about 78 hectares, with a depth of about 30 meters (Cementa AB 2017). The geology of File Hajdar is made out of pure limestone overlaying a layer of marlstone, with the surrounding ground of the quarry being located about 50 meters above sea level. Any loose layer of soil is mainly made out of weathered stone with strong elements of clay (Cementa AB 2017).

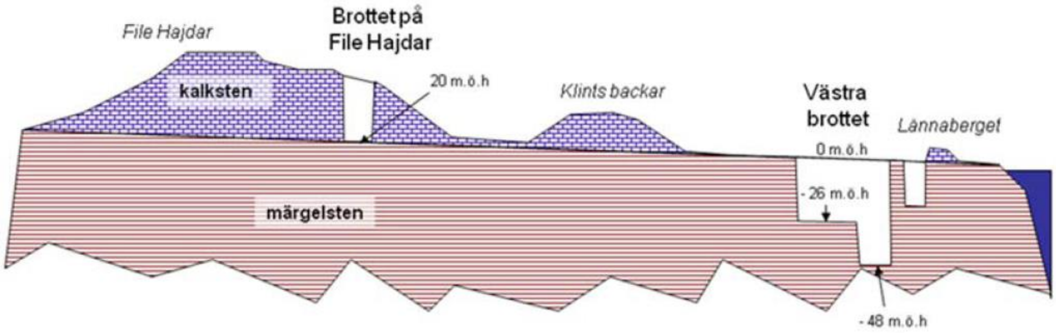

Figure 2. Principal sketch of the geology of File Hajdar and the Western Quarry (“Västra brottet”). The profile is in straight east-west direction, with the Baltic Sea to the far right in blue color (Cementa AB 2017).

2.3 Test site location, targets and descriptions

Under a two-year period (2018 & 2019) three test sites were created in the Western quarry of Cementa AB (Figure 3) as part of a restoration process. The restoration was backed by the management plan of Ulrich Tränkle (2011) and the restoration plan devised by the consultancy Ecogain AB (Björkén et al. 2017). The work was conducted during the summers, from June to August, with the aid of the quarry personnel and its machinery.

The test sites were designed by the consultancy firm Ecogain AB (Granberg 2018), with the aim to resemble habitats favourable for the establishment of alvar. The purpose of the restoration was to identify if Cementa can manage the future restoration of the quarry with their own resources (personnel, machinery and material). The choice of site location was done in dialogue with the quarry manager to make sure that the project would not disturb ongoing quarry activity.

Two sites, A and B (Figure 3) were designed to resemble habitats that was influenced by flooding and drought regimes, respectively. The third site, C, was designed to resemble a habitat favourable for the establishment of a meadow.

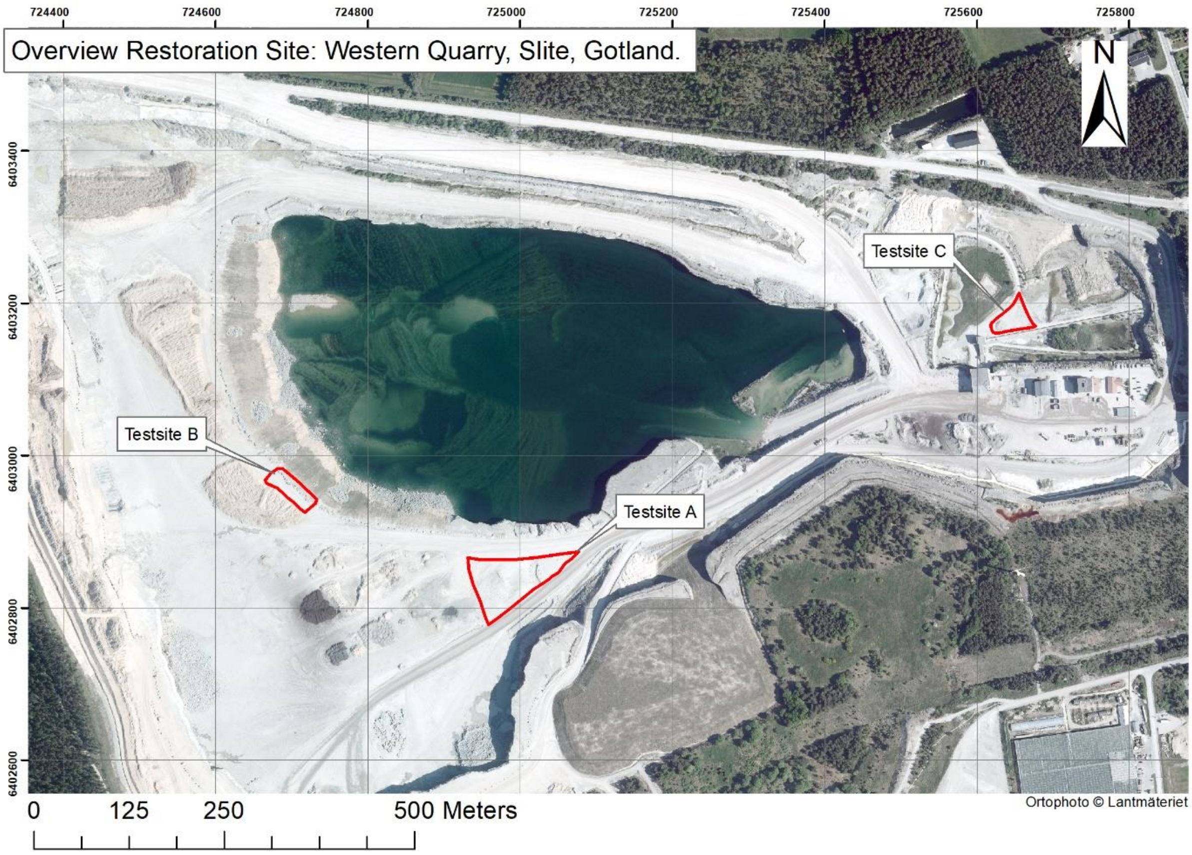

Figure 3. Overview of test site locations in the Western quarry of Cementa AB. The test site areas are marked with red. Ortophoto © Lantmäteriet (2018).

2.3.1 Test site A

The site is located south of the waterfilled part of the quarry (Figure 3) in an artificial depression due to the roads that run north and south of the site. The characteristics of the site gave rise to the opportunity to create an environment influenced by flooding regimes.

The aim of test site A is to create an environment favourable for the establishment of alvar species that are adapted to high soil-moisture content. The aim was also to create environments for the establishment of a meadow like vegetation on various heights on the area (Granberg 2018), however this aim will not be the subject of this thesis. The site is divided in two areas, a large treatment area (left) and a small reference area (right) with a drainage dike dividing the two.

Both areas where prepared by scraping off excess stone dust and other potential obstacles after which both areas were covered with marl clay and no further work was done on the reference area. This area was appreciated not to be affected by the other treatment methods in the same way as the eastern part of the treatment area might be, due to the separation by the drainage dike.

In order to keep moisture inside the treatment area a ridge, made out of sand, gravel and clay at equal ratios was constructed as a western border and a mound was dug up along the road to the south (Figure 4). The ridge was created to establish a foundation in which shrubs and trees can grow (Granberg 2018). A drainage dike was formed between the mound and the truck road as a necessity to not affect the truck road. Finally, two hills were constructed at the eastern border, left to the drainage dike, developed with the same purpose as the ridge (Granberg 2018). Any planting of shrubs and trees on the ridge, or the hills, has not yet been done. Due to differences in elevation it was impossible to make the treatment area completely even and as a result the topography of the northern part of the site is higher than the southern part, making it unnecessary to construct a barrier along the northern border.

The design of the treatment area was intended to create a flooding regime. To keep the water from draining into the drainage dike a two decimeter high metal beam was put in place between the hills and was covered with clay, acting as a water level regulator.

With the barriers in place the treatment area was covered with marl clay and divided up in three parts, a western, central, and eastern part (Figure 4). Topsoil from the original surface of the Western quarry was spread out on the western part to examine what plants that can be found in the material (Granberg 2018). The central part was treated with weathered stone from the quarry of File Hajdar with the same intent as with the topsoil from the Western quarry and lastly, the eastern part was left untreated with only the initial cover of marl clay. The ridge and the hills were covered with topsoil from the Western quarry, and hay from the mown of Hejnum to investigate the success rate for plant establishment of meadow vegetation (Granberg 2018).
A section across the treatment area, along the southern mound, were also covered with the same kind of hay (Figure 4). An area overlapping the western and central part was covered with hay from the Alvar in Bäl to examine the success-rate of using alvar hay to establish alvar plants adapted to moist conditions (Granberg 2018).

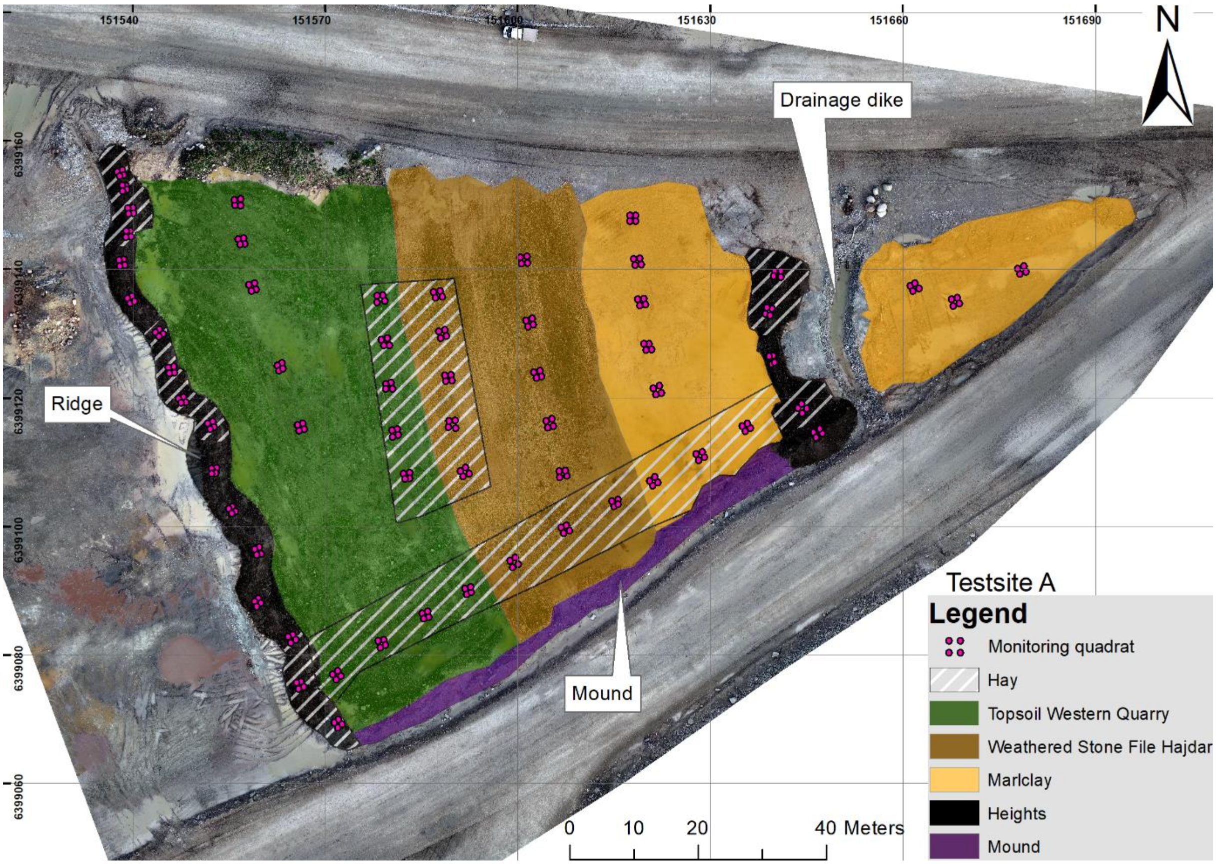

Figure 4. Drone photo of test site A depicting the methods used. Drone photo provided by Cementa AB. Graphics designed by the author.

Follow-up areas were put up in the form of monitoring quadrats (1x1m), using two yardsticks of 2 meter that were folded at 90 degrees. Four fiberglass rods were used to mark out the corners. A green rod was put at the NE corner, a yellow rod at the SW corner and two white rods made out the NW and the SE corner. A yellow, 2mm, cord was then twined around the rods, forming the quadrant. The yellow and the green rod were marked with a yellow loop lock tie with an ID number and compass direction (Figure 5).

A total number of 60 quadrats were installed on test site A (Table 1) and were photographically documented in August 2019.


Figure 5. Monitoring quadrat used at the project site. Fiberglass rods mark out the corners of the quadrat and the frame is made out of a 2mm yellow cord.

Table 1. Number of quadrats for each kind of treatment method on test site A.

Treatment Area	Number of quadrats
Topsoil	5
Topsoil + Hay (Hejnum	4
Topsoil + Hay (Bäl)	5
Weathered stone	5
Weathered stone + Hay (Hejnum)	3
Weathered stone + Hay (Bäl)	5
Marl clay	5
Marl clay + Hay (Hejnum)	3
Heights (Topsoil)	8
Heights (Topsoil + Hay (Hejnum)	14
Reference Area	Number of quadrats
Marl clay (Reference)	3

2.3.2 Test site B

The site is located west of the waterfilled part of the quarry (Figure 3) and is largely made out of bare bedrock. The characteristic of the site, with its good drainage capacity and a slight inclination in a south-east direction, provided a suitable place for the creation of an environment influenced by drought regimes. Thus, the aim of test site B is to create an environment favourable for the establishment of alvar species that are adapted to drought. The site is divided up in smaller areas by the artificial karst cracks which act as drainage that direct any waterflow to the existing waterfilled part of the quarry. The untreated parts are made up of exposed bedrock and are used as a reference area to the parts that are treated with either topsoil or weathered stone.

The area was prepared by scraping off excess stone dust and other potential obstacles. The karst cracks were hacked out by machinery and cleared out by a wheel loader. Since the test site is bordering a clay depot, a mound of gravel had to be put between the site and the depot to prevent any clay from leaking into the area and fill up the cracks. Topsoil and weathered stone were then applied according to Figure 6 to examine what plants that can be found in the material (Granberg 2018). The untreated parts act as barriers between the treated areas. A total number of 26 quadrats (Table 2) were put up in the same way as for test site A (Figure 5) and were photographically documented in August 2019.

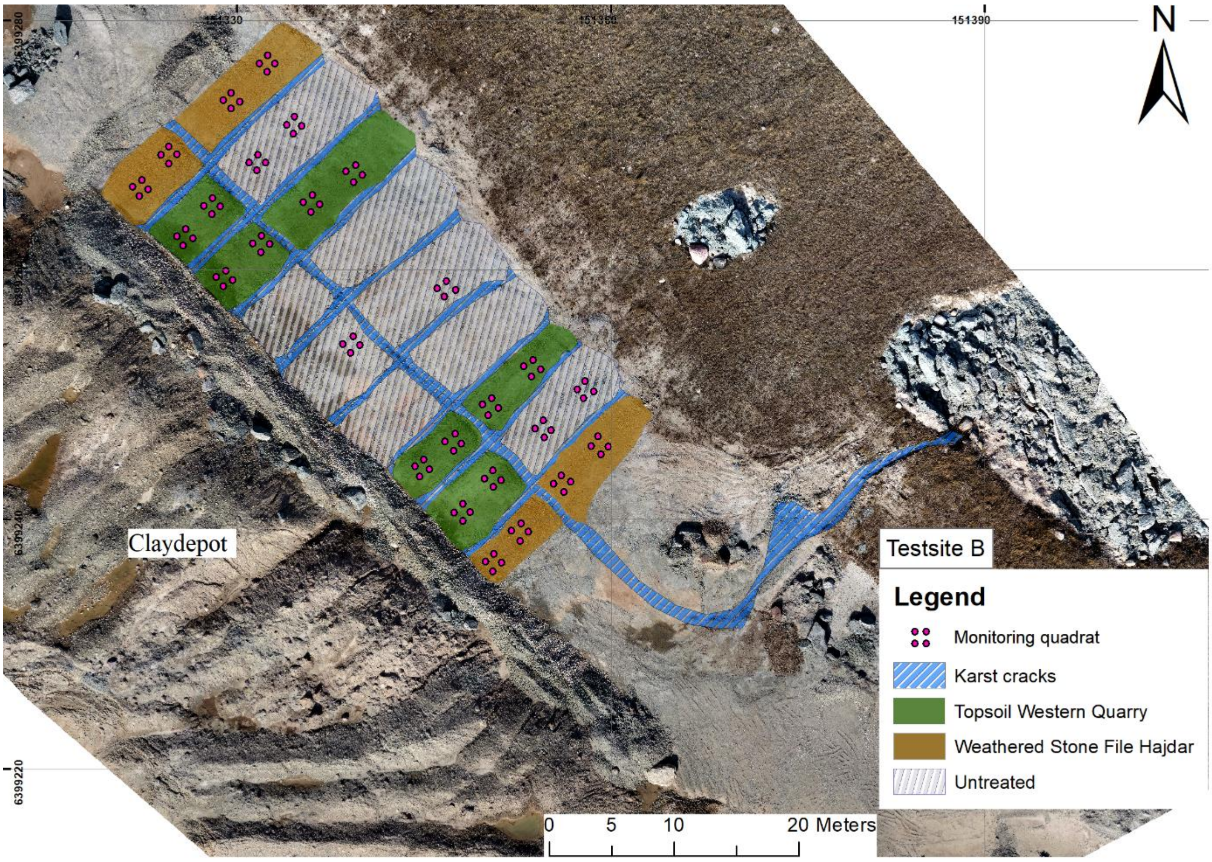

Figure 6. Drone photo of test site B depicting the methods used. Drone photo provided by Cementa AB. Graphics designed by the author.

Table 2. Number of quadrats for each kind of treatment method on test site B.

Treatment	Number of quadrats
Topsoil	12
Weathered stone	8
Untreated	6

2.3.3 Test site C

The site is located east of the waterfilled part of the quarry (Figure 3) in the oldest part of the quarry where extraction ended a long time ago (Tränkle 2011). The area, in which test site C is established, has been left alone for decades and has developed into a meadow-like area with high grass fields and smaller depressions that is being kept waterfilled all year round due to the inflow of water from the quarry walls (Tränkle 2011).

The aim of test site C is to create an environment favourable for the establishment of a herbal meadow, characterised by a slow drainage rate without a flooding regime. The targeted nature type was derived after the existing conditions of the site, to contribute to the already established nature and at the same time add to the site aesthetics (Granberg 2018). No clear objective, other than the ones mentioned above, were specified and so no reference area was established. The site is divided in two areas with an underlaying layer of granite gravel covered with material from the Western quarry and the File Hajdar quarry to examine what plants that can be found in the material (Granberg 2018).

The area was prepared by scraping off excess stone dust and other potential obstacles. In order to facilitate a slow-draining environment the area was covered with a thin layer, approximately 5 cm thick, of granite gravel. Weathered stone was applied to cover the right half of the site whilst topsoil was applied on the left side (Figure 7). Hay from the mown in Hejnum parish (Figure 1) was spread out manually on the top right, and bottom left part of the site. A total number of 20 quadrats (Table 3) were put up in the same way as for test site A (Figure 5) and were photographically documented in August 2019.

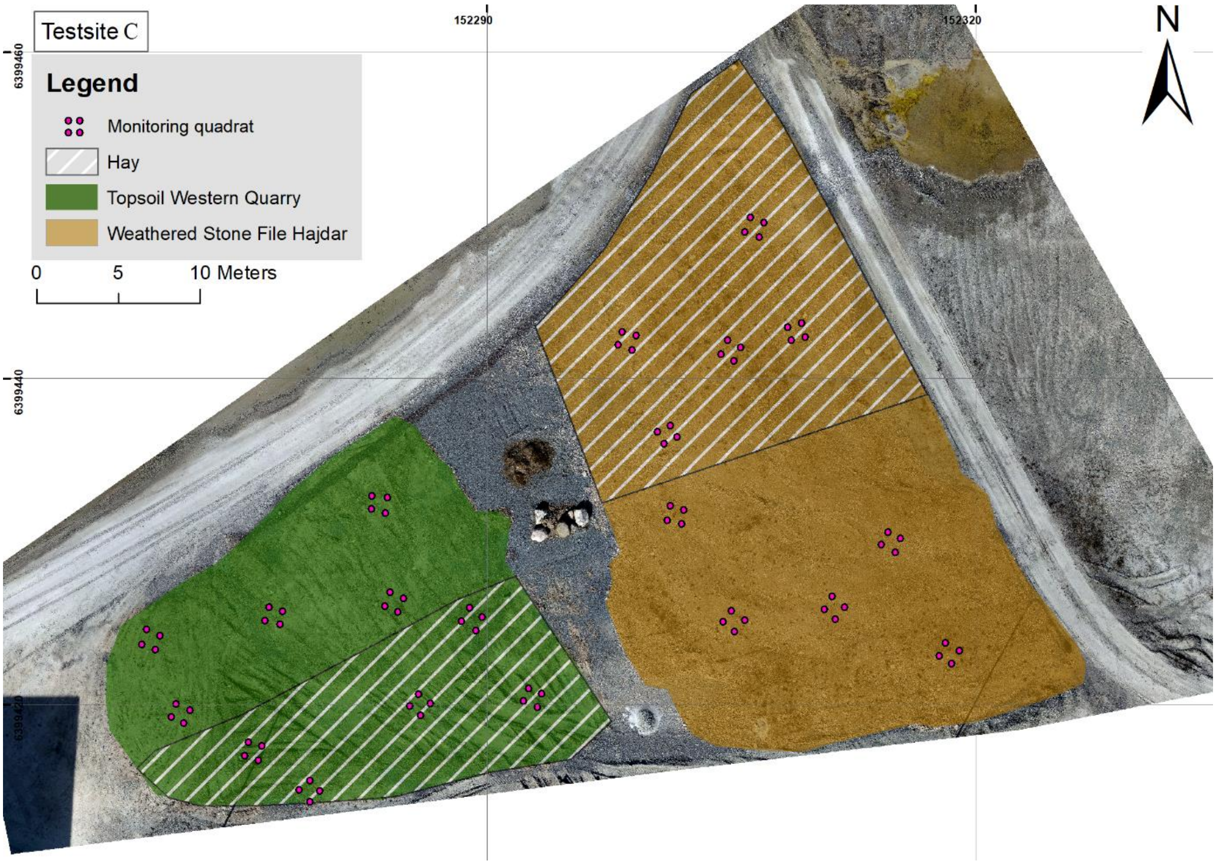

Figure 7. Drone photo of test site C depicting the methods used.

Table 3. Number of quadrats for each kind of treatment method on test site C.

Treatment	Number of quadrats
Topsoil	5
Topsoil + Hay (Hejnum)	5
Weathered stone	5
Weathered stone + Hay (Hejnum)	5

2.4 Description of the material used for restoration

The material that was spread out on the test sites was collected from the Western quarry with the exception of weathered stone, which was collected from the quarry of File Hajdar. Test site A required the highest material consumption, being almost 4 times bigger than site B and C combined (Table 4). Hay and seeds were collected from a mown in the parish of Hejnum, located about 20 km from the File Hajdar quarry (Figure 1), and from a road side (road 147) at the Alvar-area in the parish of Bäl (Granberg 2018), located about 10 km from the Western Quarry (Figure 1).

Table 4. Summary of areal size and material quantity used for all test sites.

	Testsite A	Testsite B	Testsite C
Size (m^2)	6940	930	1460
Material			
Marl clay (tonnes)	3300	-	-
Topsoil, Western Quarry (tonnes)	700	1,5	50
Weathered stone, File Hajdar (tonnes)	500	3	70
Sand (tonnes)	300	-	-
Granite gravel 10-30mm (tonnes)	300	-	70
Hay (Approximated dry volume, m^3)	1	-	1

Table 5. Material description and location.

Material	Description	Location
Marl clay	Glacial deposits, till, with a composition of at least 15% clay is defined as marl clay, which is very calcareous and contains different fractions of sand and gravel. (Lundqvist et al. 2011).	Clay depot in the Western quarry
Granite gravel	Granite in fraction 10-30mm. It was used at project site A to create a ridge and hills surrounding the moist Alvar.	Western quarry
Sand	Granular material with a particle size of 0,6-2mm (Lundqvist et al. 2011).	Western quarry
Weathered stone	Fractioned stone in various sizes mixed with marl clay. When talked about, weathered stone is the top layer that has been scraped of the surface of the, nowadays, quarry of File Hajdar (Located further west of the factory). This material contains elements of various organic materials such as roots and seeds.	Found at the quarry of File Hajdar in depot around the quarry.
Topsoil	The topmost layer from the, nowadays, west quarry. Dark in color with elements of organic elements such as roots and seeds.	Found in depot around the Western quarry.
Hay	Turned, cut and dried grass. Whenever mentioned in this report ’Hay’ is referred to what was collected in the parishes of Hejnum and Bäl	Hejnum and Bäl parish.

3. METHOD

In order to find appropriate methods for evaluation of restoration methods, a literature review focusing on characteristics of alvars and restoration studies was conducted in April to May 2020. Moreover, national environmental monitoring programs related to vegetation and soils were reviewed through the environmental monitoring web site of the Swedish Environmental Protection Agency (EPA) (Östergård and Naturvårdsverket 2020), as a basis for decisions of sampling frequency in the evaluation plan. Finally, other types of literature, regarding plant nutrients and statistical methods, was used as a complement to the literature review, and all together this was the used as a foundation from which an evaluation plan was developed.

Statistical methods were found by reviewing statistical literature by Rogerson (2014).

The literature review was performed in different steps:

- As an initial start literature was collected from the consultancy Ecogain, containing sources from the years 2004 up to 2017 (Table 6). A dialog with Ecogain showed that google scholar had been used as the primary search engine for finding the initial literature with the use of keywords: Alvar quarry, in combination with the words; restoration, reconciliation, remediation or reclamation.
- A review of the material (Review#1, Table 6) was done by skimming through the headlines and the abstracts to find if they had anything to do with Alvar restoration or quarry restoration. Additional literature was found after examining the reference list of the sources and was added to the collection of sources in Review #1.
- Further references were collected using the search engines LUBsearch and JSTOR. Combinations of keywords such as Alvar, restoration, quarry floors and conservation were entered into the two search engines. The addition of sources was compiled with the sources from Review#1 (Compilation#1, Table 6).
- A second, and final review, Review#2 was made on the material from Compilation #1, where references including limestone quarry restoration, Alvar restoration or Alvar analysis were selected. In the end a total of five sources were selected, with four of them being geographically restricted to Canada, and the fifth from Sweden (Table 7). The geographic delimitation of most of the sources was unintentionally. The search for suitable and comparable literature revealed that no apparent documentation of limestone quarry restoration has been conducted in Sweden.

Table 6. Summary of the collection process of literature.

	Report	Peer-reviewed Article	Policy documents	Thesis	Years
Initial material - Ecogain	7	3	2	3	2004-2017
Review #1	2	1	1	-	2006-2011
Compilation #1	11	9	2	1	1979-2018
Review #2 - Final	1	3	1	-	1997-2011

Table 7. Literature in chronologic order showing author, year of publication, location of the study and a general description of aim.

Author	Year	Location/origin	Aim
Schaefer & Larson	1997	Canada	Investigation of Alvar land – baseline information and edaphic factors.
Stark et al.	2004	Canada	Investigation of soil properties on Alvars
Larson et al.	2006	Canada	Comparison of abandoned limestone quarries to Alvars, determining whether alvars will make suitable reference targets for limestone quarry floor restoration.
Larson et al.	2007	Canada	Can Alvars be used as a model for quarry floor restoration?
Jacobson	2011	Sweden	Definition of Nordic alvar and Precambrian calcareous flatrocks

4. RESULTS

4.1 Literature review

Characteristic parameters of alvar

Initial research, conducted by Schaefer and Larson (1997), aimed at establishing baseline information of environmental factors that differ between alvars and adjacent habitats, providing an indication of characteristic factors of alvar. Soil parameters were analysed and used to characterize soil nutrient-levels of alvar and adjacent forest habitats. A total of 21 variables were measured and analysed using a split-plot analysis of variance. The analysis showed a significant difference between alvar and adjacent forest habitat regarding 14 variables: Soil depth, PAR (Photosynthetic Active Radiation), variables related to ground cover, sub-surface temperature, organic matter and levels of nitrate and potassium (Table 8). Seven, out of the 14 variables showed greater values on alvar: Levels of PAR and sub-surface temperature were explained by the absence of shade while the levels of nitrate correlated to the higher frequency of alga and lichens (Schaefer and Larson 1997).

The parameter ‘ground cover’ included species inventory, counting the presence and frequency of bryophytes, lichens, vascular plants and algal taxa (table 8). The inventory also measured species richness, expressed in number of species per plot or square meter. Schaefer and Larson (1997) argues that the high coverage of alga and lichens on alvar was correlated to the amount of exposed bedrock and the extreme temperature fluctuations, ranging from 20 ^{o}C to 43 ^{o}C on a daily basis during summer, by which alga and lichen can cope well with. Schaefer and Larson (1997) proceeds by explaining the nitrogen-fixing abilities of lichens and alga that result in high levels of nitrate on alvar, compared to adjacent forest, and that soil crust of algae enhance vascular plants uptake ability of essential elements.

Further studies conducted by Stark et al. (2004) aimed at examining the properties and development of soil substrate over time on alvar. Stark et al. (2004) measured a total of 15 soil parameters, seven of them in common with the research carried out by Schaefer and Larson (1997) on five alvar sites, thus measuring an addition of eight soil variables compared to Schaefer and Larson (1997): Nitrogen, pH and variables related to bulk density, particle size distribution and carbon (Table 8). Stark et al. (2004) points out that levels of phosphorus and potassium on alvar were uniformly low while levels of magnesium and calcium were high due to the material of the bedrock. Stark et al. (2004) hypothesizes that the cryptogamic crusts composed by alga, lichens, cyanobacteria, mosses and fungi provides a stabilizing function that binds mineral- and organic fractions. The particle size distribution of alvar soil was constituted mainly by silica sand and uniformly low values of clay (Stark et al. 2004).

Earlier studies of limestone quarry restorations

Research conducted in 2006 and 2007 by Larson et al. aimed to find out to what degree abandoned limestone quarries resembles alvars.

A selection of 13 abandoned quarries, with ages ranging from 12-88 years, were sampled for vegetation and environmental features. Larson et al. (2006) compared the data collected from the quarries (Table 8) with the data collected from alvars by Schaefer and Larson (1997) and Stark et al. (2004). Analysis of species composition showed that quarry floors and alvars were similar in regard to the number of plant species found, with 79 species in common by which twenty-nine being characteristic alvar plants (Larson et al. 2007). Larson et al. (2006) determined a number of factors, using a Monte Carlo permutation test, that influenced the species composition on quarry floors and alvar sites: maximum soil depth, age, percent cover of woody debris, exposed bedrock, the cover of bryophytes and lichens, organic matter, levels of nitrate, ammonium, potassium and magnesium. Later on Larson et al. (2007) also concluded that the distribution of species was more related to soil depth and access to water than age since abandonment. The recordings of Larson et al. (2006) included a drought, described as the second worst of the past 57 years (recordings were done in 2005) that resulted in a decrease of species richness on alvar and quarry floors alike (Larson et al. 2006). With the use of a ANOVA test, Larson et al. (2007) found that the only significant difference of environmental factors between alvars (Schaefer and Larson 1997) and quarry floors were the percent cover of bryophytes. Soil nutrient levels showed resembling patterns between the quarry floors and alvar, with higher levels found on alvar (Table 8). While both habitats shared similar values of pH and bulk density the soils of quarry floors were found to contain a greater proportion of silt compared to alvar (Larson et al. 2007). Larson et al. (2007) also concluded that while the inorganic fraction of soils from limestone quarry floors were almost completely calcareous, the soils of alvar were devoid of calcium carbonate. The calcareous soil of quarry floors was hypothesized to be caused by the high proportion of rock tailings (Larson et al. 2007). The physical characteristics and soil chemistry indicate that limestone quarries can be considered a suitable place for the establishment of alvar habitats (Larson et al. 2007).

Table 8. Measured variables from alvar, adjacent forest habitat and limestone quarry floor. Numbers in bold are variables that showed a significant difference, according to Schaefer and Larson (1997), with the use of canonical correspondence analysis (CCA). The level of significance (p-value) for Schaefer and Larson's (1997) data is shown in the fourth column. (* =p<0.05; ** =p<0.01; *** =p<0.001). Table created in Excel by the author.

Variables	Alvar	Adjacent Forest	Alvar vs Adjacent Forest	Alvar	Limestone Quarry
	Schaefer (1997)	Schaefer (1997)	Schaefer (1997)	Stark et al (2004)	Larson (2006) & Larson (2007)
Soil					
pH	7.5	5.8		7.8	7.69
% Moisture	73.3	95.2			
% Organic matter	**25.7**	**38.2**	**(**)**		13.10
Sub-surface Temperature (°C)	**38-43**	**< 38.0**	**(***)**		
Soil depth (cm)					
Mean	**3.6**	**14.3**	**(***)**	2.6	3.05
Maximum	**8.6**	**22.0**	**(***)**	8,0	6.52
Minimum	**0.1**	**2.0**	**(***)**		1.10
Ammonia, NH3 (mg/kg)	25.6				
Calcium, Ca (mg/kg)	8684.1	8589.0		4264.5	3706.63
Magnesium, Mg (mg/kg)	1462.3	1414,0		1159.2	558.34
Nitrate, NO3-N (mg/kg)	**17.2**	**5.7**	**(***)**		10.39
Phosphorus, P (mg/kg)	8.6	13.4		9.3	7.32
Potassium, K (mg/kg)	**169.1**	**292.9**	**(**)**	75.7	112.97
Nitrogen, N (% by weight)				0.77	0.46
Bulk density (g/cm^3)				6.3	0.82
Particle size distribution (%)					
Clay				9,0	11.31
Sand				69,0	52.86
Silt				22,0	35.58
Carbon, C (% by weight)					
Organic				13.5	7.02
Inorganic				6.4	6.34
Total				19.9	13.45
PAR					
2 meter	**92.1**	**31.3**	**(***)**		
30 centimeter	**88.3**	**24.6**	**(***)**		
Ground cover (%)					
Alga	**27.8**	**0.8**	**(***)**		
Bryophytes	5.6	3.8			5.37
Lichen	**4.6**	**1.5**	**(***)**		8.83
Coarse Woody Debris (> 1 cm)	**2.0**	**6.6**	**(***)**		6.07
Direct Shade	**0.4**	**56.5**	**(***)**		
Exposed bedrock	**23.3**	**2.3**	**(***)**		25.68
Leaf litter					18.69
Soil					28.02
Species presence					
Bryophytes	50,0				14,0
Lichen	53,0				32,0
Vascular plants	180,0				200,0
Algal taxa	50,0				
Total number of species	333,0				246,0
Species frequency (%)	x				
Species richness	x				
Average	20 species per plot / 31 species/m^2				8.72 species per plot

4.2 Environmental monitoring

The National Inventory of Landscapes in Sweden (NILS) started in 2003 as a monitoring system of landscape-environments. The program is funded by the Swedish EPA and carried out by the Department of Forest Resource Management (Sveriges Lantburksuniversitet, SLU) with the aim of examining the effects on biodiversity correlated to changes in the landscape. The inventory is carried out every 5 years and includes occurrence frequency of indicator species, species that are characteristic for a certain type of land (Naturvårdsverket 2019).

The Swedish Forest Soil Inventory is carried out by the Department of Soil and Environment at SLU and is funded by the Swedish EPA (Swedish University of Agricultural Sciences 2019). The inventory is done in ten-year intervals with one tenth of the inventory plots being revisited every year (AMAP 2020).

4.3 Statistical methods

Scientific studies that compare groups are in most cases dependent on determining causes of variation, especially when conducting experiments (Sundell 2010). When comparing values from more than two groups, e.g. different treatments, an analysis of variance (ANOVA) should be used to determine if the values are different, or alike, to each other by chance or because of a determining factor (Sundell 2010). A repeated measures ANOVA is suitable when comparing the same variables over time, e.g. yearly measurements (Lund and Lund 2011). To identify the significant factors the ANOVA can be followed up with a post hoc-test (Sundell 2010).

4.4 Evaluation plan

The overall aim of the test site is to create habitats favourable for the establishment of alvar. Once the Western quarry is closed for further quarrying the test sites will be evaluated for large scale application. To evaluate the progression of the test sites they need to be monitored and sampled to identify parameters that are prerequisites for alvar habitats.

Environmental factors

The research by Schaefer and Larson (1997) and Stark et al. (2004) identified environmental factors on alvar that, when compared to other habitats showed a significant difference (See chapter 4.1 for details). Based on the literature these factors (Table 9), could be seen as prerequisites for alvar habitats and analysed.

Table 9.

Soil factors	Ground cover (%)
Soil depth	Alga
Mean	Lichen
Maximum	Coarse woody debris (>1cm)
Minimum	Direct shade
Particle size distribution	Exposed bedrock
Bulk density	**Surface factors**
Organic matter (% of weight)	PAR
Nitrate	2 meters above ground
Potassium	30 centimeters above ground
Phosphorus	Sub-surface temperature
Magnesium	
Calcium	

Sampling method

Soil samples of 30 ml should be collected from all quadrats on the test sites on a minimum depth of 10 centimeter, representing the root zone for the majority of the species found by Schaefer and Larson (1997). Whenever 10 centimeter soil depth is not available the sample is taken to the bedrock. Samples from different test sites should be kept apart. Samples from the same type of method, separated by site, should be mixed together and a sub sample of 125 ml be sent for analysis (Schaefer and Larson 1997).

Plant species inventory

A detailed plant inventory should be carried out in all quadrats on each test site respectively and provide a list of plant species, summed up from quadrats located on the same treatment method. The inventory of each quadrat should contain the name of all found plant species, each species frequency of occurrence, species cover percentage and total species richness (number of species per quadrat). An average value of frequency and species richness can be calculated from quadrats on the same treatment method. If possible, the inventory should be carried out in the field by an experienced botanist and documented the same way as the photographic documentation of 2019. In case the inventory cannot be conducted in field each quadrat should be photographically documented and the photos should be analysed by an experienced botanist.

Interval of inventory

The method of plant documentation should be held consistent and performed on a yearly basis at the same time of year as the initial inventory (August) continuing even after the Western Quarry is closed for quarrying, for a total period of 20 years. The time span is based on the experiences of Larson et al. (2006) with the drought of 2005 that resulted in decreased species richness on the sites. To assess potential outliers in a time series a drought season should thus be included to identify potential causes. After the first 10 years a preliminary evaluation can be done to see if any drought seasons has already occurred. In the case by which the time series include a drought season the interval of documentation can be extended to a 5-year period, in accordance to the NILS-programme. Soil analyses should be carried out annually until the Western quarry closes for quarrying. After that, an evaluation of the treatment should be done. Depending on the evaluation the sampling interval for soil analysis can be adjusted to every five years, or every 10 years following the approach of the Swedish Forest Soil Inventory (Swedish University of Agricultural Sciences 2019). This will help to determine if potential differences between test sites depends on soil chemistry or treatment method.

Statistical analysis

Each test site should be analysed separately with an ANOVA test (See chapter 4.3) comparing all measured variables from each quadrat. The treatment methods on test site A and B should be compared to their respective reference sites to see if there are significant differences between them. There is no reference site for test site C. Analysis can be done comparing the effect of hay coverage on each material type. The ridge and the hills on test site A (Figure 4) should not be part of the analysis since the subject of the analysis regards alvar habitat.

The collected data sets up until the year of closure can be evaluated with the use of repeated measures ANOVA, evaluating each treatment method on all test sites separately.
The dependent variables are the composition and frequency of plant species on each treatment method. The independent variables are the environmental factors.

If the repeated measures ANOVA test shows a significant difference between the treatment methods a post hoc-test should be carried out to identify the variables that causes the difference (Sundell 2010).

5 DISCUSSION

North American alvar compared to Nordic alvar in Sweden

The literature, on which the evaluation plan is based, is centred around the alvars and limestone quarries of North America. It can be questioned if the results of the studies are applicable to alvar restoration in Sweden. However, Schaefer and Larson (1997) points out that there is a number of alvar species that occur in both North America and Sweden including 12 species of bryophytes, 10 species of lichens, 10 species of vascular plants and a singular occurrence of blue-green alga. Apart from pointing out specific species Schaefer and Larson (1997), with the aid of Swedish literature, even gives example of alvar communities that bear resemblance to the ones found in North America. Since alvar vegetation is dominated by low-lying vegetation, the physiognomy across continents also shares similarities. This fact, in combination with the comparison from the literature, might provide a safe assumption that north American alvar is suited for a first comparison with Nordic alvar in Sweden. Further research should however include confirmation from Nordic studies of alvar.

Evaluation of environmental factors

There are numerous environmental factors that governs vegetation patterns: Abiotic, i.e the non-living, physical components and biotic, i.e. the living factors such as animals (National Geographic n.d.). Each type of vegetation is governed by different environmental factors and it is therefore depending from site to site what factors should be measured. The variables included in the evaluation plan are based on comparisons between alvars and other habitats in Schaefer and Larson (1997) and Stark et al (2004). There might be other variables that should be included in the inventory of the test sites in the Western quarry.

The literature review reveals that pH is a variable that differs between alvar and adjacent habitats, indicating its importance as being a part of the soil analysis. Phosphorus, calcium and magnesium are considered primary or secondary nutrients, indicated by Chapin et al. (2011) but are also values, documented by Larson et al (2006) to be found in high levels on alvar. PAR and sub-surface temperature are factors that might not be possible to measure for economic and time-saving reasons and might therefore be excluded from the analysis. With the target habitat for the test sites being alvar, an extensive list of soil parameters should be analysed to facilitate comparison with Nordic alvar. Extensive datasets might also provide higher accuracy for the statistical tests used in the evaluation of large-scale application.

Evaluation of plant species

Alvar habitat are often seen as rich in species with a very distinctive vegetation. Larson (2006 & 2007) analysed the composition of plant species on alvar and limestone quarry floors to find similarities between them. The results showed that the species composition of alvars was made out of bryophytes, lichens, vascular plants and alga (Larson et al. 2007). A photographic documentation of the quadrats on each test site was carried out in August of 2019 but were never analysed. A time-saving procedure would be to continue with the photo documentation on a yearly basis. Since the documentation itself only demands some level of photographic experience this can be done by someone with little or no knowledge of plants, while the analysis should be carried out by an experienced botanist (Granberg 2018). The procedure of photographic documentation brings factors of uncertainties, such as picture quality and camera angle but it also opens up for more flexible and possibly less demanding, physically speaking, ways of analysing then when analysing in field. Because of the uncertainties of photographic documentation (LaFrankie and Chua 2015) it should be complemented by an actual field inventory, conducted by an experienced botanist, whenever possible.

Frequency- and cover percentage are both a measurement of abundance (The Woodland Education Centre n.d.) and can be combined to give a more specific view of the collected data. Frequency is a measure of a species occurrence in a sample and indicates how common a species is at a point in time. Percentage cover is a measure of abundance, indicating how much space a species occupies in a sample. The combination of frequency and cover can provide information of how species are distributed over the whole area (The Woodland Education Centre n.d.) and also the change in species composition over time.

Interval of documentation

The interval of documentation is based on the fact that quarrying will end in the Western Quarry in a couple of years. Due to the absence of a definite end date for the closure of the quarry the documentation of plant species should be conducted yearly over a time-period of 20 years. If the time series includes a year with a drought period it should be followed by annual measurements until the plant population recovers to the levels from the year before the drought. This will minimize the risk of wrong assumptions being made about the progression of the test sites. The documentation will thereafter be conducted every 5 years, in accordance to the NILS-programme carried out by the Swedish EPA (Naturvårdsverket 2019). The sampling interval for soil analysis is motivated by the slow progress of soil substrate formation on natural alvar habitat, ranging from 100 to 500 years (Stark et al. 2004). Yearly analyses are motivated, as mentioned in the results, by the uncertainty of a closing date for the Western quarry while the 5- and 10-year intervals might provide a more manageable monitoring from an economic and time saving perspective.

Statistical analysis

When quarry activity seizes in the Western Quarry an evaluation of the methods must be conducted, even without the presence of a drought period in the data set, in order to decide if the test sites should be scaled up for the rest of the quarry.

Because species composition on alvar differs from year to year, as in the case of the 2005 drought (Larson et al 2006), one cannot expect a linear progression of species composition towards alvar habitats.

6 CONCLUSION

Vegetation types and soil characteristics that are distinctive for alvar could be identified with the help of research studies from alvar habitats in North America. These variables were used as a foundation from which a plan of evaluation was formed. Studies from places closer to Sweden, where alvar is situated, would provide more support for the analysis of these variables. The sampling frequency in the evaluation plan was based on the method of existing monitoring programmes, in combination with the time-plan for the Western quarry. The conditions on alvar are unique and special, making restoration methods dependent on a higher, initial, sampling frequency with an early evaluation after the first five years.
It is important that data is available for evaluation when it is time for large scale restoration of the Western quarry, after which new decisions should be made on how the evaluation plan should proceed regarding inventory frequency and analysis.

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