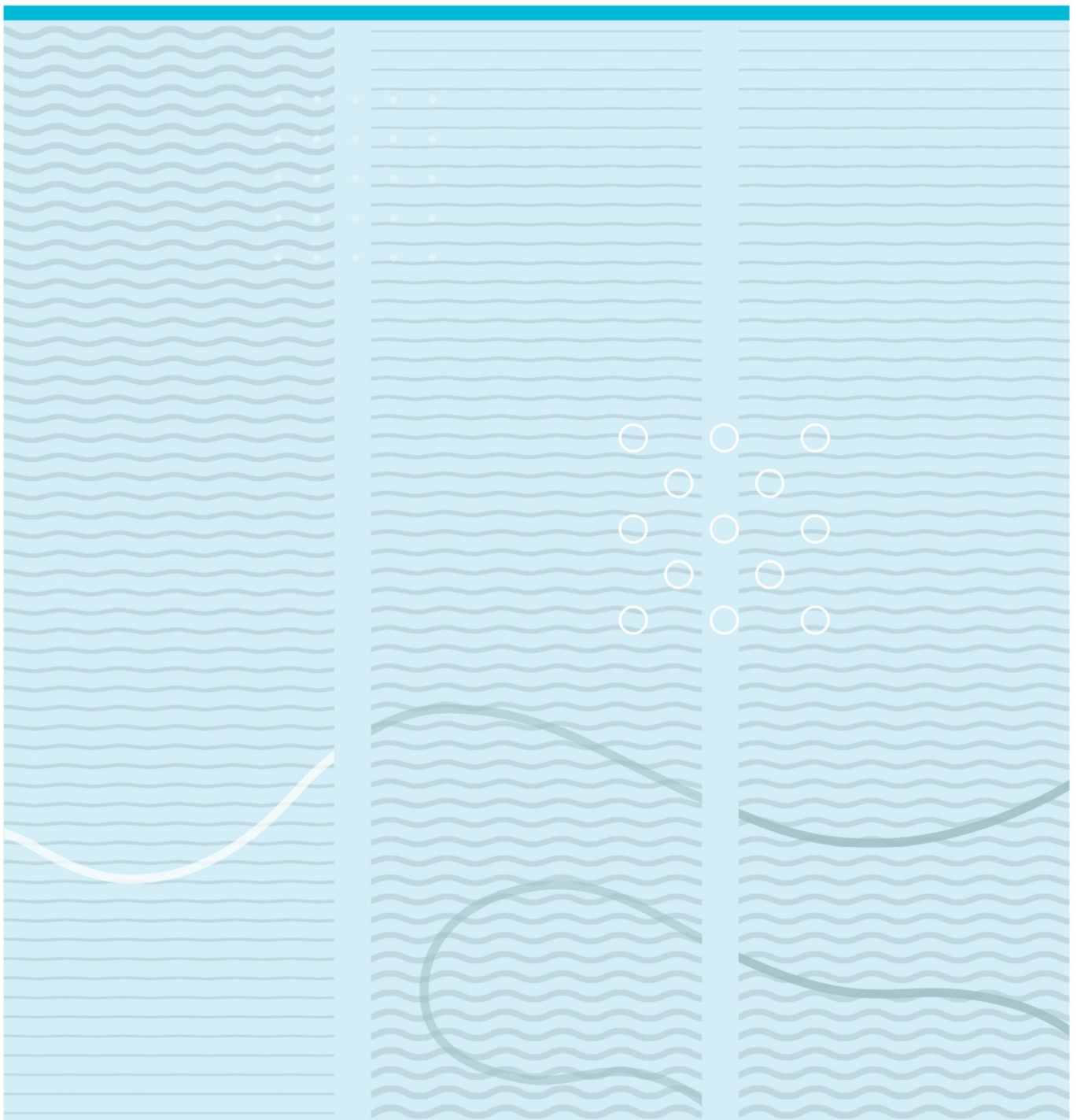


Marina Bakhtina

Vegetation composition of extensive green roofs in Oslo, Norway



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This thesis is worth 60 study points

Abstract

Green roofs are systems which can be considered dynamic and living and at the same time engineered constructed system. In this thesis, I am looking at a specific type of green roofs – extensive green roofs with sedum-moss vegetation, which has a shallow depth of growing medium. The major objective of this thesis is to study extensive green roofs in the Oslo region to discover how their vegetation composition has changed after installation and to relate the vegetation composition to environmental conditions. Vegetation analyses were conducted and soil samples were taken on 18 extensive green roofs which were one to 13 years old. In addition, information about composition of the originally planted species, for each studied extensive green roof was obtained to compare with the current vegetation composition and richness. The results demonstrate that richness of the originally planted species has declined after the extensive green roofs' installation. However, the richness of plant species has increased, because of spontaneously established species that were found. Half of the studied plots experience decrease of the originally planted vegetation. The results are discussed to find out the reasons behind the difference and changes of the vegetation composition on the green roofs. Abundance and richness of species are mostly affected by a biotic factor, such as the type of *Sedum* mix, abiotic factors, such as soil depth, pH, phosphorus, potassium levels, organic matter, and age. The conclusions are drawn for various factors that affect vegetation on the green roofs. Deeper and more acidic soils with a higher amount of organic matter support more spontaneously established species. Decline in abundance of originally planted species is associated with decline of pH level in the soil on extensive green roofs, shallow soil depth, and succession dynamics.

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Abbreviations

The following abbreviations are used in the thesis:

EGR	extensive green roof
SES	spontaneously established species
P	phosphorous
K	potassium
Mg	magnesium
Ca	calcium
CCA	Canonical Correspondence Analysis
PCA	Principal Component Analysis
DCA	Detrended Correspondence Analysis

Foreword

This thesis is submitted to the University College of Southeast Norway in partial fulfilment of the requirements for the degree Master of Science. This work has been conducted at the Institute of Environmental and Health Studies, the Faculty of Art and Science, University College of Southeast Norway in 2014–2016. In the beginning of the studies, the institution was called Telemark University College.

The motivation for this thesis originates in challenges that the modern urban society face every day. More and more new houses are growing around big cities, and Oslo is not an exception. Who wants to live a compact life without a private yard or big house? Probably, only a minority is ready to give up their habits and consume less. A big house for a lonely person sounds very dramatically, but despite the statistics that shows that there is less people per private household in Oslo city, the size of urban settlements slowly grew. According to the main alternative of the population growth in the Oslo region for 2014-2040, it can raise for a third. Poor quality of green spaces in cities leads to urban sprawl and degradation of nature around cities. Green city and Compact city approaches can help to create dense cities with good quality of green space which leads to environmental, economic, and social benefits for citizens. Green roofs are a tool for ecosystem replacement in the limited space of dense cities. Therefore, I decided to study green roofs in the Oslo region.

My work on this thesis was supported by several academics and professionals. I would like to thank my supervisor Associate professor at University College of Southeast Norway Stefanie Reinhardt for the help, support and useful advices, help with plants identification and pleasant communication. I would also like to thank Professor Arvid Odland for advices for statistical analysis, Head of department Live Semb Vestgarden and Engineer Tom Aage Aarnes for the help with soil analysis from University College of Southeast Norway; Biologist Torbjørn Høitomt for help with mosses identification and Biologist Jon Tellef Klepsland with lichen identification from BioFokus. I would also like to thank people from industry including Director of Research and Development Ralf Walker from ZinCo GmbH for advices for choosing factors for study, green roof companies in Norway including Ole Christian Trandem from ZinCo, Bengt Tovslid from Bergknapp, Jostein Sundby from Vital Vekst, Karen Flinder from Veg Tech, Øistein

Kvarme from Blomstektak, and Reiersøl Planteskole for providing information. Thanks to all the people who opened their green roofs to me and allowed to study them.

Bø i Telemark, Norway / 28 June 2016

Marina Bakhtina

1 Introduction

1.1 Green roofs in urban regions

High-density development and restrained urban conditions in cities allow less space for plants. One of the ways of bringing nature back to city is a green roof, which can also be called a living roof (Sutton, 2015). Utilizing roof space for vegetation is a good practice in the dense city environment. Green roofs can be part of green corridors ("Grønne korridorer i Oslo skal hjelpe humlene," 2015), support biodiversity and storm water mitigation, and introduce a replacement of habitat for some species.

Green roofs with public areas or private terraces or even good view on a green roof can raise a property value (Barton et al.). Green roof should get appropriate conditions to thrive and give feedback to people, and the urban environment.

The major contribution of green roofs to urban ecosystem services in Norway is represented in the report by Magnussen et al. (2015). The services covered in the report include CO₂ uptake, local climate regulation, and storm water management. The emphasis is made on reduction of runoff after rainfalls and snowmelt (Braskerud, 2014).

Climate conditions in Norway are tough which often make it challenging to apply international research and best practices in this field. German FLL Guidelines for green roofs is the main guide in Europe (Forschungsgesellschaft, 2008), and Malmo green roof botanical garden is one of the leaders in Scandinavia for testing EGRs. However, Norwegian precipitation gradients are different from to Germany and South Sweden.

1.2 Extensive Green Roofs

Green roofs are classified as extensive, semi-intensive, and intensive (Sutton, 2015). The Extensive Green Roof (EGR) type has shallow depth of growing medium (less than 15 cm). This type of green roofs does usually not need irrigation system and requires minimum maintenance. Intensive green roofs, also known as rooftop gardens, can have deepest growing medium, applied for roofs which allow more weight loads on building construction. The soil depth of semi-intensive green roofs is between extensive and intensive.

Layers of extensive green roofs may be different and the consistence depends of the vegetation they need to support. They mimic the natural soil layers (Fig. 1). For the EGRs, the usual layers from the top are:

- Vegetation and growing medium (substrate)
- Filter sheet (drainage filter)
- Drainage layer
- Protection layer (root barrier) and waterproof membrane

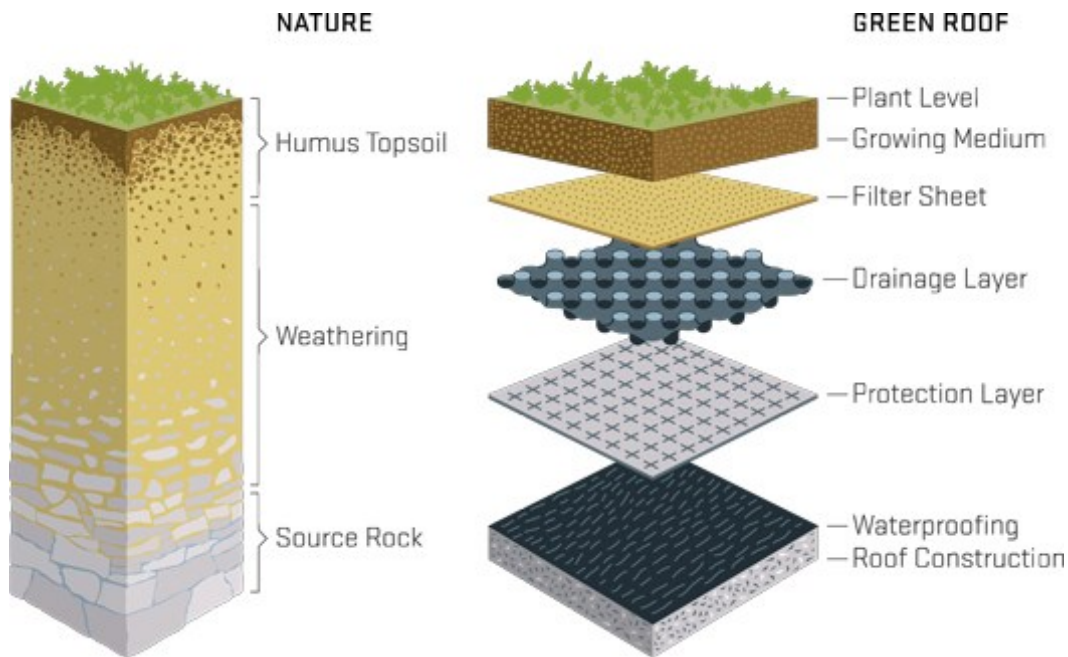


Figure 1. EGR system and layers (Nagler, 2008)

Modern EGRs (*sedum*-moss) are the most popular type of green roofs in Norwegian urban environments. Even if Norway has a long history of traditional green roofs or turf roofs (in Norwegian: *torvtak*), the new technology allows room for improvement.

1.3 Vegetation on extensive green roofs

According to their vegetation composition EGRs are divided into *sedum*-moss, *sedum*-moss-herbaceous, *sedum*-herbaceous-grass, and grass-herbaceous roofs (Forschungsgesellschaft, 2008). A green roof with the type of vegetation *sedum*-moss includes plant species from the *Crassulaceae* family.

Species composition of EGR usually includes genera such as *Sedum*, *Phedimus*, and *Hylotelephium*. EGRs in Norway can include four native Norwegian species. All other species that are planted on EGRs are considered to be introduced. The native

Norwegian species used on EGRs are *Sedum album*, *Sedum anglicum*, *Sedum acre*, and *Sedum rupestre* (Hanslin et al., 2015).

Two species used on EGRs in Norway *Phedimus spurius* and *Phedimus hybridus* are forbidden to plant, sell, and import in Norway from January 1, 2016 ("Forskrift om fremmede organismer," 2016). Green roofs are an exception, although an approval should be received in Oslo, as a region with 'open shallow lime soil' (from Norwegian: åpen grunnlendt kalkmark). This prohibition does not apply to sterile cultivars.

EGRs (*sedum*-moss) represented limited ability for biodiversity, because a few spontaneously established plants were found (Emilsson, 2008). In the experimental study of *sedum*-moss EGRs in Malmö, Sweden found Spontaneously Established Species (SES) are ruderals which usually present on dry places. It is no difference over time of establishment of spontaneous species, but more species colonize EGRs in spring than in autumn, and the species composition is different between these seasons. The cover of moss increases during time; it can be explained by unfertilized conditions.

Favorable conditions for Sedums can be created in EGRs. Many succulent species have adaptation to water availability; they can switch between C3 and CAM photosynthetic pathways (Lambrinos, 2015). This water use plasticity is species-oriented, *Sedum album*, *Phedimus kamtschaticus*, and *Phedimus floriferum* are good examples. *Sedum album* is the leader in surviving in the water absence conditions.

Presence of mosses on the EGRs can lower the temperature and increase water availability, which can give opportunity for vascular plants to establish (Lambrinos, 2015).

1.4 Environmental conditions on extensive green roofs

Abiotic factors which influence green roofs are temperature, precipitation, growing medium, wind, and insulation. Their gradients can be helpful for understanding green roof niches. Abiotic factors such as temperature and rainfall are more important to species richness on EGRs than roof size, slope and age (Rowe, 2015). Age can influence species diversity until some point, after which it becomes limited and the length/duration of study is important for recommendation of species suitable for EGRs.

Biotic factors include human impact of plant choice for roof, migration of invasive species, competition for water, and nutrients (Sutton, 2015).

Research in Norwegian climate indicates that after two seasons of monitoring there is an interaction between green roof system, vegetation mix, and climate conditions (Hanslin et al., 2015). Vegetation problems on green roofs in Oslo can be caused by insufficient slope to the drain or lack of emergency overflow, wind, and SES (Noreng et al., 2012).

Soil for the EGRs (sedum-moss) is specially designed to support life of *Sedum* species. Despite the fact that *Sedum* species can usually grow on nutrient-poor soils, the EGR growing medium is typically homogenous and nutrient-rich. Slow-released fertilizer is used for maintenance and pre-grown mat production. Well-being of vegetation on EGRs is important also because it prevents substrate loss from wind pressure (Sutton, 2015). Soil is designed to hold water and give soil to drain for avoiding standing water near roots of plants. The soil composition is important for plant cover, total succulent cover, and biomass development (Emilsson, 2008). According to Best et al. (2015), "Mineral base can take diverse forms: naturally sourced clay, sand, gravel, or vesicular volcanic rocks or artificial or modified minerals such as perlite, vermiculite, rockwool, or expand clay, slate or shale". Compost, peat, coconut coir, decomposed sawdust, and bark can be used as organic ingredients in engineered soil.

Substrate depth of less than 10 cm can support only drought adapted species, because store of water available for plants can increase with the soil depth (Lambrinos, 2015). Therefore, EGRs with the shallow substrate can support only drought-tolerant species such as succulents. However, even between them the soil depth will influence species coverage of all and individual species (Rowe, 2015). In Berlin, without irrigation the *Sedum* species started to dominate over wildflower meadow species. Deeper substrates can increase the range of potential species to graminoids, herbs, and woody plants.

Organic matter is one of the most important components in EGR substrates, because it improves water retention (Buffam et al., 2015). Shallow substrate and winds can influence drying of substrates. The amount of the organic matter in EGRs in the multilayer construction is given in the maximum and optimal amounts (Forschungsgesellschaft, 2008). The latter is usually much smaller, because the organic

matter can easily decompose in several years and lessen an already shallow depth of growing medium (Luckett, 2009). Rising amount of organic matter occurs due to high biomass production of *Sedum* species.

Nutrients in the substrate are vital for ERGs. It is apparent from the literature that certain nutrients affect vegetation on EGRs. Macronutrients (N, P, and K), secondary nutrients (Ca, Mg, and S), and some of micronutrients are important for plant growth and development (Best et al., 2015). They must be present in the green roof substrate in soluble form.

pH level influences the nutrients uptake by plants. A range of pH level for EGRs in Norway is recommended in FLL Green Roof guide (Forschungsgesellschaft, 2008). Some studies of green roofs say that the pH declines over time (Thuring et al., 2014). However, it is important to avoid acidification to support the originally planted succulent composition (Emilsson, 2008; Zheng et al., 2013).

Bulk density (or Specific weight) is important for the roof limited weight loadings (Best et al., 2015). Bulk density should also influence the thermal conductivity, and saturated weight.

Maintenance treatments have also impact the SES such as annual removing and fertilizer treatments (Rowe, 2015). SES have difficulties in colonizing on the roofs with annual removing treatments.

1.5 Objectives of the study

Vegetation composition on EGRs is changing over time (Rowe, 2015). Vegetation composition depends on different biotic and abiotic factors (Sutton, 2015). Biotic factors that influence EGRs including specific species mix to be planted and competition between species. Maintenance treatments and SES also can influence vegetation composition. Even though there has been a study conducted in Norway studying EGRs (Hanslin et al., 2015; Noreng et al., 2012) there is little information available on the change in vegetation composition and richness over years.

The main aims of this study are:

1. Has the vegetation composition on the studied EGRs in Oslo changed after it has been established?

2. How has the composition changed?
3. What is the relation between vegetation composition and environmental variables?

2 Materials and Methods

The data for this master project have been collected from three main sources: (1) communication with companies that constructed the studied EGRs, and roof owners, (2) vegetation sampling on the roofs, and (3) soil samples collected on the roofs. Several methods were used for data analysis.

2.1 Preparation for fieldwork: collection of general data

Locations of EGRs in Oslo were found through search on websites of green mat suppliers, in the news, and by contacting Oslo municipality. Search in online maps such as Google map, Gulesider map (<http://kart.gulesider.no/>), and Norge i Bilder (<http://www.norgeibilder.no/>) gave same good results. I contacted the main green roof companies in Norway, interviewing them and, asking to provide general information (data related to the construction and contact details of roof owners). The interviews were done prior to the field work, on the field or after the field work depending on the availability of the companies and roof owners.

Interview questions for supplier companies related to construction aimed to acquire the following data:

- Area of the green roof
- Year of implementation (installation)
- Type of mat (plant species in the mix)
- Type of green roof system (all layers) and soil depth
- Flat roof or the roof with slope

Interview questions for the owners of the green roofs related to annual maintenance:

- Is someone taking care of the EGRs now? If yes, please specify for each year:
- What kind of maintenance have you been using since installation?
- Are you taking out weed plants and how often?
- What amount of fertilizer do you use and how many times a year?
- Have you made any reconstruction and other changes at this green roof?
- Did you have any problems with this green roof over the years?

I did not receive enough general data from the green roof suppliers before the fieldwork, and for the locations of the green roofs. In addition, I did not succeed in getting access to the EGRs from some of the owners for security reasons and other issues. Therefore, EGRs I studied were not chosen randomly. Still, I tried to include both new and old EGRs. The amount of EGRs in Oslo has been increasing over the time, and it was easy to find new EGRs. I also tried to select EGRs in different parts of the city. However, I studied some clusters of green roofs (for example, in Pilestredet park, Sørenga, and Bjørvika). Overall, my choice was limited by the availability of contact information and accessibility of the green roofs.

The EGRs studied in this thesis are located in the Oslo region, including Oslo city and Bærum municipality (Fig. 2). The border of Oslo city is taken according to Oslo municipality (kommune, 2013). One EGR from Bærum municipality on Fornebu peninsula has been included into the fieldwork (Fig. 2, bottom, left part).

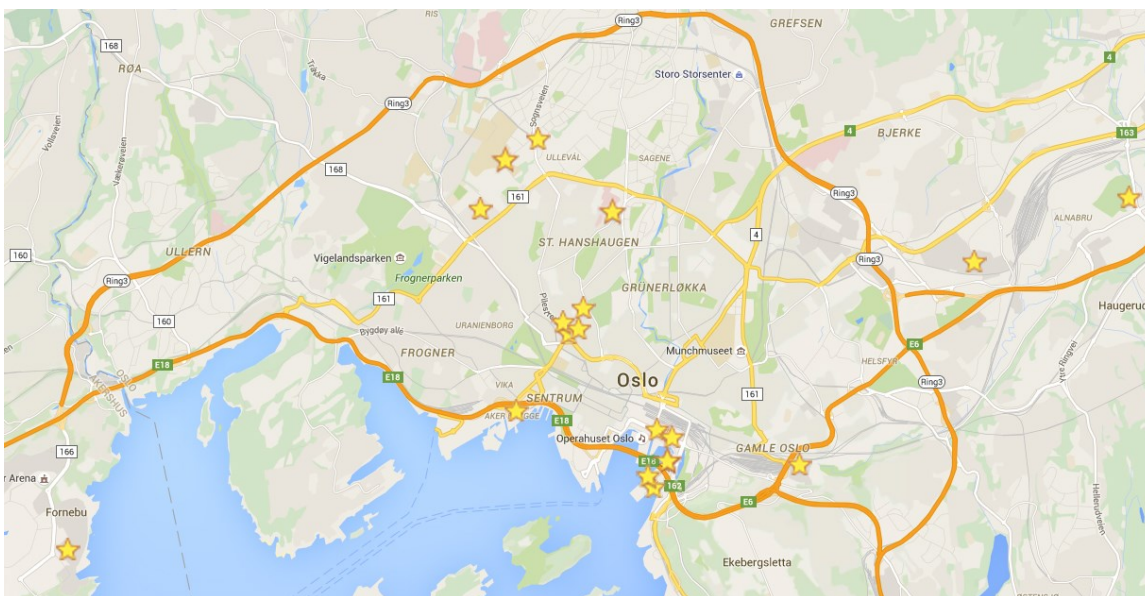


Figure 2. Map of Oslo showing the location of the 18 studied EGRs

The fieldwork in Oslo region has been conducted from July 11 to August 15, 2015. In total, I studied 92 plots and collected 46 soil samples on 18 EGRs (Fig. 2, yellow stars). In order to narrow down the study domain and avoid extra factors, I selected flat EGRs. The steepest slope found in the studied EGRs is 5 degrees (on EGR of Alfaset Cremation Center), and I consider this EGR as a roof with a slope.

In the process of search and identification of EGRs, I have obtained information from producers of *Sedum* mats for EGRs:

- ZinCo Norge AS (<http://www.zinco.no/>)
- Veg Tech AB (<http://www.vegtech.no/>) / Blomstertak AS (<http://www.blomstertak.no/>)
- Vital Vekst AS (<http://www.vitalvekst.no/>)
- Bergknapp AS (<http://www.bergknapp.no/>)
- Reiersøl Planteskole AS (<http://www.reiersol.no/>)
- BG Byggros A/S (<http://www.byggros.com/>)

The general information about the studied EGRs is summarized in Table 1.

Table 1. General information on the studied EGRs

#	Abbreviation	Building name	Building address	Area (m ²)	Supplier company	Year of implementation	#of plots
1	HOEG	Lovisenberg Diaconal University College	Lovisenberggata 15B, Oslo	320	ZinCo	2013	4
2	GJEN	Norsk Gjenvinning AS	Haraldrudveien 31, Oslo	27000	Blomstertak	2006	12
3	PI25	Pilestredet Park 25	Pilestredet Park 25, Oslo	120	Veg Tech	2006	4
4	SORE2	Sørenga II, 65	Sørengkaia 65, Oslo	150	Blomstertak*	2012	4
5	PI41	Pilestredet Park 41	Pilestredet 32 (41), Oslo	710	Veg Tech	2012	6
6	FORN	Statoil (IT Fornebu)	Martin Linges vei 15, Fornebu	9000	Blomstertak	2012	8
7	STEN	Pilestredet Park, Stensberggata 10,12	Stensberggata 10-12, Oslo	700	Veg Tech	2006	6
8	PI20	Pilestredet Park 20	Pilestredet Park 20, Oslo	380	Veg Tech	2006	4
9	UNIV	University of Oslo, Blindern	Georg Morgenstiernes hus, Blindernveien 31, Oslo	250	Reiersøl Planteskole	2002	4
10	SORE1 (build85)	Sørenga I, 85	Sørengkaia 85, Oslo	110	Bergknapp/Byggros	2011	4
11	SORE1 (build99)	Sørenga I, 99	Sørengkaia 99, Oslo	120	Bergknapp/Byggros	2011	4
12	BARN1	Sognsveien barnehage	Sognsveien 13, Oslo	270	Veg Tech	2007	4

#	Abbreviation	Building name	Building address	Area (m ²)	Supplier company	Year of implementation	#of plots
13	BARN2	Solbærtorvet barnehage	Gardeveien 4, Oslo	334	Vital Vekst	2010	4
14	AKER	Aker Brygge	Bryggegata 16, Oslo	700	Bergknapp	2014	4
15	BJOR	Barcode project, 10	Dronning Eufemias gate 10, Oslo	60	Vital Vekst	2009	4
16	BJOR2	Barcode project, 18	Dronning Eufemias gate 18, Oslo	400	Vital Vekst	2013	4
17	KREM	Alfaset krematorium (cremation center)	Nedre Kalbakkvei 99, Oslo	1050	Vital Vekst	2009	8
18	KVAR	Kværnerbyen	Turbinveien 4B, Oslo	600	Bergknapp	2013	4

The area and year of implementation for the EGRs were mostly obtained from interviews with the supplier companies (or on their websites). The area for some roofs (#3, #4, #5, #7, #10, #11, and #12) were measured by the tool "Mål areal" at the website Norge i Bilder (<http://www.norgeibilder.no/>). Year of implementation for roofs #4, #5, and #12 was estimated by the change of satellite images from different years to find when the EGR appears on Norge i Bilder website. Roof #5 was established between 2011 and 2013, so I consider year 2012 as year of implementation. The age of the roofs was count from installation to fieldwork year of 2015.

*The EGR of Sjørenga II is considered to be made by Blomstertak, because they repaired it, after the other unknown company.

The information about originally planted species which used in the *Sedum* mixes for each EGR has been obtained by personal communication with companies ZinCo, Vital Vekst, Bergknapp, Veg Tech/Blomstertak, Reiersøl Planteskole. Byggros *Sedum* mix composition was taken from its website. It was confirmed by the companies that these mixes were used in the period when the studied EGRs were implemented.

2.2 Floristic sampling and soil sampling

Floristic sampling was done in the field. The plants were identified partly on the field and partly at the biology laboratory at University College of Southeast Norway, campus Bø. Accepted Latin names, Norwegian names and plants characteristics were checked in several books for vascular plants (Lid et al., 2005) for bryophytes (Hallingbäck et al., 2006; Hallingbäck et al., 2008; Hedenäs et al., 2014) and a web resource for lichens

(<http://data.artsdatabanken.no/ScientificName/975>). Characteristics of several species that are not listed in the main sources were obtained from other books (Horvath, 2014; Mossberg et al., 2012) and web resources (Anderberg, 2000; "Avenella flexuosa," ; "Phedimus selskianus," ; "Sedum forsterianum - Sm.," ; "SEDUM montanum ssp. orientale," ; "SEDUM takesimense,"). I checked for all species if they are listed in the Norwegian Red List (<http://data.artsdatabanken.no/Rodliste>) or Black List (<http://www.artsdatabanken.no/fremmedarterinorge/2012>) using the online database.

According to PlantList website (<http://www.theplantlist.org/>), *Phedimus kamtschaticus* and *Phedimus/Sedum floriferum* are synonyms, thus I combined these two species in one. The same was done with *Sedum rupestre* which has a synonym *Sedum reflexum*. On the EGRs, plants are in extreme environmental conditions, which can lead to not reaching an average plant size (Sutton, 2015). Therefore, it was difficult to distinguish between *Phedimus hybridus* and *Phedimus kamtschaticus*, because the main differences are length of leaf and petals (Lid et al., 2005). Therefore, these two species are also considered as one in my study.

Before visiting each roof, I assigned the number of plots to be taken, depending on its size (area) and complexity (if the roof consists of several parts). I took four plots on the EGRs less or equal to 1000 m² and eight plots for larger roofs. Several exceptions occurred:

- 12 plots on the roof #2, because of its exceptionally large size and non-homogenous vegetation.
- Six plots on roof #5, because the green roof is located on three levels (three different floors).
- EGR #7 consists of three parts, two of them were accessible. On this roof, I studied four plots on one part and two on another.

EGRs were not always visible on the satellite maps, because of the weather conditions or because they were new and not on the map yet. Therefore, the most suitable way to locate sample plots was random walk ("Randomly locating sample plots," 2011), which explained more detailed in Appendix I.

For generating true random numbers, I used the website or an application from Random.org. The major limitations for selecting the plots were roof edges, ventilation shafts, and security regulations. The random numbers of direction and distance were generated until they comply with these limitations. I took the GPS point in the middle of each plot.

On all roofs, I used a standard plot size of 1 m². I made floristic sampling and measured above-ground cover abundance for species groups and for individual species. It was measured in percentage of cover for each square meter (Thuring et al., 2014). All species are classified in six species groups, additionally there was the category bare ground (Fig.3):

4. Succulents (species from Crassulacean family)
5. Herbaceous plants (herbaceous flowering plants)
6. Graminoids
7. Bryophytes
8. Lichens
9. Woody plants (trees and shrubs)
10. Bare ground

Succulent species were separated from other vascular plants (herbs, graminoids, and woody plants), because succulent species is a single group which was originally planted on the studied EGRs (with originally planted species: *Sedum*, *Phedimus*, and *Hylotelephium*). In this study *Bryum* was identified to the genus level, except *Bryum argenteum*.

Species also were divided into three categories: originally planted species (the succulent species group), found planted species (from the succulent species group, which I found during fieldwork), and SES (herbs, graminoids, woody plants, bryophytes, and lichen species groups). Even though EGRs with *Sedum* are usually called *sedum*-moss, however bryophytes are included into the category of SES, because they are not planted. List of planted species for each roof was checked with green mat producers, on which plants that were in use at the time of EGRs implementation.

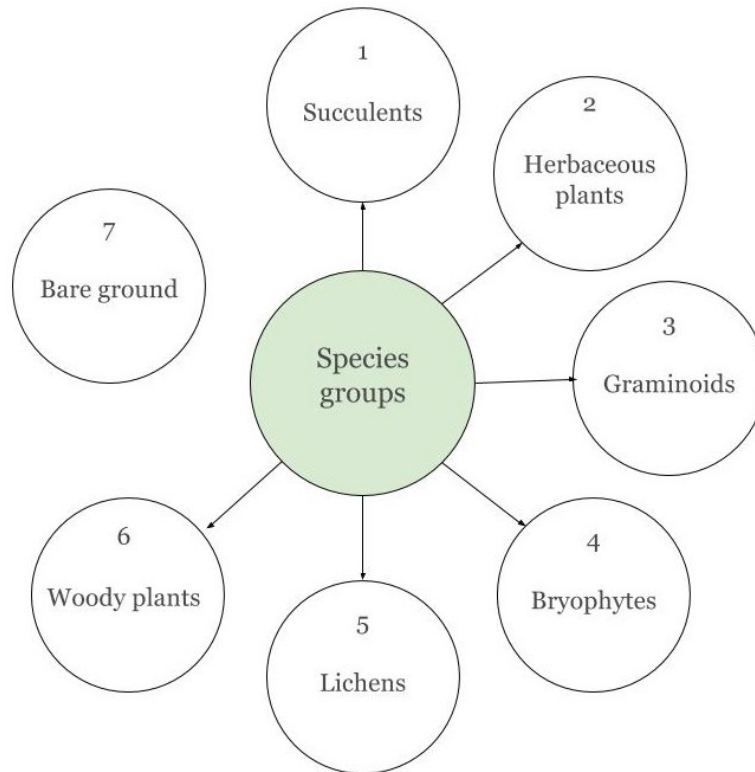


Figure 3. *Species groups for floristic sampling*

A soil sample was taken on every second plot on each roof. The soil-sample place was cleaned from above ground vegetation and a retaining cylinder placed. The same amount of soil was taken for each sample. In some cases, the depth of the soil was not enough to fill the cylinder; therefore, I took extra soil from places around to fill in the cylinder to the required volume. Holes left in the substrate after sampling were filled with substitute soil.

The soil depth was measured three times on each plot, as recommended by Thuring et al. (2014). The measurement was done from the top of the substrate surface to the root barrier. However, some studied roofs did not have a root barrier between the substrate and the drainage layer. In this case, the measurement was done until the drainage layer.

Extra notes were taken about sun/shade exposure. These notes were based on the direct observations on the field. Sun conditions means that the plot is almost all the time exposed to the maximum sunlight. Shade conditions mean that the plot is from minimal to maximum shade. This observation was done not on the particular sunlight

exposure during sampling, but on the potential condition during the whole day based on the cardinal directions.

Equipment used for field work:

- GPS Garmin
- Compass
- Two measuring sticks (1 m)
- Soil measurement stick
- Paper envelopes for plants
- Cylinder (7 cm in diameter and 5 cm in height)
- Plastic bags with zipper for soil (1 L)
- Application for random numbers

2.3 Soil analyses

Soil analyses included measuring pH level, loss on ignition, phosphorus (P), Potassium (K), Calcium (Ca), and Magnesium (Mg). The measurements were done in the soil laboratory at University College of Southeast Norway, campus Bø. The analyses were done using three manuals (Corporation, 1996; Instruments, 2001; Krogstad, 1992). Preparation to soil analyses included drying and sifting procedures (Krogstad, 1992). Drying was done in the drying cabinet for at least one week with the recommended temperature 35–40°C. The fraction of soil for analyses became less than 2 mm after applying the sifting machine.

Specific weight in the laboratory (SW lab) represents a weight of the soil in the volume of 5 m.

In order to analyze the amount of dry matter and calcination loss (loss on ignition), I applied the following procedure (a) I took 3 to 5 g of soil, weighed into a previously weighed crucible, and dried in a drying cabinet for at least 6 hours at 105 +/- 5° C, (b) I cooled the crucible with sample in the exsiccator for 30 minutes, and (c) I weighted the crucible with sample (Krogstad, 1992).

In order to determine calcination loss (loss on ignition), I applied the following: (a) I placed the crucible with the dried soil in the calcinating oven and left it for at least 3

hours at 550 +/- 25° C, (b) I cooled the crucible with sample in the exsiccator for 30 minutes, and (c) I weighted the crucible with sample (Krogstad, 1992).

The percentage of Dry matter has been calculated using formula (1).

$$\% \text{ dry matter} = \frac{m_3 - m_1}{m_2} * 100 \quad (1)$$

The percentage of calcination loss (loss on ignition) has been calculated using formula (2).

$$\% \text{ calcination loss (loss on ignition)} = \frac{m_3 - m_4}{m_3 - m_1} * 100 \quad (2)$$

In formulas (1) and (2), m1 is weight of crucible, m2 is weight of soil sample before drying, m3 is weight of crucible with sample after drying, and m4 is weight of crucible and sample after calcination.

Dry matter and calcination loss (loss on ignition) are given as percentages to one decimal point. Calcination loss (loss on ignition) has not been corrected for clay content.

In order to analyze the pH level, I applied the following procedure: (a) I transferred 20 ml of soil to a graduated beaker with the help of a cylindrical measure, (b) I added 50 ml of distilled water, and snapped on the lid, (c) I shook by hand until the soil is well mixed with the water, (d) I allowed to stand until the next day, (e) I shook the samples once again, (f) I measured the pH after the samples have stood for at least another 15 minutes and some of the soil has settled to the bottom, (g) I calibrated the pH meter with two buffer solutions (pH 4.00 and pH 7.00), (h) I inserted the electrode in plastic glass so that the glass globe PH-meter stand over the bottom, (i) I poured prepared sample in the plastic glass, above the electrode level, (j) I red off the pH when the instrument displays a stable pH value, and (k) I wash glass and PH-meter with the distilled water (Krogstad, 1992).

In order to prepare samples for determine soluble phosphorus, potassium, magnesium and calcium, extraction by the Al-method is done by applying the following procedure: (a) I transferred 4.00 g soil to the extraction bottle, (b) I added 80 ml of the AL-solution, described in the manual (Krogstad, 1992) (c) I screwed the top tight, (d) I immediately placed the bottle on the vibrator so that it lies lengthways along the line of the vibrations which have been set to shake back and forth at the rate of 100 times a minute for precisely 90 minutes at 20 +/- 1° C, (e) I added control soil sample and blank

sample. These samples were placed on the vibrator and filtered in the same way as the sample, (f) I filtered the suspension through a folded filter into plastic bottle, 100 ml, immediately after the shaking process has been completed. It is a soil extract, (g) I took 2 ml of soil extract and 8 ml of concentrated strontium chloride solution and put to 15 ml test-tube by using Hamilton Microlab Controller diluter. I did it twice for each sample (Krogstad, 1992).

The analytical method is based upon determining the content of orthophosphate in the soil extract (chapter 3.3.4). The principal of the phosphate content in the AL-extract is determined colorimetrically according to the molybdenum blue method. Soluble phosphorus is measured in mg P/100g air-dries soil to one decimal point (Corporation, 1996; Instruments, 2001).

I extracted the total content of soluble potassium from the soil extract (chapter 2.3.4). It is determined by atomic absorption spectroscopy. Potassium was measured with PinAAcle Atomic Absorption Spectrometer by atomic absorption on a wavelength of 766.5, alternatively 769.9 nm in an acetylene/air flame in degrees of absorption or concentration in reference solutions, samples, and blank samples. Soluble potassium was measured in mg K/100 g air-dried soil to one decimal point (Corporation, 1996; Krogstad, 1992).

Magnesium and calcium were measured by atomic absorption on a wavelength of 285.2 or alternatively 202.6 nm for g and 423.1 nm for Ca, in an acetylene/air flame in degrees of absorption or concentration for reference solutions, samples, and blank samples. Soluble magnesium and calcium are measured in mg/100 g air-dried soil to one decimal point (Corporation, 1996; Krogstad, 1992).

2.4 Statistical analyses

The data set had 0 values, therefore I added $x+2$ to all data and then performed a log₁₀-base transformation of all variables to normalize not normally distributed values of data which conducted from histograms of frequency distribution and that variance for some variables is more than mean (Legendre et al., 1998). The exceptions are pH (because it is already in logarithmic unit), binominal, and dummy variables.

Categorical variables were transformed in two types. The first type, binomial variables, was used for shade/sun as shade is 0 (absence of abiotic factor) and sun is 1 (presence of abiotic factor). The same was done for flat/slope. The second type, dummy variables, was used for EGR system, company, and type of *Sedum* mat.

For multivariable statistical analysis between species data (abundance), plots, and environmental data ordination methods (gradient analysis) were used. In order to get an overview of the data set, first I used Detrended Correspondence Analysis (DCA). It is an unconstrained unimodal analysis which is used to test length of the DCA Axis 1 and see the distribution of species along environmental gradient (Wildi, 2010). In DCA, the dummy variables are presented as factors. For DCA original data without logarithmic transformation were used.

Next, I reformed Canonical Correspondence Analysis (CCA) with forward selection to see what the most important gradients are in relation to species abundance data (Palmer, 1994). The p-value was set to 0.05 or less. CCA is a constrained unimodal analysis. It assumes unimodal response of species variables along linear gradients defined by environmental data (Wildi, 2010). Then, DCA was used again with the most important variables defined using CCA.

Depending on the length, linear or unimodal methods can be applied (Zelený). Even the length of DCA axis 1 exceed 4 SD units, Principal Component Analysis (PCA) is used. It is a linear method of unconstrained ordination (Zelený).

Regression analysis was performed (a) to find out the relations between variables and (b) to predict the vegetation changes from environmental variables. The regression fit is linear and polynomial. The P-value is < 0.05 , and the confidence interval is 95%. Data from soil analysis consists of missing values (NA), because I took soil samples for every second plot. To fill in the NA gaps, I used a mean value for each EGR. The regression equations are valid for logarithmically transformed data. Paired T-test and Wilcoxon test were used to compare two means and medians respectively (Fowler et al., 1998): richness of originally planted species and richness of the found planted species, and richness of originally species and richness of all species found during fieldwork (P-value < 0.05 , confidence interval = 95%).

PCA and regressions were done using PAST software (<http://folk.uio.no/ohammer/past/>), DCA (Clapham, 2015) and CCA with forward selection were done in R software (<https://www.r-project.org/>) applying the Vegan package (Oksanen et al., 2009). Mean values for variables were calculated with R software, using R commander. Script for DCA and CCA is in Appendix II. I used manuals for R, vegan package, PAST manual (Hammer, 1999-2016) and several web resources (e.g., <http://www.inside-r.org/>).

3 Results

3.1 General data

The studied EGRs were constructed between 2002 and 2014 (1-13 years old). Frequency distribution of the studied plots according to the age of the roof is shown in Figure 4.

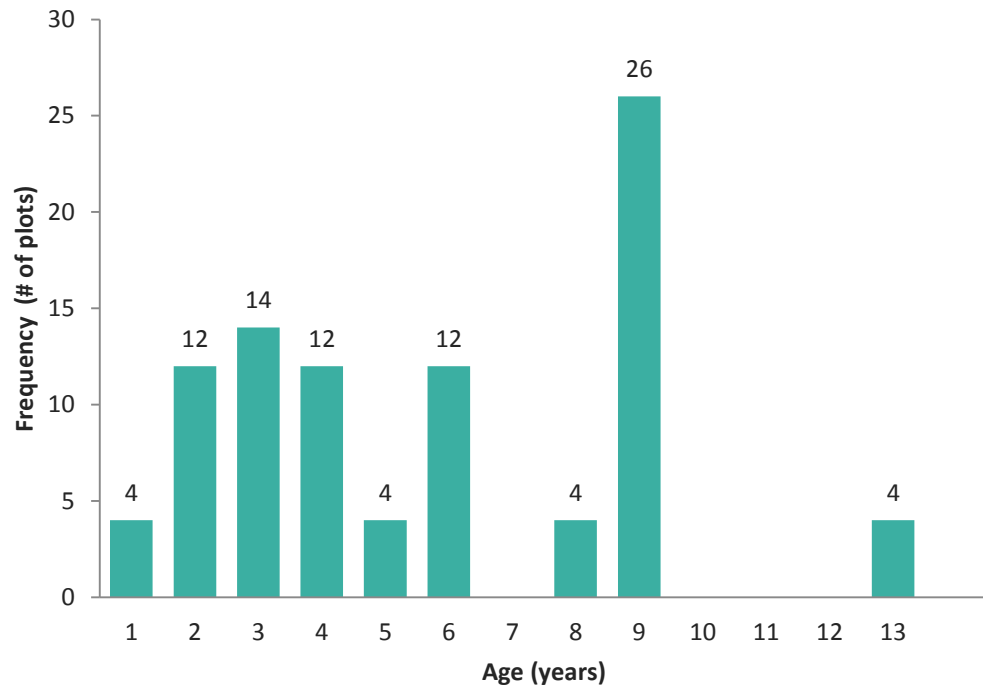


Figure 4. *Histogram of frequency distribution of the study plots according to the age of EGRs*

The largest amount of plots (26) was from EGRs that are nine years old while the ages 7, 10, 11, and 12 years not occurred. The company which installed the oldest EGR studied in this thesis is Reiersøl Planteskole AS. EGRs that are eight and nine years old were constructed by Veg Tech AS. EGRs which were installed five or six years ago are from Vital Vekst. The younger roofs are from different companies.

Sedum mixes used on the studied EGRs were of eight types produced by six companies (one *Sedum* mix for each EGR). 92 plots represent 100%, more than half of the studied plots (52%) consist of a *Sedum* mat mix produced by Veg Tech/Blomstertak. For the other plots *Sedum* mixes which are produced by variety of companies used, one for each roof (Figure 5).

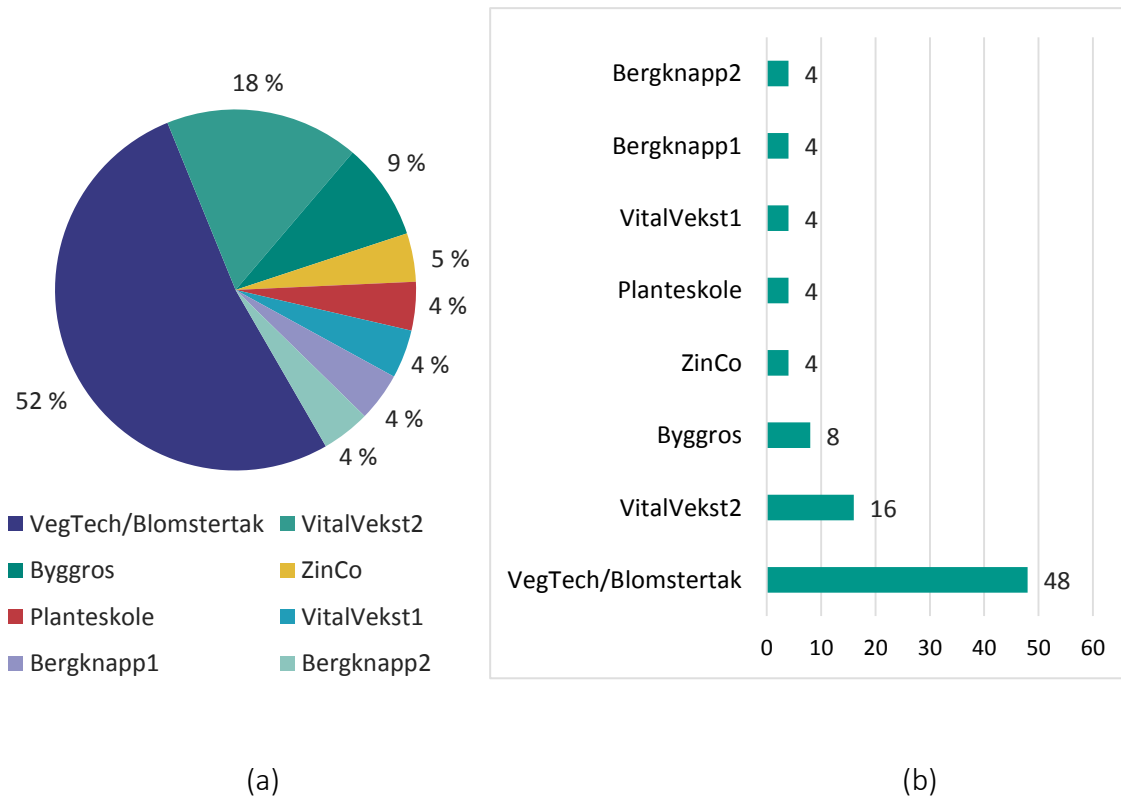


Figure 5. Distribution of studied plots according to used *Sedum* mat type (a) in percentage, (b) frequency distribution in number of plots

The EGR systems on the studied roofs were of six types (one for each producer). Blomstertak AS exploits a system from Veg Tech AS. Bergknapp AS used two types of systems on the studied EGRs. It is unknown whether Type 3 or Type 4 system by Bergknapp AS has been used on two buildings in Sørenga 1 (roof #10, #11). The correspondence data between the EGRs and system used on these roofs are presented below (Table 2).

Table 2. Studied EGRs and their system type

# of roof	Abbreviation	Name	Type of green roof system
1	HOEG	Lovisenberg Diaconal University College	Type 1. ZinCo
2	GJEN	Norsk Gjenvinning AS	Type 6. Vegtech/Blomstertak
3	PI25	Pilestredet Park 25	Type 6. Vegtech/Blomstertak
4	SORE2	Sørenga II, 65	Type 6. Vegtech/Blomstertak
5	PI41	Pilestredet Park 41	Type 6. Vegtech/Blomstertak
6	FORN	Statoil (IT Fornebu)	Type 6. Vegtech/Blomstertak
7	STEN	Pilestredet Park, Stensberggata 10,12	Type 6. Vegtech/Blomstertak
8	PI20	Pilestredet Park 20	Type 6. Vegtech/Blomstertak
9	UNIV	University of Oslo, Blindern	Type 5. Reiersøl Planteskole AS
10	SORE1 (build85)	Sørenga I, 85	Type 3. Bergknapp/ Type 4. Bergknapp
11	SORE1 (build99)	Sørenga I, 99	Type 3. Bergknapp/ Type 4. Bergknapp
12	BARN1	Sognsveien barnehage	Type 6. Vegtech/Blomstertak
13	BARN2	Solbærtorget barnehage	Type 2. Vital Vekst
14	AKER	Aker Brygge	Type 3. Bergknapp
15	BJOR	Barcode project, 10	Type 2. Vital Vekst
16	BJOR2	Barcode project, 18	Type 2. Vital Vekst
17	KREM	Alfaset krematorium (cremation center)	Type 2. Vital Vekst
18	KVAR	Kvæernerbyen	Type 4. Bergknapp

The EGR systems consist of several main components/layers (see Section 1.2). For specific details of each system used on the studied EGRs (see Appendix III).

The Area of the studied EGRs varies from 60 to 27000 m². The smallest EGR is #15, and the largest is #2 (Table 1). The variable 'Sun and shade exposure' for each plot are presented in Appendix IV. All but one roof (#17, 5 degrees) were flat roofs (0-4 degrees).

3.2 Vegetation

The richness of originally planted vegetation is 15 species of succulents (*Sedum*, *Hylotelephium*, and *Phedimus*) on all studied EGRs. The species richness of plants found

during fieldwork consists of both planted species and SES. Ten succulent species were found on the EGRs. SES included herbs, graminoids, mosses, lichens, and woody plants (Table 3). For the studied plots, the mean value for richness of the originally planted species is 7.7, the mean value for richness of all found species is 9.4, and the mean value for richness of the found planted species is 4.2.

Table 3. *Summary of richness in species groups for studied EGRs*

Species group	Richness of originally planted species	Richness found planted species and SES (observed during fieldwork)
Succulents	15	10
Herbs	0	43
Graminoids	0	10
Woody plants	0	5
Bryophytes	0	25
Lichens	0	3
Sum	15	96

Abundance and richness of species groups by plots are presented in Appendix V. Abundance of species groups is representing a large variety for succulents (0-100 %), herbs (0-80%), graminoids (0-50%), woody plants (0-50%), bryophytes (0-90%), lichens (0-60%) and bare ground (0-50%). Frequency distribution of succulents, bryophytes and bare ground abundance is presented in Appendix VI.

Relationship between abundance of succulents (found planted species) and abundance of SES is presented in regressions (Fig. 6). Abundance of succulents and abundance of herbs have a negative correlation. Abundance of succulents and abundance of graminoids have “u-shaped” relationship. Abundance of succulents has “humped-shaped” relations with abundance of bryophytes and lichens.

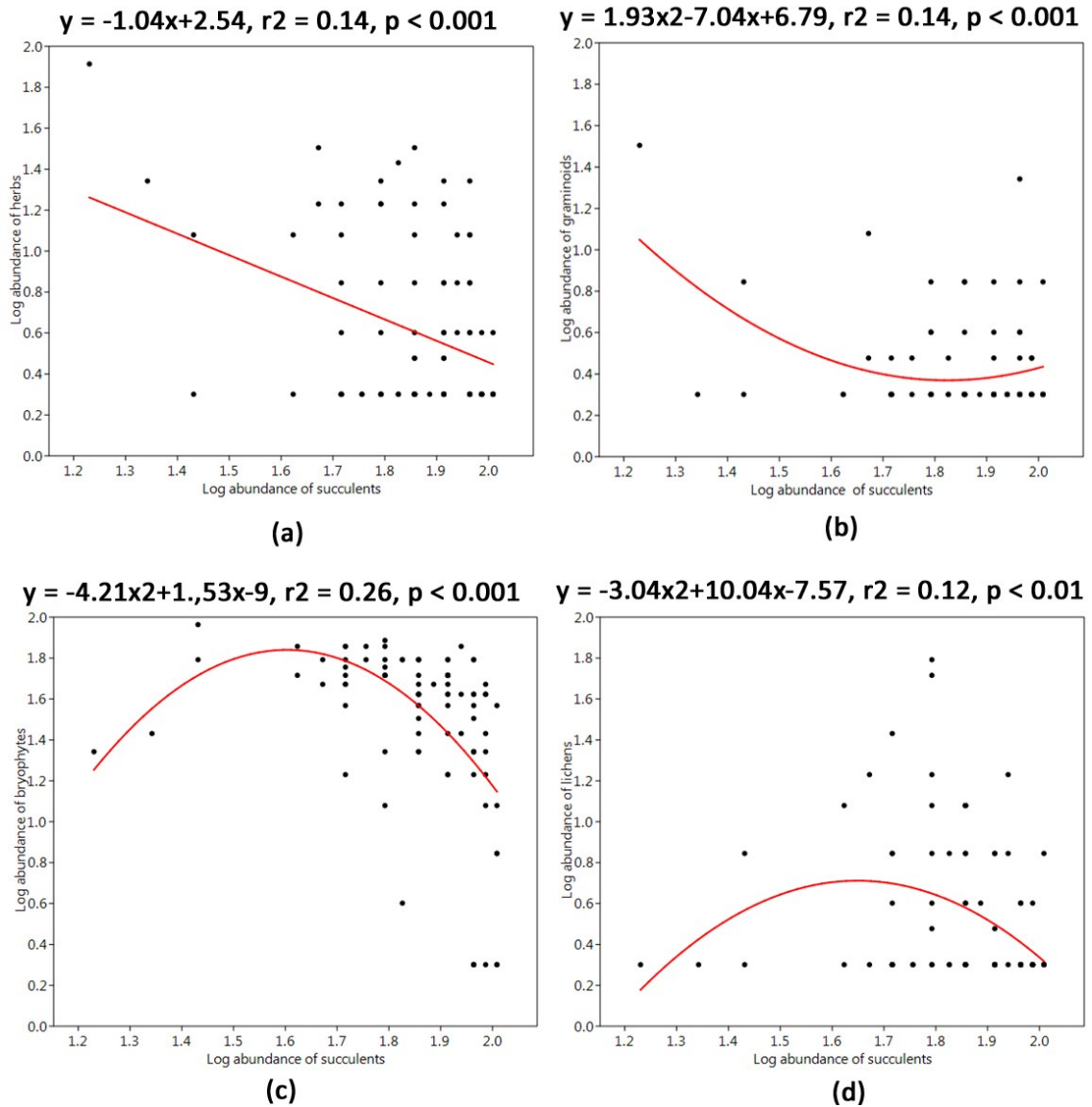


Figure 6. Regressions of (a) abundance of herbs, (b) abundance of graminoids, (c) abundance of bryophytes (d) abundance of lichens; on abundance of succulent; with regression equation, R-squared and p-value on the top of each graph

3.2.1 Planted vegetation

Green roof companies (producers) grow different *Sedum* mats, as components of EGR systems. Eight mixes from the studied EGRs are presented in Table 4. Veg Tech and Blomstertak use the same mix, which is called 'Veg Tech'. Vital Vekst changed the range of species in their *Sedum* mats (from 'Vital Vekst 2' to 'Vital Vekst 1'). The 'Bergknapp 1' type is called "Sedummix" on the company website. The 'Bergknapp 2' is called "Bergknapp Oslomatte" and does not contain Black List species. Reiersøl Planteskole and Byggros use one type of *Sedum* mat.

Table 4. Type of Sedum mat from the green roofs

#	Company	Abbreviation	Name	Type of mat
1	ZinCo	HOEG	Lovisenberg Diaconal College University College	<i>Sedum</i> mat ZinCo Norge
2	Blomstertak	GJEN	Norsk Gjenvinning AS	<i>Sedum</i> mat Veg Tech/Blomstertak
3	Veg Tech	PI25	Pilestredet Park 25	<i>Sedum</i> mat Veg Tech/Blomstertak
4	Blomstertak	SORE2	Sørenga II, 65	<i>Sedum</i> mat Veg Tech/Blomstertak
5	Veg Tech	PI41	Pilestredet Park 41	<i>Sedum</i> mat Veg Tech/Blomstertak
6	Blomstertak	FORN	Statoil (IT Fornebu)	<i>Sedum</i> mat Veg Tech/Blomstertak
7	Veg Tech	STEN	Pilestredet Park, Stensberggata 10,12	<i>Sedum</i> mat Veg Tech/Blomstertak
8	Veg Tech	PI20	Pilestredet Park 20	<i>Sedum</i> mat Veg Tech/Blomstertak
9	Reiersøl Planteskole	UNIV	University of Oslo, Blindern	<i>Sedum</i> mat Reiersøl Planteskole
10	Bergknapp/ Byggros	SORE1 (build85)	Sørenga I, 85	<i>Sedum</i> mat Byggros
11	Bergknapp/ Byggros	SORE1 (build99)	Sørenga I, 99	<i>Sedum</i> mat Byggros
12	Veg Tech	BARN1	Sognsveien barnehage	<i>Sedum</i> mat Veg Tech/Blomstertak
13	Vital Vekst	BARN2	Solbærtorget barnehage	<i>Sedum</i> mat Vital Vekst 2
14	Bergknapp	AKER	Aker Brygge	<i>Sedum</i> mat Bergknapp 2
15	Vital Vekst	BJOR	Barcode project, 10	<i>Sedum</i> mat Vital Vekst 2
16	Vital Vekst	BJOR2	Barcode project, 18	<i>Sedum</i> mat Vital Vekst 1
17	Vital Vekst	KREM	Alfaset krematorium (cremation center)	<i>Sedum</i> mat Vital Vekst 2
18	Bergknapp	KVAR	Kværnerbyen	<i>Sedum</i> mat Bergknapp 1

A total of 40 sorts (16 species), were used in the mixes on the studied EGRs (Table 5). In this study, *Phedimus hybridus* and *Phedimus kamtschaticus* are considered as one

species, therefore a total of 15 species are included. Abundance of found planted species on studied plots is presented in Appendix XIV.

The species *Phedimus kamtschaticus* is included in all eight *Sedum* mixes. *Sedum acre*, *Sedum album*, *Sedum rupestre* and *Sedum sexangulare* are in seven mixes. Three species *Phedimus selskianus*, *Sedum anglicum* and *Sedum takesimense* are used only in one mix each. *Sedum hispanicum* is an annual/biennial species, the life cycle of the other species is perennial. Only four native Norwegian species were present in the mixes on the studied EGRs (*Sedum acre*, *Sedum alba*, *Sedum rupestre*, and *Sedum anglicum*).

Two of the originally planted species *Phedimus spurius* and *Phedimus hybridus* are in the Black List (Gederaas et al., 2012). They are present in *Sedum* mixes six and seven respectively, and they were found on the studied EGRs during the fieldwork (Table 5). Presence and absence of the Black-listed found planted species are in Appendix VII.

Table 5. List of succulent species with sorts used in *Sedum* mixes on the studied EGRs and species which were found on EGRs during fieldwork

#	Species Latin name	Norwegian name	Found species	Life cycle type	Black List category	Sort name	Sedum mix											
							ZinCo Norge	Vital Vekst 1	Vital Vekst 2	Bergknapp 1	Bergknapp 2	Veg Tech	Reiersøl Planteskole	Byggros				
1	<i>Hylotelephium ewersii</i> (Ledeb.) <i>H. Ohba</i>	haustbergknapp	X	perennial	LO							X	X					
2	<i>Phedimus hybridus</i> (L.) 't Hart	sibirbergknapp	X	perennial	SE			X	X			X		X				
3						'Immergrünchen'	X			X								
4	<i>Phedimus kamtschaticus</i> (Fisch. & C.A.Mey.) 't Hart	gullbergknapp				perennial	LO			X	X	X	X	X	X	X	X	
5								subsp. ellacombeanum										X
6								'Weihenstephaner Gold'	X			X				X		
7								'Middendorffianum'	X									
8	<i>Phedimus selskianus</i>						perennial									X		
9	<i>Phedimus spurius</i> (M.Bieb.) 't Hart	gravbergknapp	X	perennial	SE				X	X		X	X					
10						'Album superbum'		X										
11						'Coccineum'		X								X		
12						'Fuldaglut'												
13						'John creech'		X										
14						'Rosea'												
15		'Summer glory'		X														
16	<i>Sedum acre</i> L.	bitterbergknapp	X	perennial			X	X	X		X	X	X					

#	Species Latin name	Norwegian name	Found species	Life cycle type	Black List category	Sort name	Sedum mix							
							ZinCo Norge	Vital Vekst 1	Vital Vekst 2	Bergknapp 1	Bergknapp 2	Veg Tech	Reiersøl Planteskole	Byggros
17				ennial		'Oktoberfest'								
18	<i>Sedum album L.</i>	kvitbergknapp	X	perennial					X		X	X	X	X
19						'Minor'								
20						'Murale'	X	X				X		
21						'Chloroticum'	X					X		
22						'Coral Carpet'	X	X						
23						'Laconicum'	X							
24						'Lime'						X		
25						'Micranthum chloroticum'		X						
26						'Minus'	X							
27	<i>Sedum anglicum Huds.</i>	kystbergknapp	X	perennial							X			
28	<i>Sedum forsterianum Sm.</i>	konglebergknapp		perennial	PH			X	X					X
29	<i>Sedum hispanicum L.</i>	gråbergknapp	X	annual & biennial			X	X		X	X			
30					PH	'Minus'			X					
31	<i>Sedum lydium Boiss.</i>	lydisk bergknapp	X	perennial			X	X	X	X	X			
32					NK	'Glaucum'				X	X			
33	<i>Sedum montanum t Hart</i>			perennial		subsp. orientale								X
34	<i>Sedum pulchellum</i>	skuggfetknopp		perennial								X		X

#	Species Latin name	Norwegian name	Found species	Life cycle type	Black List category	Sort name	Sedum mix							
							ZinCo Norge	Vital Vekst 1	Vital Vekst 2	Bergknapp 1	Bergknapp 2	Veg Tech	Reiersøl Planteskole	Byggros
				ennial										
35	<i>Sedum rupestre</i> L.	broddbergknapp	X	perennial			X		X	X			X	X
36	(<i>Sedum reflexum</i>)					'Angelina'		X						
37						'Blue spruce'		X						
38						'Green spruce'		X			X			
39	<i>Sedum sexangulare</i> L.	kantbergknapp	X	perennial	PH		X	X	X	X	X	X		X
40	<i>Sedum takesimense</i> <i>Nakai</i>			perennial				X						
Sum of sorts							13	18	10	9	9	12	6	11
Sum of species							8	11	10	7	8	8	6	10
Sum of species (studied categories)*							7	10	9	6	8	7	6	9

Black List categories: SE - severe impact, HI - high impact, PH - potentially high impact, LO - low impact, NK - no known impact. *Studied category of species: *Phedimus hybridus* and *Phedimus kantschaticus* are combined into one category

3.2.2 Spontaneously established species

In addition to the succulents, other vascular plants (herbs, graminoid and woody plants) were found on the studied plots. They became established after the installation of *Sedum* mats and are considered ‘spontaneously established species’ or SES. In total, 58 vascular SES were found and identified, including 36 herbaceous plants, 10 graminoids, and four woody plants (Table 5). In addition, seven herb and one tree species were found, but could not be identified.

In the herbs species group, there were nine annual species, three annual and biennial species, three annual and perennial species, 18 perennial species, and 10 unknown species. Five woody species were found on the studied EGRs, most of them where small (< 2m). On roof #2, some *Betula pendula* and *Salix caprea* were found of more than 2m height (Fig. 6).



Figure 7. *Betula pendula* and *Salix caprea* on EGR #2 (Plot 47)

Two of the herbs found on the roofs are listed in the Norwegian Black List (Gederaas et al., 2012), *Epilobium ciliatum* is listed in the category “severe impact (SE)” and *Senecio viscosus* has “high impact (HI)”. *Conyza canadensis* is listed in Black List in the “potentially high impact (PH)” category. *Veronica verna* is listed in the Norwegian Red list, its category is “near threatened (NT)” (Binns et al., 2010).

Table 6. *SES of vascular plants found on the studied EGRs*

#	Latin name	Norwegian name	Black List category	Life cycle type
Herb (herbaceous) species groups				
1	<i>Achillea millefolium</i> L.	ryllik		perennial
2	<i>Allium schoenoprasum</i> L.	grasløk	-	perennial
3	<i>Artemisia vulgaris</i> L.	burot	-	perennial

#	Latin name	Norwegian name	Black List category	Life cycle type
4	<i>Asteraceae</i>	korgplantefamilien	-	
5	<i>Cerastium fontanum</i> Baumg.	-	-	
6	<i>Cerastium</i> sp. L.	stovarveslekta	-	biennial
7	<i>Cirsium</i> sp. Mill.	tistelslekta	-	biennial and perennial
8	<i>Conyza canadensis</i> (L.) Cronquist	hestehamp	PH	annual
9	<i>Crepis tectorum</i> L.	takhaukeskjegg	-	annual and biennial
10	<i>Dianthus deltoides</i> L.	engnellik	-	perennial
11	<i>Epilobium ciliatum</i> Raf.	amerikamjølke	SE	perennial
12	<i>Epilobium collinum</i> C.C.Gmel.	bergmjølke	-	perennial
13	<i>Epilobium</i> sp. L.	mjølkeslekta	-	perennial
14	<i>Brassicaceae</i>	korsblomstfamilien	-	-
15	<i>Geranium pusillum</i> L.	småstorkenebb	-	annual
16	<i>Leontodon autumnalis</i> L.	føllblom	-	perennial
17	<i>Medicago lupulina</i> L.	snigleskolm	-	annual and biennial
18	<i>Moehringia trinervia</i> (L.) Clairv.	maurarve	-	annual
19	<i>Mycelis muralis</i> (L.) Dumort.	skogsalat	-	perennial
20	<i>Pilosella</i> sp. (<i>Hieracium</i> subgen. <i>Pilosella</i> (Hill) Gray)	hårsveveslekta	-	perennial
21	<i>Potentilla norvegica</i> L.	norsk mure	-	annual
22	<i>Rumex acetosella</i> L.	engsyre	-	perennial
23	<i>Sagina procumbens</i> L.	tunsmåarve	-	annual and perennial
24	<i>Senecio viscosus</i> L.	klistersvineblom	HI	annual
25	<i>Senecio vulgaris</i> L.	åkersvineblom	-	annual
26	<i>Sonchus oleraceus</i> L.	haredylle	-	annual
27	<i>Tanacetum vulgare</i> L.	reinfann	-	perennial
28	<i>Taraxacum</i> sp. F.H.Wigg	løvetannslekta	-	perennial
29	<i>Trifolium pratense</i> L.	raudkløver		perennial
30	<i>Trifolium repens</i> L.	kvitkløver		perennial
31	<i>Trifolium</i> sp. L.	kløverslekta	-	annual and perennial
32	<i>Tripleurospermum inodorum</i> (L.) Sch.Bip.	balderbrå		annual
33	<i>Tussilago farfara</i> L.	hestehov		perennial
34	<i>Veronica</i> sp. L.	veronikaslekta	-	annual and perennial
35	<i>Veronica verna</i> L. (!!)	vårveronika	-	annual
36	<i>Viola tricolor</i> L.	stemorsblomst	-	annual or biennial
Gramininoid species group				
1	<i>Poa</i> sp. L.	rappslekta		perennial

#	Latin name	Norwegian name	Black List category	Life cycle type
2	<i>Poa compressa</i> L.	flatrapp		perennial
3	<i>Poa alpina</i> L.	fjellrapp		perennial
4	<i>Poa annua</i> L.	tunrapp		annual
5	<i>Agrostis</i> sp. L.	kveinslekta		perennial
6	<i>Agrostis vinealis</i> Schreb.	bergkvein		perennial
7	<i>Festuca rubra</i> L.	raudsvingel		perennial
8	<i>Avenella flexuosa</i> (L.) Drejer	smyle		perennial
9	<i>Deschampsia cespitosa</i> (L.)	sølvbunke		perennial
10	<i>Poaceae</i>	grasfamilien		perennial
Woody species group				
1	<i>Betula pendula</i> Roth	hengebjørk		perennial
2	<i>Salix caprea</i> L.	selje		perennial
3	<i>Acer</i> sp. L.	lønneslekta		perennial
4	<i>Pinus sylvestris</i> L.	furu		perennial

Categories from Black List: SE - severe impact, HI - high impact, PH - potentially high impact, LO - low impact, NK - no known impact. Black List species are only from SE and HI. !! Category from Red List: sign NT - near threatened category.

25 bryophyte species were found on the studied EGRs, 22 of them could be identified (Table 7). None of the identified bryophytes is listed in the Norwegian Red List or in the Norwegian Black List.

Table 7. SES of bryophytes found on the studied EGRs

#	Latin name	Norwegian name
1	<i>Abietinella abietina</i> (Hedw.) M.Fleisch.	granmose
2	<i>Amblystegium serpens</i> (Hedw.) Schimp.	trådkrypmose
3	<i>Aulacomnium palustre</i> (Hedw.) Schwägr.	myrfiltmose
4	<i>Barbula unguiculata</i> Hedw.	vegskruemose
5	<i>Brachythecium albicans</i> (Hedw.) Schimp.	bleiklundmose
6	<i>Brachythecium glareosum</i> (Bruch ex Spruce) Schimp.	gull-lundmose
7	<i>Brachythecium</i> sp.	lundmoseslekta
8	<i>Bryum argenteum</i> Hedw.	sølvvrangmose
9	<i>Bryum</i> sp.	vrangmoseslekta
10	<i>Ceratodon purpureus</i> (Hedw.) Brid.	ugrasvegmose
11	<i>Didymodon ferrugineus</i> (Schimp. ex Besch.) M.O.Hill	sprikekurlmose
12	<i>Funaria hygrometrica</i> Hedw.	pestbråtemose
13	<i>Homalothecium sericeum</i> (Hedw.) Schimp.	krypsilkemose
14	<i>Hypnum cupressiforme</i> Hedw.	matteflette
15	<i>Marchantia polymorpha</i> L.	vasstvare
16	<i>Plagiomnium cuspidatum</i> (Hedw.) T.J.Kop.	broddfagermose
17	<i>Polytrichum juniperinum</i> Hedw.	einerbjørnemose
18	<i>Racomitrium canescens</i> (Hedw.) Brid.	sandgråmose
19	<i>Racomitrium lanuginosum</i> (Hedw.) Brid.	heigråmose

#	Latin name	Norwegian name
20	<i>Sanionia uncinata</i> (Hedw.) Loeske	klobleikmose
21	<i>Sciuro-hypnum populeum</i> (Hedw.) Ignatov & Huttunen	ospelundmose
22	<i>Syntrichia ruralis</i> (Hedw.) F.Weber & D.Mohr	putehårstjerne

Three lichen species were found (Table 8):

Table 8. SES lichens found on the studied EGRs

#	Latin name	Norwegian name
1	<i>Peltigera didactyla</i> (With.) J.R. Laundon	smånever
2	<i>Peltigera rufescens</i> (Weis) Humb.	brunnever
3	<i>Hypogymnia physodes</i> (L.) Nyl	vanlig kvistlav

3.3 Soil data

Average results of soil data for each studied EGR are presented below (Table 9).

Table 9. Results of soil depth and soil analysis (mean value for each roof)

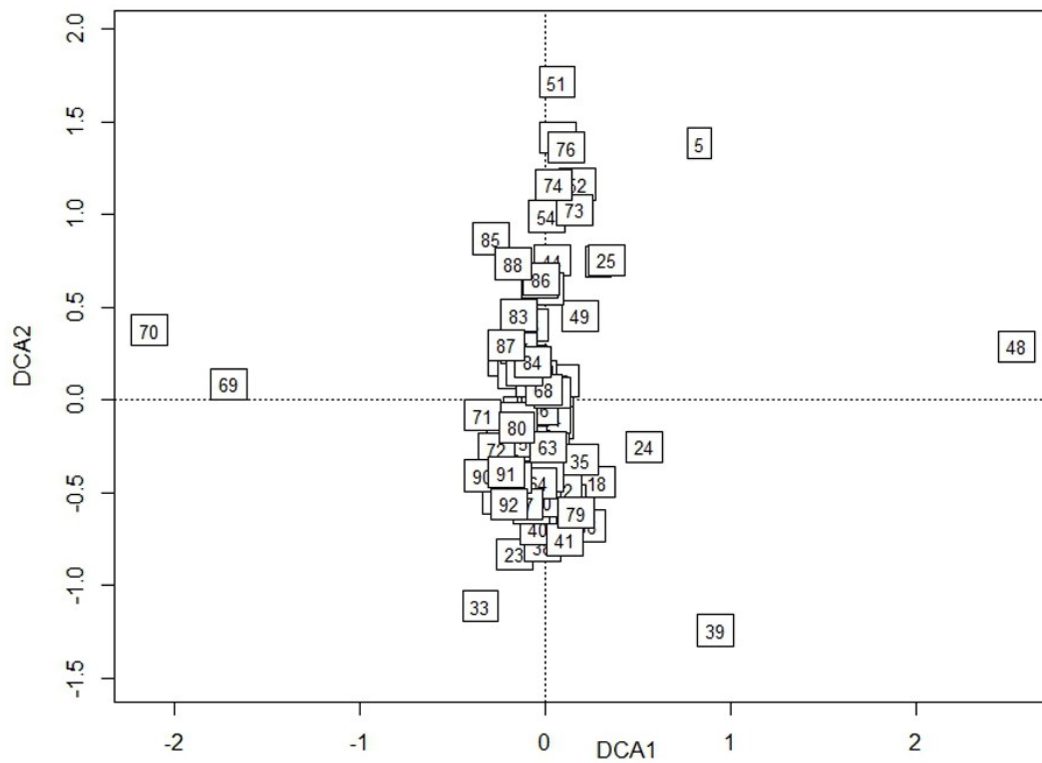
# of EGR	Place (# of plots)	Soil depth, cm	pH	Dry matter, %	Loss on Ignition, %	K	P	Mg	Ca	Vol, g for 1 ml of soil
1	HOEG (4)	4.7	5.8	95.91	31.44	17.6	5.3	53.1	404.6	0.44
2	GJEN (12)	5.4	7.2	98.56	7.91	9.1	8.2	28.3	2656.8	0.86
3	PI25 (4)	3.9	7.2	98.13	9.01	11.1	5.4	24.3	3455.5	0.85
4	SORE2 (4)	3.5	7.1	99.45	3.47	3.3	12.3	15.2	2082	1.26
5	PI41 (6)	4.2	6.9	97.91	12.88	19.6	16.5	24.2	1098	0.84
6	FORN (8)	3	6.8	97.73	10.81	18.4	6.8	11.4	996.5	0.82
7	STEN14 (6)	3.2	6.8	97.40	10.82	11.9	7.8	22.6	3179.7	0.77
8	PI20 (4)	3.5	6.9	98.40	8.03	8.8	12.6	23.6	3540.5	0.88
9	UNIV (4)	2.3	6.4	96.58	20.27	28.4	11.2	35.1	4663.5	0.54
10	SORE1, building (4)	85 2.5	6.7	97.72	13.67	15.2	9.2	15.9	1421	0.70
11	SORE1, building (4)	90 2.2	6.5	97.93	13.77	18.9	16.1	17.4	1159	0.68
12	BARN (4)	1.9	6.4	98.33	7.45	54	6.3	30.2	342	1.03
13	BARN2 (4)	4.4	5.2	97.51	16.69	62.6	5.2	25.3	236.3	0.75
14	AKER (4)	2.6	6.5	98.45	12.11	20	38.9	3384.4	450	0.63
15	BJOR (4)	2.9	4.7	96.68	28.54	32.3	7.4	46.1	335.3	0.54
16	BJOR2 (4)	3	5.5	97.42	18.19	37.1	10.1	48.2	347.9	0.69
17	KREM (8)	3.6	5.2	97.11	21.75	47.2	6.8	32.5	325.1	0.59
18	KVAR (4)	2.4	6.6	99.19	6.12	8.6	8.5	180.9	5578	0.87

Mean value for GJEN is calculated without outlier Plot 47. The data for each plot represented in Appendix VIII. Volv is a specific weight.

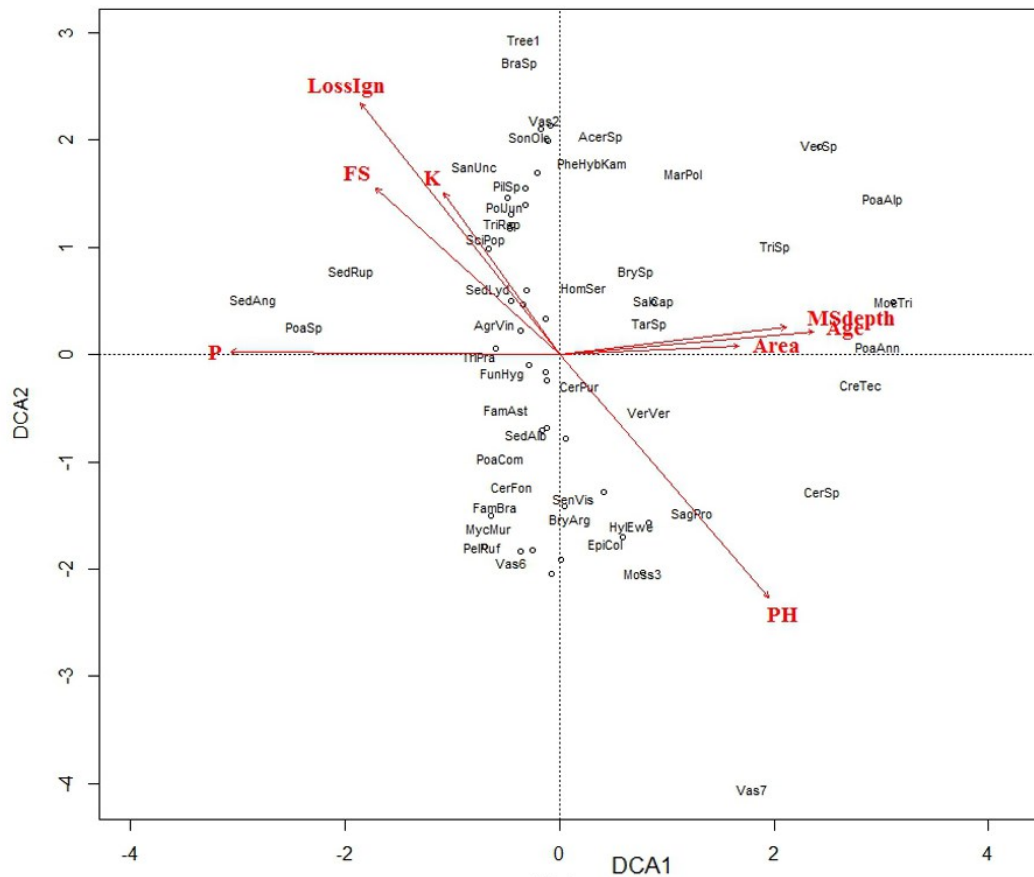
3.4 Main gradients

The DCA results of species and study plots in relation to DCA axis 1 and DCA axis 2 are shown in Figure 8. Eigenvalues for DCA axis 1 is 0.48 and for DCA axis 2 is 0.37. First two axis show the highest explanation of the environmental factors. The first axis length is 4.69 and the second is 2.95. The length of Axis 1 exceeds 4 SD units, therefore the gradient indicates an unimodal data structure (Jongman et al., 1995). Exception is plot 47 (roof #2), which represent outlier on DCA ordination diagram for species and plots in Appendix IX with length of DCA axis 1 which exceeds 20 SD units. The plot consists of species which rarely or never presented on other plots such as *Achillea millefolium*, *Salix Caprea*, and *Tussilago farfara*.

The plot distribution is homogenous on DCA ordination diagram (Figure 8, a), but six plots (5, 33, 39, 48, 69, and 70) are not similar to the main mass. They have some species, which they mostly not share with other plots. Succulents and bryophytes tend to occur in the same study plots. The distribution of the plots is smooth along DCA axis 2.



(a)



(b)

Figure 8. DCA ordination diagram without outlier for (a) study plots (b) species and environmental data (only statistically significant according to CCA) as vectors. *LossIgn* = loss on ignition, *FS* = flat roof or with slope, *K* = potassium, *P* = phosphorus, *Age* = age, *Area* = area, *MSdepth* = soil depth

Environmental variables found to be significant in the CCA were post-hoc introduced to the DCA ordination diagram. The variation in the species composition expressed along DCA axis 1 is correlated to P level, age, mean of soil depth, and area (Fig. 8). Types of the EGR *Sedum* mat are dispersed along the DCA axis 2, and explain the variation in species distribution along it presented in Appendix X.

PCA ordination shows that soil depth, age, elevation and flat roof/with slope, abundance of herbs, graminoids, bryophytes, lichens and woody plants; richness of herbs, graminoids, bryophytes, lichens and woody plants positively correlation with each other and all of them has a negative correlation to abundance and richness of succulents, P level, Mg level, and sun/shade conditions (Fig. 9). PH level, dry matter, specific weight, and Ca level are positively correlated and they are negatively correlated to K level, loss on ignition and richness of originally planted species.

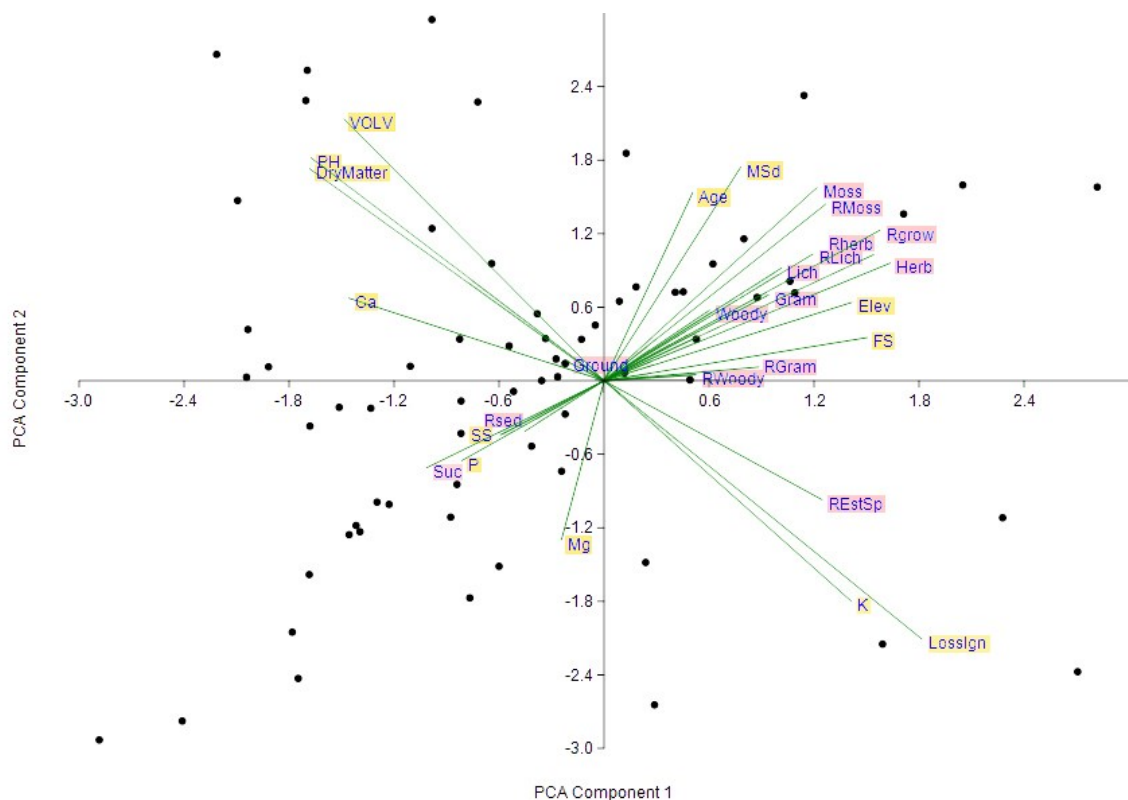


Figure 9. PCA ordination diagram with plots distribution (black circles), with vectors (green lines). Pink highlighted vectors represent vegetation; yellow highlighted vectors represent environmental variables. Abbreviations of the vectors are LossIgn = loss on ignition, DryMatter = dry matter, VOLV = specific weight, SS = sun/shade conditions, FS = flat roof or with slope, K = potassium, P = phosphorus, CA = calcium, MG = magnesium, Age = age, area= area, MSd = mean of soil depth, Elev = elevation, REstSP= richness of planted species, Rgrow = richness of found species, Rsuc =richness of succulents, Rmoss =richness of bryophytes, Rlich =richness of lichens, Rgram =richness of graminoids, Rwoody = richness of woody plants, RHerb =

abundance of herbs, Suc = abundance of succulents, Herb = abundance of herbs, Gram = abundance of graminoids, Moss = abundance of bryophytes, Lich = abundance of lichens, Ground = abundance of bare ground

PCA axis 1 shows 19.5 % of variance (5.47units eigenvalue) and PCA axis 2 has 12.0 % of variance (3.37unit eigenvalue).

3.5 Vegetation in relation to environmental variables

Mean depth of soil has positive correlation to richness and abundance of herbs, and abundance of bryophytes and graminoids (Fig. 10).

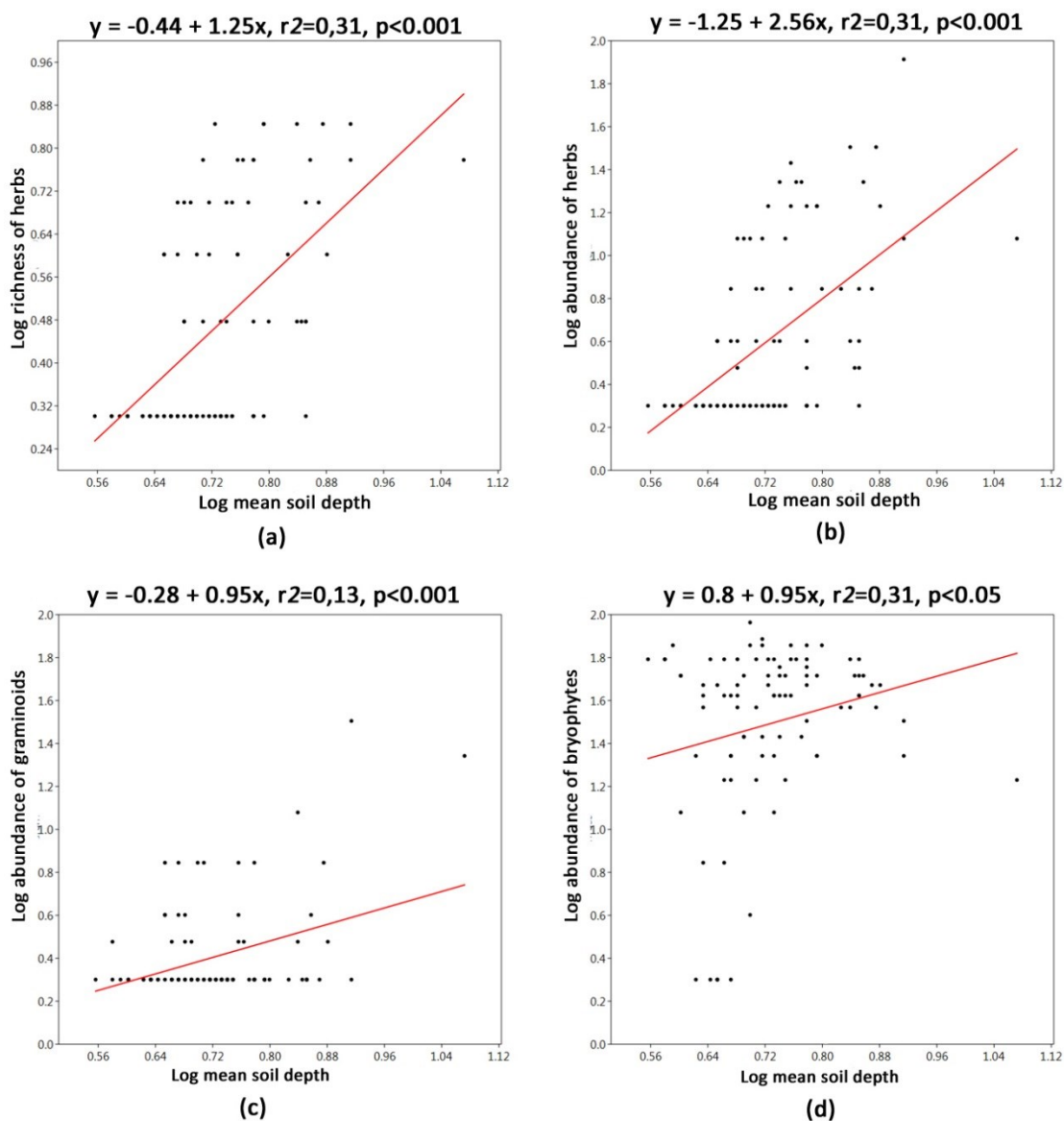


Figure 10. Linear regressions of (a) richness of herbs, (b) abundance of herbs, (c) abundance of graminoids, (d) abundance of bryophytes; on mean soil depth with regression equation, R-squared and p-value on the top of each graph

PH level has negative relations with richness and abundance of herbs; abundance and richness of lichens; richness of bryophytes, and richness of all species found during fieldwork (Fig. 11).

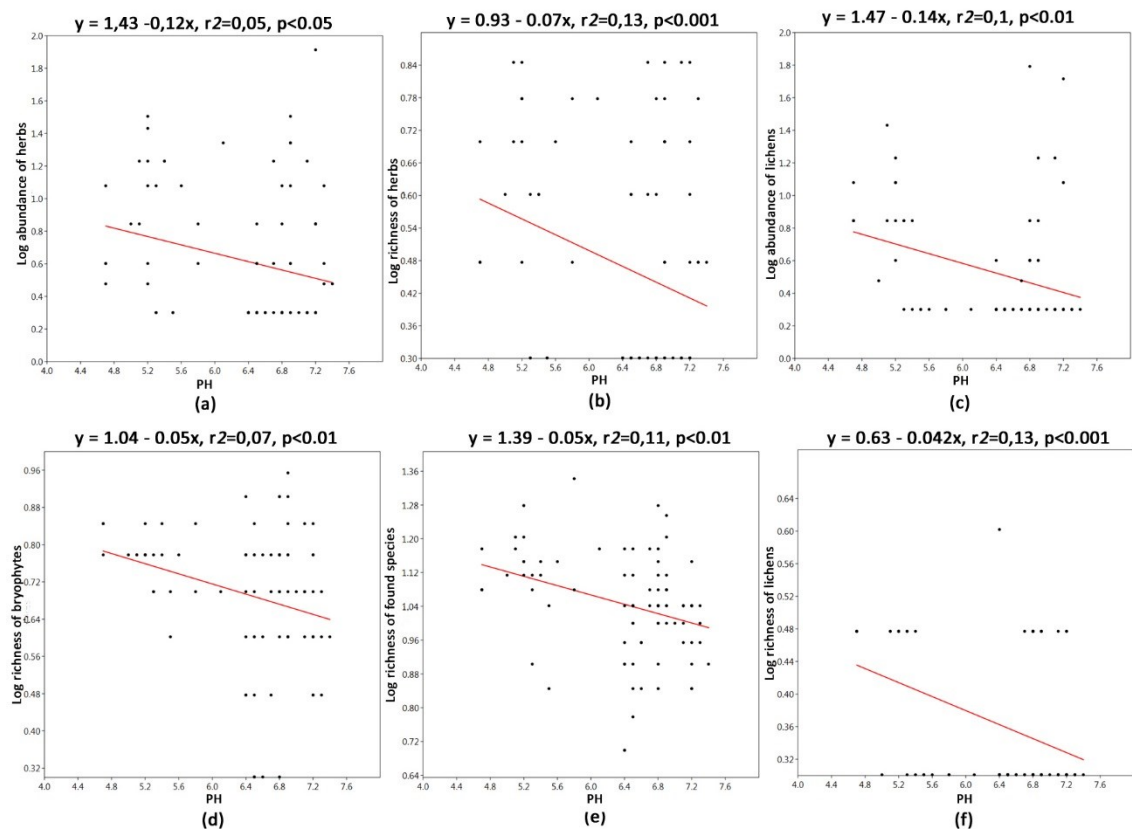


Figure 11. Linear regressions of (a) abundance of herbs, (b) richness of herbs, (c) abundance of lichens, (d) richness of bryophytes, (e) richness of all species, found during fieldwork, (f) richness of lichens; on pH level with regression equation, R-squared and p-value on the top of each graph

PH level is positively correlated with Ca level (Appendix XI). Abundance of succulents has positive correlation with Ca (Fig. 12).

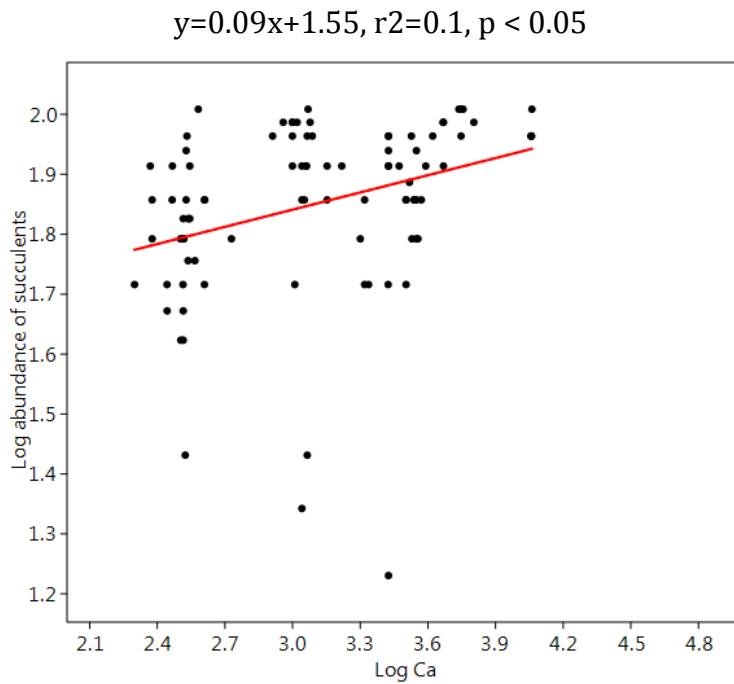


Figure 12. Linear regressions of abundance of succulents on Ca level with regression equation, R-squared and p-value on the top of each graph

Regression on Figure 13 shows non-linear (u-shaped) relationship between abundance of succulents and age.

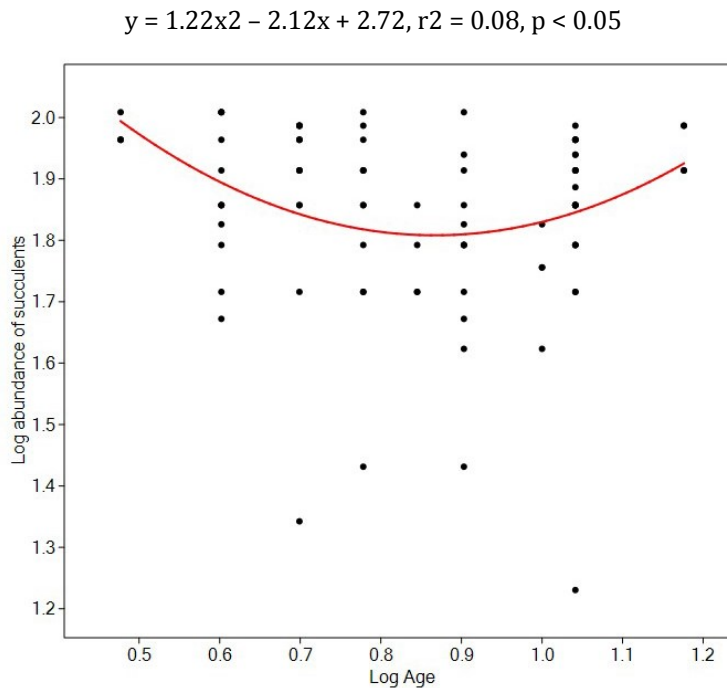


Figure 13. Polynomial regression of abundance of succulents on age of EGRs with regression equation, R-squared and p-value on the top of the graph

Age has linear negative correlation with richness of succulents, and richness of graminoids (Fig.14). Positive linear relationships are between age and richness and abundance of bryophytes, and richness and abundance of lichens.

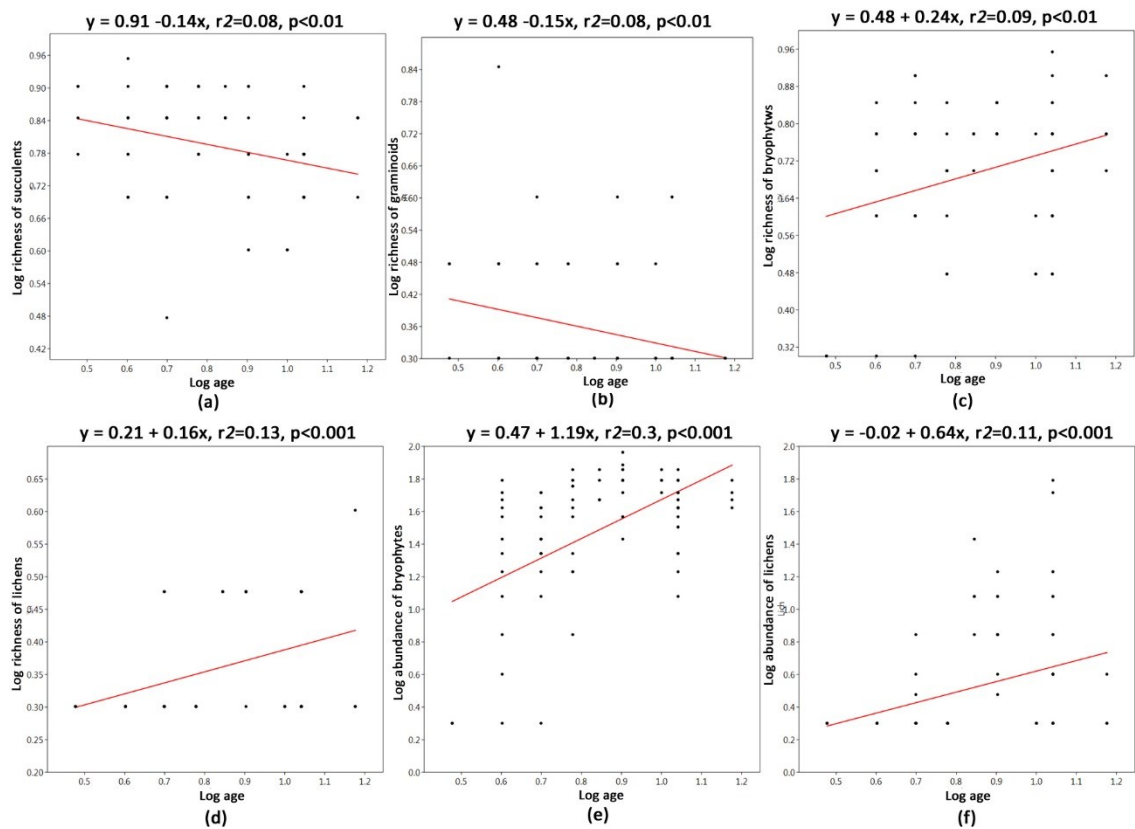


Figure 14. Linear regressions of (a) richness of succulents, (b) richness of graminoids, (c) richness of bryophytes, (d) richness of lichens, (e) abundance of bryophytes, (f) abundance of lichens; on age of EGRs with regression equation, R-squared and p-value on the top of each graph

Loss on Ignition is positively correlated to richness and abundance of herbs, richness of bryophytes, richness of graminoids, richness of species found during fieldwork, richness and abundance of lichens and richness of woody plants (Fig. 15 and Fig. 16). Loss on Ignition has negative correlation with pH level (Appendix XII).

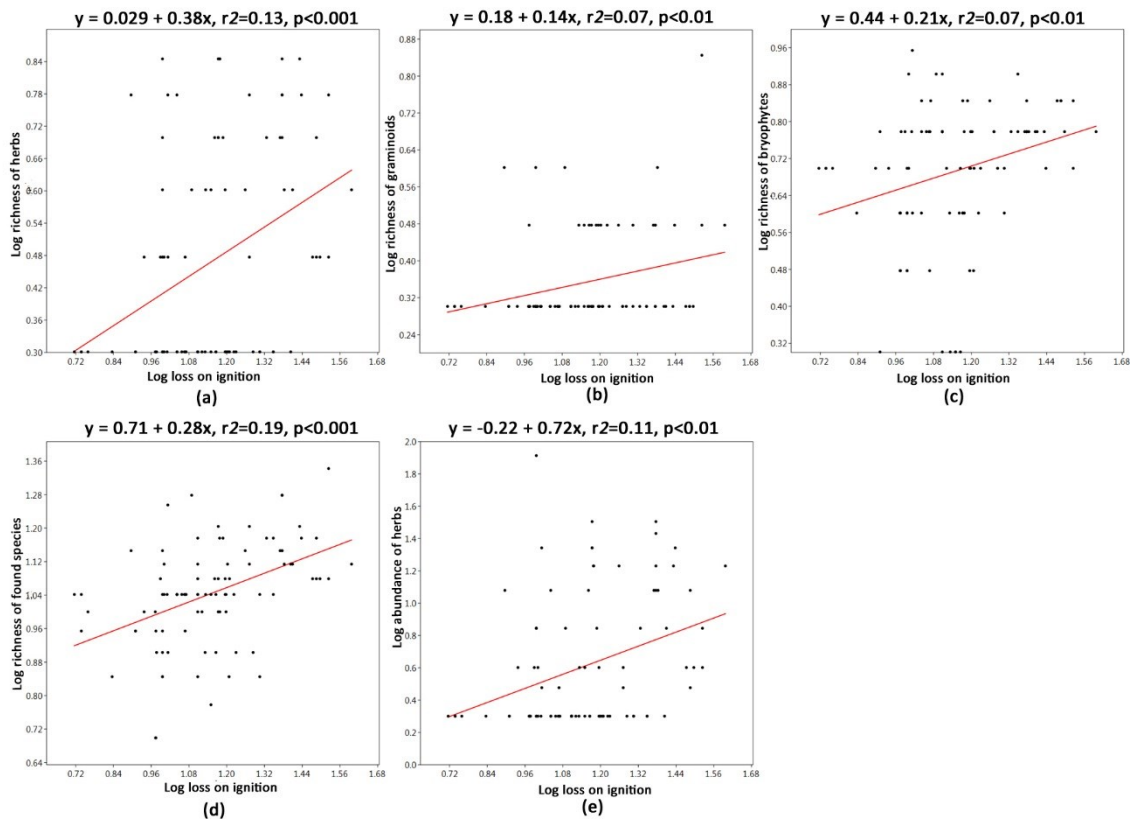


Figure 15. Linear regressions of (a) richness of herbs, (b) richness of graminoids, (c) richness of bryophytes, (d) richness of all species, found during fieldwork group, (e) abundance of herbs, on loss on ignition of EGRs with regression equation on the top of each graph

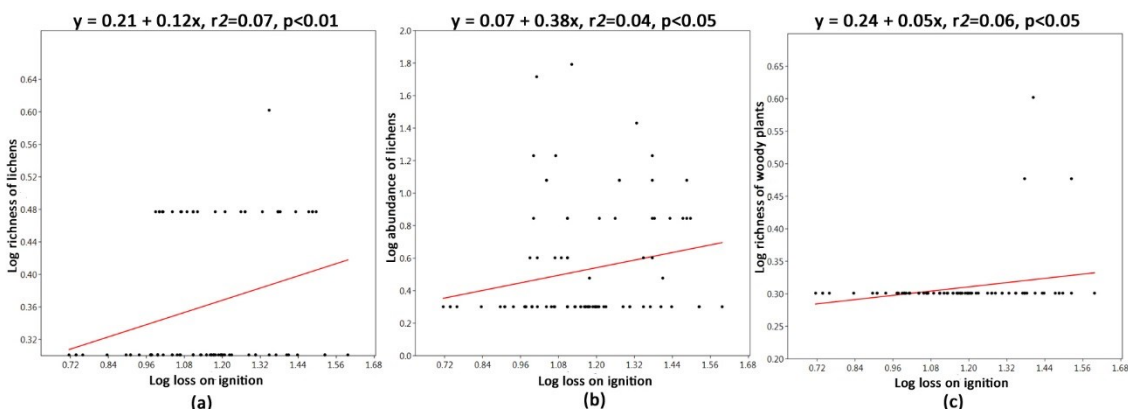


Figure 16. Regressions of (a) richness of lichens, (b) abundance of lichens, (c) richness of woody plants, on loss on ignition of EGRs with regression equation on the top of each graph

P level is negatively correlated to richness and abundance of bryophytes, richness and abundance of lichens (Fig. 17). K level has linear correlation to abundance of lichens.

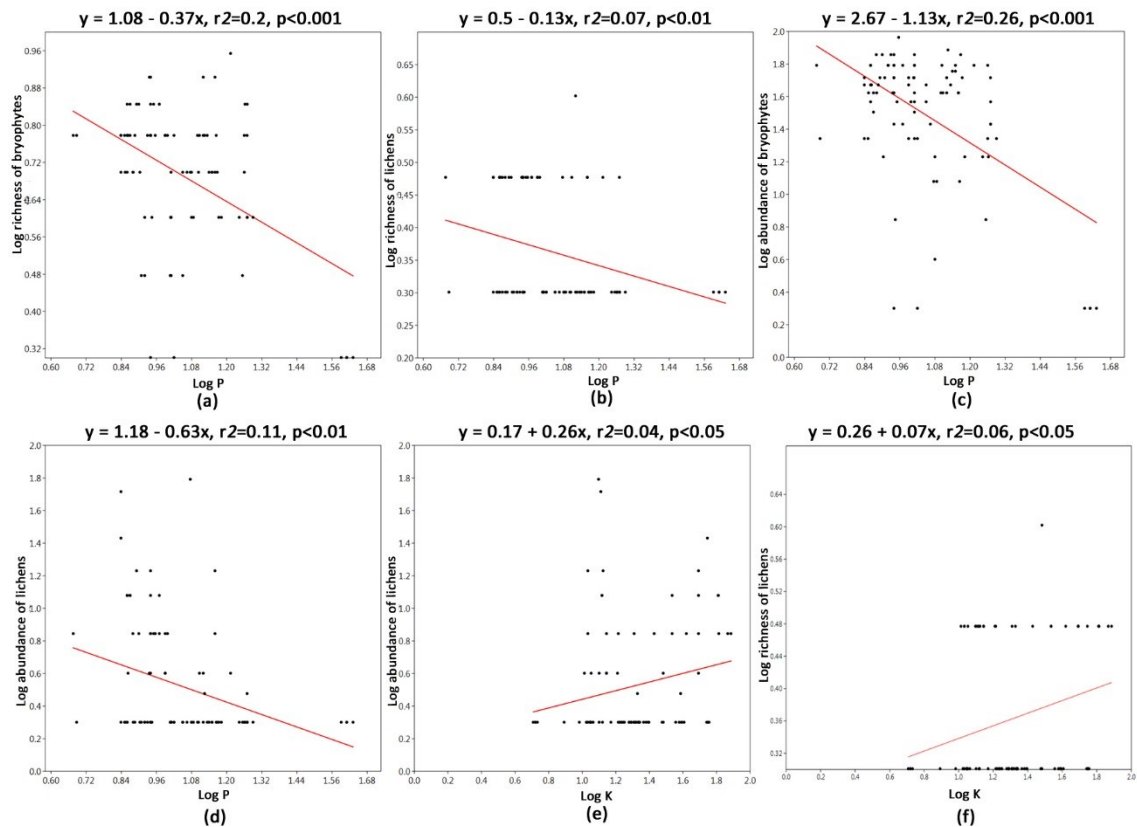


Figure 17. Linear regressions of (a) richness of succulents, (b) richness of graminoids, (c) richness of bryophytes, (d) richness of lichens, (e) abundance of bryophytes, (f) abundance of lichens; on age of EGRs with regression equation on the top of each graph

Abundance of succulents and K level has “hump-shaped” relationship (Fig.18).

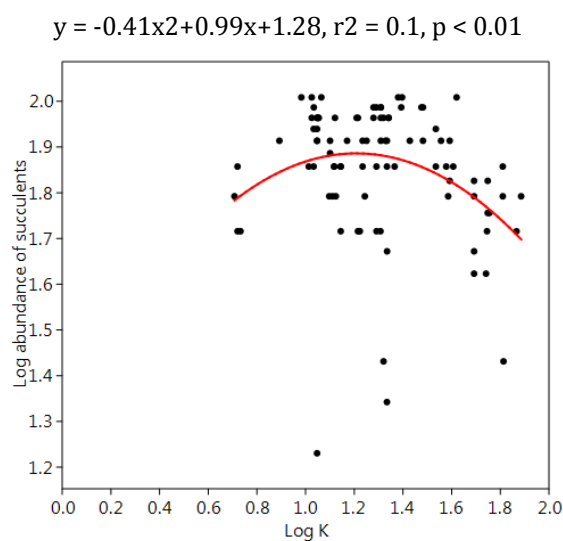


Figure 18. Polynomial regression of abundance of succulents on K level of EGRs with regression equation, R-squared and p-value on the top of the graph

4 Discussion

4.1 General data

Among the variables such as *Sedum mix*, company, and type of green roof system, which were set up for CCA ordination with forward selection, the most statistically significant one is type of *Sedum mix*. It is clear that originally planted vegetation influence species distribution. However, each company also uses their own soil and their green roof systems, which create environment for plants. In addition, more than a half of the plots (52%) have *Sedum* mats from a single producer (Veg Tech/Blomstertak). Therefore, it is difficult to compare the influence of the variables *Sedum mix*, company and green roof system separately. Studying the influence of these variables separately would require to use an experimental design with modules, as in the study of Hanslin et al. (2015). They concluded that there is an interaction between green roof system, vegetation mix and climate conditions.

The environmental variable 'flat roof/roof with a slope' was tested to be significant for species distribution, according to CCA. In the study of Noreng et al. (2012) it can be explained by the factors such as insufficient slope to the drain or lack of emergency overflow for runoff, which can cause vegetation degradation. The type "flat roof" is not completely flat, as for example, roofs with slope less than 1.1° should have an extra construction under the EGR system to provide positive drainage for water runoff (Roehr et al., 2015).

Area is a significant variable for all species distribution (DCA ordination), although it does not show any significant correlation with richness and abundance of species groups (Fig. 8). In the study of Köhler (2006) the area of green roof was not statistically significant factor for species distribution.

Elevation can be important because of the wind exposure, which can make conditions harder for plant growth (Sutton, 2015). However, in this study the elevation is not statistically significant. The reasons can be that the elevation is not showing the height of the building, and the elevation difference is not so large. The youngest roofs were at low elevations and close to the sea which might have stronger winds. However, it is not possible to draw any conclusions according to the data collected in this thesis.

4.2 Vegetation

Originally planted vegetation has a large influence on species distribution on the studied EGRs. The dominant species group on 77 out of 92 plots is the originally planted succulents. SES of vascular plants dominate on two plots (plot #47 and #48), while bryophytes are dominant on 13 plots. Richness of species has risen statistically highly significant after the installation on the studied EGRs. However, richness of the originally planted species (succulents) has decreased statistically highly significant. Similarly, the study Rowe et al. (2012) shows succession of succulents over seven years, and only six of 25 originally planted succulents survived. In soil depth of 2.5 cm, the succulents with the highest abundance were *Sedum album*, *Sedum acre*, *Sedum middendorffianum* and *Phedimus spurius*. All but *Sedum middendorffianum* are present in the found planted species group in my study. According to the study of Rowe et al. (2012), *Sedum album* and *Sedum acre* spread better and they are stronger competitors in the depth of 2.5 cm. It is also supported in my study on the roof #12 with the shallowest substrate depth (1.9 cm). On this roof, only *Sedum album* and *Sedum acre* survived on 3 out of 4 plots. In the fourth plot, *Phedimus hybridus/kamtschaticus* and *Sedum sexangulare* were also found.

The data shows that on the studied EGRs the abundance of vascular SES (herbs and graminoids) rises, while abundance of succulent declines. When abundance of succulents reaches medium level, the highest abundance of bryophytes and lichens is present, and the abundance of herbs and graminoids declines. The highest abundance of succulents refers to decrease of SES. Change of abundance of species can be the result of competition for water and nutrients (as presented in the study of EGR conducted over 6-years (Rowe, 2015)) or the available niches taken by SES.

According to the FLL guide (Forschungsgesellschaft, 2008), the total cover of originally planted vegetation must exceed 80% in *sedum*-moss mats during installation. Originally planted vegetation includes only succulent species (not bryophytes), 47 plots (51%) of the 92 plots studied in this thesis demonstrate decrease of originally planted vegetation. On most of the studied EGRs' plots, SES cover available space. Only five plots from three EGRs have more than 20% of bare ground: plot 2 (roof #2), plots 25 and 39 (roof #5), and plot 77 and 80 (roof #16). However, vascular SES are depending

on water availability, which is also related to soil depth, soil properties and rain events. Similarly, there is no relation between seasons and age of the site for establishment of these species (Emilsson, 2008). Therefore, vascular SES discovered in the study can appear on EGRs when the environmental conditions become optimal for them.

The report with case study about EGRs in Eastern Norway and Oslo region made by SINTEF in cooperation the Norwegian University of Life Sciences reported lack of vegetation on three out of six studied EGRs, while all of them have vegetation-related problems, such as poor growth, invasion of weeds and wind erosion (Noreng et al., 2012). In the same case study, vegetation on one of the roofs studied in this thesis (roof #2) was checked in 2012. They found six species *Sedum acre*, *Sedum album*, *Hylotelephium ewersii*, *Phedimus kamtschaticus*, *Sedum floriferum*, and *Sedum sexangulare*. I also found these six species, and in addition *Phedimus spurius*. However, I considered *Sedum floriferum* and *Phedimus kamtschaticus* as synonyms and both of them belong to the category of *Phedimus kamtschaticus/Phedimus hybridus*.

Ceratodon purpureus was also present on the studied EGRs as a dominant bryophyte, which was also the fact in Swedish three-year-long experiment (Emilsson, 2008). Mosses in general have a positive function on EGRs – they cover bare ground and therefore reduce moist loss from soil (Hanslin et al., 2015).

Woody plants (*Betula pendula* and *Salix caprea*) which are growing on plot 47 are problematic for *sedum*-moss EGRs, because of an increased weight and the penetration of the waterproof membrane by their roots (Roehr et al., 2015). On studied plot 47, woody plants of two meter height could survive with the soil depth of 10.8 cm. However, Emilsson (2008) reported that only a few woody plants can survive a summer drought condition in 4 cm soil depth, which is usual soil depth for *sedum*-moss EGRs.

Hanslin et al. (2015) in the experimental study in Norway reported that during the summer 2015, which was the summer of my fieldwork, EGRs were moister compare to usual conditions. Therefore, they think that it gave an opportunity to SES to overcome the dry period of July and August.

Veronica Verna is single Red-listed species found on two EGRs (#1 and #5). Abundance of this annual SES is in small range 1-5%. Therefore, it is doubtful that *Veronica Verna* will appear next year on the EGRs.

Two Black-listed species *Phedimus spurius* and *Phedimus hybridus* were present in most of the *Sedum* mixes of the originally planted vegetation (Gederaas et al., 2012). *Phedimus spurius* is present on 13 EGRs (37 plots), except for roofs # 8, #9, #12, #13, and #14. The maximum abundance is 50% on plot 85 (EGR #17), where it is a dominant succulent. The average abundance of this species is 7% among studied plots with presence of *Phedimus spurius*.

For *Phedimus hybridus*, it is possible to say the presence and absence only for the category *Phedimus hybridus/Phedimus kamtschaticus*. This category is present on 14 EGRs (52 plots), except for roofs #2, #3, #9 and #13. Roof #9 originally had species from category *Phedimus hybridus/Phedimus kamtschaticus*. However, *Phedimus hybridus* is not used in the *Sedum* mix, therefore I assume it is *Phedimus kamtschaticus*. The maximum abundance is 90% on plot 5 (roof #2), the average abundance of this species category is 24% among studied plots where the category is present. It is challenging to tell about the risk and influence of the Black List vegetation on EGR biodiversity without knowing the initial percentage of succulents in the *Sedum* mix. A study of Hanslin et al. (2015) states that it is challenging to use Black List species on EGRs in Norway, because of potential effect on biodiversity, even if it is allowed to use them on EGRs as an exception. Sterile cultivars of these species have no risk for the spreading to the natural environment, but there was no data if the species are sterile cultivar.

According to Rowe et al. (2012), deeper substrates allow *Phedimus hybridus*, *Phedimus kamtschaticus* and *Phedimus spurius* to outcompete *Sedum album* and *Sedum acre*, which are native Norwegian species.

4.3 Vegetation and environmental variables

Abundance and richness of species is mostly affected by a biotic factor (type of *Sedum* mix), abiotic factors (soil depth, pH, P, K and loss on ignition) and age.

Sun and shade conditions did not show statistical significance for all species distribution according to CCA in this thesis. Succulents' abundance and richness show a correlation with sun conditions, and SES are related to the shade on the PCA ordination diagram (Fig. 9). A long-term study found that there is no difference in overall species abundance, but some species prefer sun or shade conditions (Rowe, 2015).

Soil depth is limited on EGRs and depends on what company set on EGR (Appendix VIII). Deeper soil depth supports more abundance of SES of herbs, graminoids, and bryophytes (Fig. 10 b, c, d). Richness of herbs is also growing with soil depth (Fig. 10 a). This should lead to the decline of abundance of succulents as the niches are taken (Rowe, 2015).

More acidic soil is supporting more SES of herbs, bryophytes, lichens and richness of species found during fieldwork. Abundance of herbs and lichens is also higher in more acidic soils. Succulents (*Sedum*) prefer more alkaline soil (Zheng et al., 2013). PH level shows an indirect effect on succulents' abundance. If the abundance of SES rises, abundance of succulents declines (Fig. 9).

Abundance of succulents shows a decline over time until approximately five years after EGR installation. After that, the abundance rises, which represents normal succession. Richness of succulents and graminoids declines with age. However, at the same time richness and abundance of bryophytes and lichens grow. Rowe (2015) confirms that abundance of species on EGRs is subjected to fluctuations over time.

In my study, richness of all SES grows with more organic matter in soil. Abundance of herbs and lichens also increase with raising organic matter. Thuring et al. (2014) reported opposite results that richness of all life forms and abundance of all except succulents decline with more organic matter.

P and K levels influence species distribution more than Mg and Ca. P level influences abundance and richness of bryophytes and lichens negatively. Abundance of succulents rises with amount K until a certain point, and after it declines. K level is positively correlated only with lichens. Thuring et al. (2014) found that P level was also important, but influence all species groups except succulents negatively.

4.4 Soil

Soil for the EGRs is produced by companies, which grow *Sedum* mats. It was not possible to collect the accurate information about the soil properties and soil depth in the time of the establishment of the studied EGRs. Soil depth is important for vegetation survival, and generally more soil depth can support more species (Rowe et al., 2012).

Declared soil depth from *Sedum* mat suppliers varies from 2.0 to 6.0 cm (all data are presented in Appendix III). The measured soil depth for each roof shows the range from 1.9 to 5.4 cm (Table 9). The smallest value of soil depth is 1.9 cm was found on the EGR #12 (highlighted in blue color in Table 9). The value declared in green roof construction by Veg Tech is 3 cm for the EGR #12 (Appendix III). The soil decreased from 3 cm to 1.9 cm in eight years this roof existed. I assume that low abundance of succulents (40-65%) and high abundance of bryophytes (50-70%) produce low biomass. It can result in decrease of organic matter and therefore decrease in soil depth. At the same time, other EGRs from Veg Tech also show low loss on ignition values. Therefore, another reason for substrate loss can be wind erosion, because of lack of originally planted vegetation (Sutton, 2015). Other studies also support that soil depth declines with time. (Thuring et al., 2014).

Soil depth on several roofs #10, #11, #14 and #18 from Bergknapp has also decreased from the declared depth. The age of these roofs varies from 1 to 4 years, so it shows that the soil depth can decrease in relatively short time. Roof #9 also demonstrates a decrease in depth substrate from the value declared by Reiersøl Planteskole, and the EGR is 13 years old. Declared soil depth by Vital Vekst is set to a single value "2–4 cm", therefore it is difficult to discuss changes in soil depth. Other EGRs have soil depth as declared in each company's description of EGR system or higher (Appendix III).

The maximum mean soil depth for an unusual individual plot is 10.8 cm (plot 47, roof #2), which was excluded from counting the mean soil depth for each roof (Appendix VIII). The mean value for the EGR #2 is 5.4cm. The plot also demonstrates the highest level of loss on ignition (71%), which can be explained by the presence of SES with higher biomass production than *Sedum* species.

The range of mean pH level for each EGR is from 4.7 to 7.2 units. According to FLL guide (Forschungsgesellschaft, 2008), pH level should be within 6.0-8.5. EGRs #1, #13, #15, #16, and #17 have value less than 6.0 units (Table 9). Ca and pH levels are correlated. Some plots demonstrate a high level of Ca (roof #14), which the producer explained by the usage of silt sand in substrate. The optimal pH level for five individual species, which are also present on the studied EGRs, varies for individual species within 5.7-6.4 (Zheng et al., 2013). However, for the mineral soil used on EGRs the number can be higher. PH

level less than 5.6 influences Ca and Mg availability. With values higher than 6.2, P becomes less available. However, abundance of herbs declines with raising pH level.

Organic matter extends the allowed amount of $\leq 65\%$ (Forschungsgesellschaft, 2008) in one plot 47 (roof #2), because of high biomass production of the present of herbs (50%), graminoids (50%), and woody plants (50%). The lowest value for loss on ignition is 3.4%, and it should decrease the water holding capacity of the substrate. Several sources provide different recommended levels of organic matter by volume for EGRs, for example, from 4 to 8% according to one guide (Landschaftsbau, 2002) and according to another study 20% (Lockett, 2009). However, Norwegian standard for EGRs demands no more than 20% volume of organic matter in at least 3 cm soil depth, because of fire safety ("Grønne tak : planlegging, prosjektering, utførelse, skjøtsel og drift - Ekstensive tak," 2015). The organic matter level shows a negative correlation with the pH level in the studied soils, which was also found in another study (Molineux et al., 2009).

Maintenance treatments are unknown for the EGRs. However, from the interviews, I conducted, it can be seen that some studied EGRs have not received annual weed plants removal and fertilization treatments from installation or for a long period of time. The FLL guide (Forschungsgesellschaft, 2008) recommends maintenance treatments 2-4 times per year which include fertilizing, removal of unwanted plants, removal of plants on technical facilities, replacement of eroded substrate and repeated seedlings on free areas. Mosses can become dominant and reach more than 80% abundance on unfertilized EGRs (Emilsson, 2008), and fertilization reduce abundance of mosses (Hanslin et al., 2015). Fertilization also helps plants with winter surviving.

Nutrients level is not possible to compare with the FLL guide, because of different methods used for analyzing the data (see study limitations in Appendix XIII).

5 Conclusion

5.1 Major study conclusions

The vegetation composition on the studied EGRs has changed after installation. SES (herbaceous plants, graminoids, bryophytes, lichens and woody plants) grew in addition to the originally planted species (succulents). Plant species richness of EGRs increases after the installation. However, richness of the originally planted species of all the studied EGRs declined from 15 to 10 species. The SES are represented by 86 species.

The studied EGRs experience a decrease of abundance of originally planted vegetation, 51% of the studied plots have less than 80% of succulent abundance. SES become established in niches, which are free from succulents. Otherwise, SES outcompete succulents. Only five studied plots demonstrate more than 20% of bare ground.

Originally planted species still dominate on the majority of the studied plots, but some plots are dominated by SES (13 plots are dominated by bryophytes and several by herbaceous plants). Abundance of bryophytes reached 90% on some studied plots. Red-listed species were found on two roofs. Black-listed species were found on the majority of studied EGRs, since two of originally planted species are listed in the Norwegian Black List.

Soil depth, pH level and organic matter show only indirect effect on succulents. In my results, when abundance of the originally planted species declines, the abundance of SES increases. Deeper soil and low pH support more SES, at the same time succulents decline. Soil depth is the main abiotic factor (gradient) that influences species distribution on the studied EGRs. Deeper soil supports more herbs and demonstrates higher abundance of herbaceous plants, graminoids and bryophytes. More organic matter in soil shows an increase in SES richness and abundance.

Richness of succulents decreases with age, while richness of bryophytes increases. Abundance of the originally planted species shows a decline in the first five years and growth afterwards.

Elevation, sun and shade conditions, dry matter, specific weight, Mg and Ca levels, and area are not important for species distribution.

5.2 Achieving the main study objectives

The main objectives of the study are achieved through answering all research questions.

The objective of the study “Has vegetation composition on studied EGRs in Oslo changed after it has been established?” has been confirmed with floristic sampling on 18 EGRs in the Oslo region. The data about vegetation composition and richness found during fieldwork was compared with vegetation composition and richness of originally planted species from *Sedum* mat producers.

The objective of the study “How has the composition changed?” has been achieved by SES identification and comparing the abundance of the found planted species with the declared species abundance in FLL guide.

The objective of the study “What is the relation between vegetation composition and environmental variables?” has been achieved through soil sampling with soil analysis and collecting general data. Statistical analyses such as ordination analysis and regressions have been performed to find relationship between vegetation and environmental variables.

5.3 Future work

The results of the study are presented in this thesis allows several options for future research work:

- Abundance of individual species can be used to count a dominant species for each roof and see the difference between the age and the dominant species to better understand the succession on EGRs in Oslo.
- Vegetation richness and abundance studied in this thesis can be used to compare them with the availability of water in substrates, because water availability is one of the limiting factors in shallow substrates of EGRs.
- Richness, abundance and vegetation composition of originally planted vegetation and SES can be monitored over several years, because most of the species are perennials, therefore it would be interesting to see the dynamics of succession.

- Abundance of the Black-listed species *Phedimus hybridus* and *Phedimus spurius* can be monitored for studying their influence on EGR biodiversity.
- The data about species distribution can be applied to the Artsdatabanken website for studying vegetation in cities.
- Nutrient levels in this study determined by AI –method can be compared indirectly with the nutrient levels in FLL guide and other studies, determined by different methods though comparison with agricultural norms.

5.4 Recommendations

The results of this thesis allow formulating a number of practical recommendations for industrial and academic organizations working with designing, installing, maintaining and studying EGRs.

1. Add soil. Soil depth usually declines with age and the amount of originally planted species declines too.
2. Add fertilizer. Unfertilized EGRs are associated with decline of originally planted species abundance and raise of mosses. Slow-realized fertilizer in limited amounts can be added to support originally planted species.
3. Raise pH level. PH level usually declines with the age, and it should be kept within the recommended range to support the originally planted species.
4. Woody plants should be removed especially *Betula sp.*

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Appendix I: Steps of method random walk

1. The starting point was the location where I stepped on the roof.
2. I draw one random number from 0 to 360 degrees to determining the direction. Using the compass, I check if I can walk in this direction.
3. Depending on the size of the roof, I define the range of distances for generating the second random number (how far I can walk in the chosen direction).
4. I draw another random number to count steps in the chosen direction. In this way, I found my first random sample plot on the green roof.
5. To find next the sample plot, I generated random number for the direction and distance again, from the point where I stood.

Appendix II: DCA and CCA script in R

```
art<-read.table('clipboard',header=T, row.names=1,dec=",")
env<-read.table('clipboard',header=T, row.names=1,dec=",")
attach(env)
names(env)
art <-as.data.frame(art)
attach(art)
names(art)
#dummy Grmat
dummy <- model.matrix( ~ Grmat - 1, data = env)
dummy
dummy[,1]
factor(dummy[, 1])
library(vegan)
DCA.res<-decorana(art)
#performs DCA
plot(DCA.res)
#DCA
summary(DCA.res)
scores(DCA.res,display="sites") #extracts sample/site axis scores
scores(DCA.res,display="species") #extracts variable/species axis scores
scores(DCA.res,display="sites",choice=1:2) #extracts sample/site scores for axes 1 and 2
only
scores(DCA.res,display="species",choice=2:3) #extracts sample/site scores for axes 2
and 3 only
plot(DCA.res)
#env to DCA
plot(DCA.res)
dca1.fit <-envfit(DCA.res, env, perm = 999, na.rm=TRUE)
dca1.fit
#transparent yellow small labels
plot(DCA.res)
plot(dca1.fit, bg = rgb(1,1,0,0.5), fond = 2,
      cex = 0.8, col = "dark green", fond = 2)
```

```

layout(matrix(1:2, ncol = 2)) # makes side by side species:sites
ordiplot (DCA.res, display = 'sp', type = 'n')
orditorp (DCA.res, display = 'sp')
ordiplot (DCA.res, display = 'si', type = 'n')
orditorp (DCA.res, display = 'si')
ordilabel (DCA.res, display = 'si')
#Perform CCA with forward selection
art2<-read.table('clipboard',header=T, row.names=1,dec=",")
env2<-read.table('clipboard',header=T, row.names=1,dec=",")
library(vegan)
attach(env2)
names(env2)
art <-as.data.frame(art2)
attach(art2)
names(art2)
#dummies
dummy <- model.matrix( ~GRs - 1, data = env2)
dummy
dummy[,1]
factor(dummy[, 1])
dummy2 <- model.matrix( ~Grmat - 1, data = env2)
dummy2
dummy2[,1]
factor(dummy2[, 1])
dummy3 <- model.matrix( ~Company - 1, data = env2)
dummy3
dummy3[,1]
factor(dummy3[, 1])
cca(art2 ~ ., env2, na=na.omit, subset = complete.cases(art2))
cca.art2.0 <- cca (art2 ~ 1, data = env2) # model containing only species matrix and
intercept
cca.art2.all <- cca (art2 ~ ., data = env2, na=na.omit) # model including all variables from
matrix env (the dot after tilde (~) means ALL!)
ordistep (cca.art2.0, scope = formula (cca.art2.all), direction = 'forward')

```

Appendix III: Types of EGR systems used on studied EGRs (layers are numbered from the surface)

Type 1. ZinCo System build-up:

1. *Sedum* cuttings or plug plants according to plant list “*Sedum Carpet*”
2. System Substrate “*Sedum Carpet*”, ca. 6 cm
3. Filter Sheet SF
4. Drainage Floradrain® FD 25-E
5. Protection Mat SSM 45
6. If waterproofing is not root resistant the Root Barrier, WSF40 is required additionally

Type 2. Vital Vekst (flat roof 0-5 degrees):

1. Sempergreen *sedum* mixblankets, 20-40 mm
2. Extensive roof garden substrate, 40 mm
3. Drainage, Oldroyd Green 10B, 10 mm
4. Waterproof membrane

Type 3. Bergknapp (flat roofs 0-5 degrees):

1. Bergknapp *sedum*-Moss Mat, 30 mm
2. Colorgent 600 gr/m², 5 mm
3. Drainage mat Isola de 25, 20 mm
4. Waterproof membrane

Type 4. Bergknapp (flat roofs, 0-5 degrees):

1. Bergknapp *sedum*-Mose Mat, 30 mm
2. Drainage mat OLDROYD® Xv Green 25 with 5mm thick geotextile (600 g/m²), 20 mm
3. Waterproof membrane

Type 5. Reiersøl Planteskole AS (structure flat roofs, 0-5 degrees):

1. Nordic Green Roof® *sedum* mat, 25 mm
2. VH1200 Nordic Green Roof® water holding fabric, 10 mm
3. Dren17 Nordic Green Roof®, 17 mm

Type 6. Vegtech/Blomstertak (system XMS 0-4° Recommended pitch: 0-4 degrees):

1. Xeroflor *sedum*-moss mat growing in a structure of nonwovens with an integrated nylon nets system Xeroflor, 30 mm
2. Nophadrain 5+1 Drainage mat, 25 mm
3. Waterproof membrane
4. Under *sedum*-moss roof is not needed extra root protection

Appendix IV: Sun and shade conditions and elevation for each studied plot

Table 1. Sun and shade conditions and elevation

# of plot	Abbreviation of place	Sun/Shade conditions	Elevation, meters above sea level
1	HOEG	sun	94
2	HOEG	sun	88
3	HOEG	sun	89
4	HOEG	shade	91
5	GJEN	sun	132
6	GJEN	sun	131
7	GJEN	sun	128
8	GJEN	shade	125
9	GJEN	shade	123
10	GJEN	sun	122
11	GJEN	sun	121
12	GJEN	sun	127
13	GJEN	sun	123
14	GJEN	sun	122
15	PI25	shade	58
16	PI25	shade	44
17	PI25	sun	56
18	PI25	sun	58
19	SORE	sun	37
20	SORE	sun	32
21	SORE	sun	32
22	SORE	shade	32
23	PI41	sun	70
24	PI41	shade	72
25	PI41	sun	71
26	FORN	shade	37
27	FORN	sun	31
28	FORN	sun	30
29	STEN14	shade	68
30	STEN 14	sun	64
31	STEN 14	sun	62
32	STEN 14	sun	65
33	STEN 14	sun	66
34	STEN 14	sun	66
35	PI20	shade	49

# of plot	Abbreviation of place	Sun/Shade conditions	Elevation, meters above sea level
36	PI20	shade	36
37	PI20	sun	47
38	PI20	shade	45
39	PI41	sun	66
40	PI41	sun	52
41	PI41	sun	56
42	FORN	sun	41
43	FORN	sun	39
44	FORN	sun	39
45	FORN	sun	48
46	FORN	sun	44
47	GJEN	shade	131
48	GJEN	shade	126
49	UNIV	shade	118
50	UNIV	shade	225
51	UNIV	shade	131
52	UNIV	shade	110
53	SORE1 (building 85)	shade	44
54	SORE1 (building 85)	shade	42
55	SORE1 (building 85)	sun	26
56	SORE1 (building 85)	sun	32
57	SORE1 (building 90)	sun	27
58	SORE1 (building 90)	sun	27
59	SORE1 (building 90)	shade	30
60	SORE1 (building 90)	sun	29
61	BARN	shade	106
62	BARN	shade	106
63	BARN	shade	102
64	BARN	shade	100
65	BARN2	shade	82
66	BARN2	sun	117
67	BARN2	sun	92
68	BARN2	shade	93
69	AKER	sun	25
70	AKER	sun	27
71	AKER	sun	34
72	AKER	sun	37
73	BJOR	shade	108
74	BJOR	shade	33
75	BJOR	shade	102

# of plot	Abbreviation of place	Sun/Shade conditions	Elevation, meters above sea level
76	BJOR	shade	100
77	BJOR2	sun	114
78	BJOR2	sun	70
79	BJOR2	sun	62
80	BJOR2	shade	62
81	KREM	sun	134
82	KREM	shade	132
83	KREM	sun	110
84	KREM	sun	137
85	KREM	sun	133
86	KREM	sun	132
87	KREM	sun	132
88	KREM	sun	134
89	KVAR	sun	52
90	KVAR	sun	52
91	KVAR	sun	57
92	KVAR	sun	53

Appendix V: Richness and abundance of species from studied EGRs

Table 2. *Richness and abundance of species groups on studied EGRs*

Plot #	Abbreviation of place	Richness of								Abundance of						
		Planted species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Found species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Bare ground
1	HOEG	7	5	4	1	3	0	0	13	60	20	2	50	0	0	10
2	HOEG	7	5	1	1	3	0	0	10	50	2	1	35	0	0	30
3	HOEG	7	4	2	1	4	0	0	11	45	15	1	45	0	0	25
4	HOEG	7	5	4	5	5	0	1	20	70	5	5	60	0	1	10
5	GJEN	7	3	4	2	3	0	0	12	90	10	20	15	0	0	2
6	GJEN	7	3	0	0	2	0	0	5	90	0	0	60	0	0	0
7	GJEN	7	3	1	0	2	0	0	6	80	1	0	50	0	0	5
8	GJEN	7	4	3	0	2	0	0	9	80	5	0	40	0	0	5
9	GJEN	7	3	4	0	2	0	0	9	90	10	0	30	0	0	5
10	GJEN	7	3	1	0	1	0	0	5	85	5	0	70	0	0	5
11	GJEN	7	5	1	0	1	0	0	7	80	1	0	50	0	0	5
12	GJEN	7	3	2	0	1	0	0	6	90	5	0	35	0	0	5
13	GJEN	7	4	1	0	3	0	0	8	95	2	0	40	0	0	5
14	GJEN	7	4	0	0	3	0	0	7	80	0	0	60	0	0	5
15	PI25	7	4	0	0	4	1	0	9	60	0	0	20	50	0	5
16	PI25	7	4	0	0	4	1	0	9	70	0	0	30	10	0	2
17	PI25	7	3	0	0	5	1	0	9	60	0	0	50	15	0	2

Plot #	Abbreviation of place	Richness of								Abundance of						
		Planted species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Found species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Bare ground
18	PI25	7	4	0	0	5	0	0	9	70	0	0	40	10	0	15
19	Sore	7	6	0	0	3	0	0	9	60	0	0	55	0	0	5
20	Sore	7	4	0	0	3	0	0	7	50	0	0	55	0	0	10
21	Sore	7	5	0	0	3	0	0	8	50	0	0	70	0	0	10
22	Sore	7	6	0	0	3	0	0	9	70	0	0	60	0	0	10
23	PI41	7	1	5	0	2	0	0	8	70	15	0	20	0	0	15
24	PI41	7	3	5	1	5	0	0	14	70	30	5	35	0	0	5
25	PI41	7	5	3	0	2	0	0	10	50	10	0	15	0	0	50
26	FORN	7	6	2	2	6	1	0	17	90	5	5	40	2	0	1
27	FORN	7	6	0	0	6	1	0	13	80	0	0	50	5	0	5
28	FORN	7	5	0	0	4	0	0	9	90	0	0	20	0	0	5
29	Sten14	7	4	0	0	2	0	0	6	50	0	0	50	0	0	10
30	Sten14	7	3	0	0	4	1	0	8	70	0	0	50	5	0	5
31	Sten14	7	4	0	0	4	1	0	9	75	0	0	45	2	0	5
32	Sten14	7	4	0	0	4	1	0	9	50	0	0	45	2	0	10
33	Sten14	7	4	0	0	3	1	0	8	60	0	0	10	60	0	1
34	Sten14	7	6	0	0	4	1	0	11	70	0	0	20	2	0	5
35	PI20	7	4	4	0	7	1	0	16	90	20	1	60	2	0	1
36	PI20	7	4	0	0	6	1	0	11	70	0	0	40	5	0	5
37	PI20	7	4	1	0	4	1	0	10	70	2	0	40	2	0	5
38	PI20	7	4	1	0	3	1	0	9	85	2	0	40	15	0	0

Plot #	Abbreviation of place	Richness of								Abundance of						
		Planted species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Found species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Bare ground
39	PI41	7	5	3	0	2	0	0	10	20	20	0	25	0	0	50
40	PI41	7	3	5	0	4	1	0	13	80	15	0	50	1	0	15
41	PI41	7	3	3	0	2	0	0	8	80	20	0	25	0	0	20
42	FORN	7	6	0	0	4	0	0	10	95	0	0	25	0	0	1
43	FORN	7	5	0	0	4	0	0	9	95	0	0	20	0	0	2
44	FORN	7	5	0	0	0	0	0	5	95	0	0	0	0	0	2
45	FORN	7	6	0	1	4	0	0	11	95	0	1	10	0	0	1
46	FORN	7	5	0	0	4	0	0	9	90	0	0	40	0	0	0
47	GJEN	7	0	4	1	0	0	2	7	0	50	50	0	0	50	0
48	GJEN	7	3	5	2	2	0	0	12	15	80	30	20	0	0	10
49	UNIV	6	3	0	0	3	0	0	6	80	0	0	60	0	0	2
50	UNIV	6	5	0	0	4	0	0	9	80	0	0	50	0	0	5
51	UNIV	6	5	0	0	4	0	2	11	95	0	0	45	0	2	0
52	UNIV	6	5	0	0	6	2	0	13	95	0	0	40	2	0	1
53	SORE1 (building 85)	9	6	0	1	2	0	0	9	95	0	1	15	0	0	5
54	SORE1 (building 85)	9	6	2	1	1	0	0	10	80	2	2	45	0	0	1
55	SORE1 (building 85)	9	6	0	0	3	0	0	9	80	0	0	40	0	0	0

Plot #	Abbreviation of place	Richness of								Abundance of						
		Planted species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Found species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Bare ground
	85)															
56	SORE1 (building 85)	9	6	0	0	3	0	0	9	70	0	0	35	0	0	10
57	SORE1 (building 90)	9	4	0	0	1	0	0	5	100	0	0	5	0	0	0
58	SORE1 (building 90)	9	5	0	0	3	0	0	8	90	0	0	20	0	0	1
59	SORE1 (building 90)	9	4	3	1	5	0	0	13	80	5	5	15	0	0	2
60	SORE1 (building 90)	9	5	0	0	4	0	0	9	25	0	0	60	0	0	20
61	BARN	7	2	0	0	1	0	0	3	40	0	0	50	0	0	20
62	BARN	7	4	0	1	2	0	0	7	55	0	1	60	0	0	5
63	BARN	7	2	0	0	4	0	0	6	55	0	0	70	0	0	5
64	BARN	7	2	0	0	1	0	0	3	65	0	0	60	0	0	5
65	BARN2	10	5	3	0	4	1	0	13	50	5	0	45	25	0	0
66	BARN2	10	5	1	0	4	1	0	11	70	1	0	45	10	0	2
67	BARN2	10	6	0	0	3	1	0	10	50	0	0	70	5	0	5

Plot #	Abbreviation of place	Richness of								Abundance of						
		Planted species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Found species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Bare ground
68	BARN2	10	5	4	0	4	1	0	14	60	2	0	60	10	0	5
69	AKER	8	5	0	1	0	0	0	6	100	0	5	0	0	0	0
70	AKER	8	4	0	0	0	0	0	4	90	0	0	0	0	0	10
71	AKER	8	6	2	1	0	0	0	9	90	2	2	0	0	0	10
72	AKER	8	6	2	1	0	0	0	9	90	2	2	0	0	0	10
73	BJOR	10	3	1	0	5	1	0	10	80	2	1	35	5	0	0
74	BJOR	10	4	3	0	5	1	0	13	85	10	0	25	5	0	0
75	BJOR	10	4	1	0	4	1	0	10	100	2	0	35	5	0	0
76	BJOR	10	3	1	0	5	1	0	10	70	1	0	60	10	0	5
77	BJOR2	9	3	0	0	3	0	0	6	70	0	0	25	0	0	25
78	BJOR2	9	3	0	0	2	0	0	5	65	0	0	2	0	0	0
79	BJOR2	9	4	3	1	4	0	0	12	70	10	2	40	0	0	15
80	BJOR2	9	5	0	1	3	0	0	9	80	0	0	15	0	0	30
81	KREM	10	2	2	2	4	1	0	11	25	10	5	90	5	0	1
82	KREM	10	2	4	1	4	1	0	12	65	25	1	60	5	0	0
83	KREM	10	3	2	1	5	1	0	12	60	15	2	70	5	0	2
84	KREM	10	6	4	1	4	1	1	17	60	15	5	50	2	1	2
85	KREM	10	5	2	0	4	0	0	11	60	5	0	75	1	0	0
86	KREM	10	4	3	0	4	1	0	12	40	10	0	70	10	0	2
87	KREM	10	4	5	0	4	1	0	14	50	15	0	60	5	0	2
88	KREM	10	6	5	0	5	1	0	17	45	30	10	60	15	0	0

Plot #	Abbreviation of place	Richness of								Abundance of						
		Planted species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Found species	Succulents	Herbs	Graminoids	Bryophytes	Lichens	Woody plants	Bare ground
89	KVAR	6	3	0	0	2	0	0	5	100	0	0	5	0	0	0
90	KVAR	6	7	0	0	0	0	0	7	100	0	0	0	0	0	0
91	KVAR	6	6	0	0	2	0	0	8	100	0	0	10	0	0	0
92	KVAR	6	3	0	0	4	0	0	7	90	0	0	20	0	0	0

Blue color represents abundance of succulents, which is less than 80 %

Appendix VI: Histograms of frequency distribution of succulent abundance on studied plots

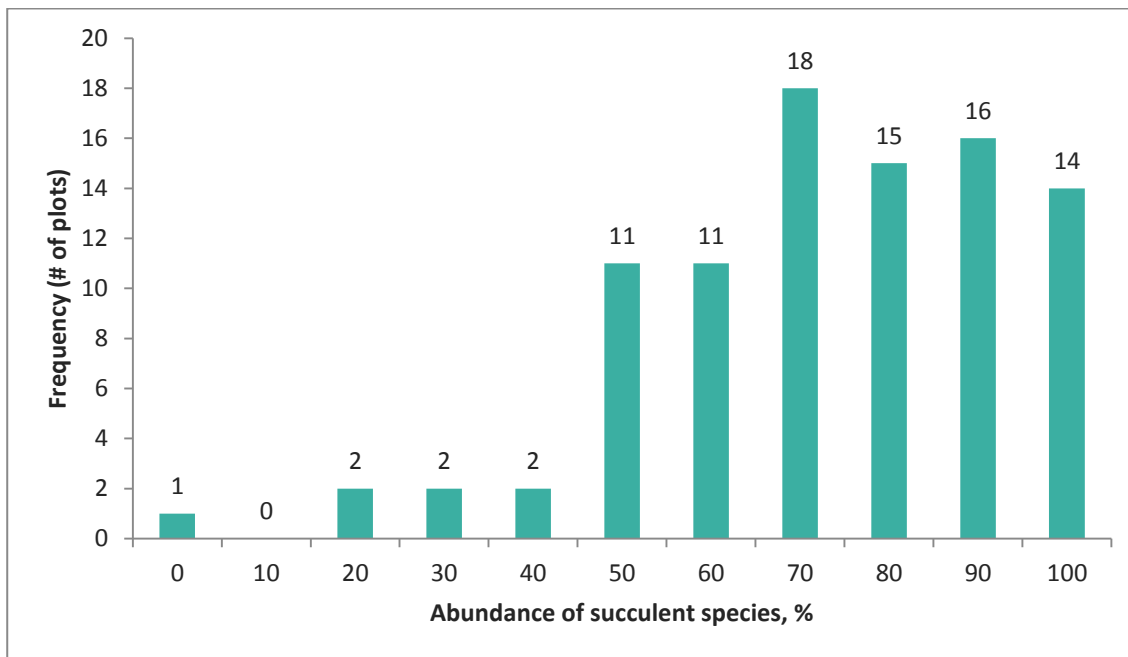


Figure 1. Histogram of frequency distribution of succulent species abundance on studied plots

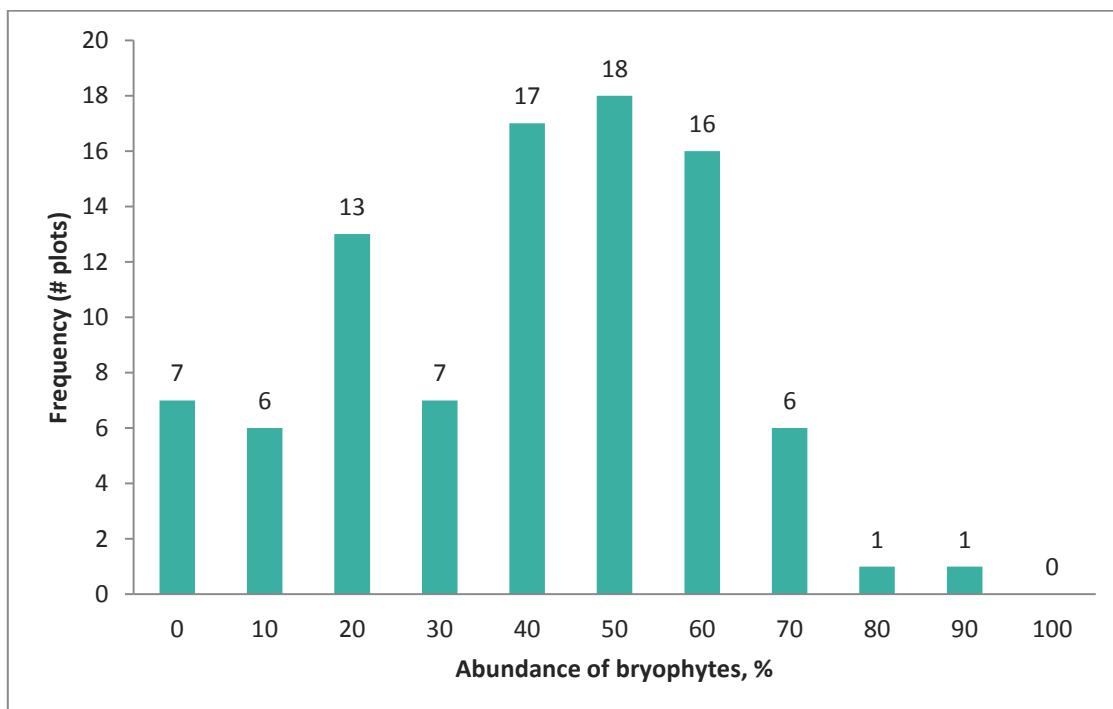


Figure 2. Histogram of frequency distribution of bryophyte species abundance on studied plots

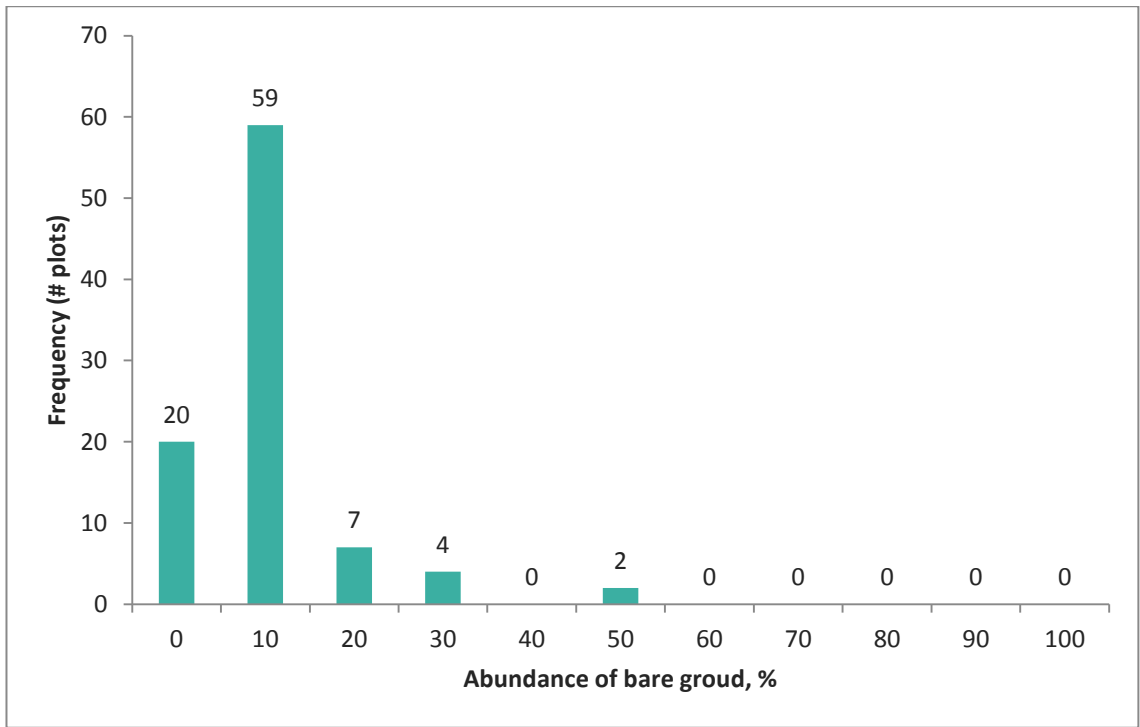


Figure 3. Histogram of frequency distribution of bare ground abundance on studied plots

Appendix VII: Presence and absence of *Phedimus hybridus/ kamtschaticus* and *Phedimus spurius*

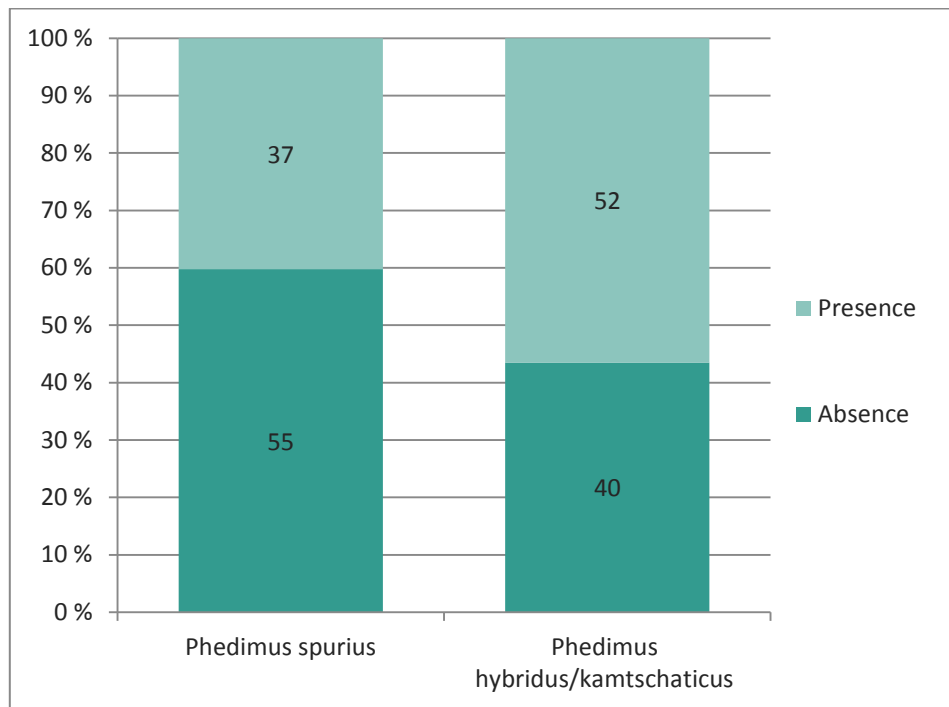


Figure 4. Mosaic plot of presence and absence of two species *Phedimus hybridus/ kamtschaticus* and *Phedimus spurius* on studied plots

Appendix VIII: Results from soil analysis for each studied plot

Table 3. Results of soil depth and soil analysis for each plot on studied EGRs

# of plot	Soil depth, cm	Dry Matter, %	Loss on Ignition, %	Specific weight, g for 1 ml of soil	PH	P	K	Mg	Ca
						mg nutrient/100 g air-dried soil			
1	5,2	96,506	25,375	0.45	6,1	4,90	15,5	52,2	533,4
2	4,9	NA	NA	NA	NA	NA	NA	NA	NA
3	5,6	95,329	37,505	0.43	5,4	5,70	19,6	54,0	275,7
4	3,1	NA	NA	NA	NA	NA	NA	NA	NA
5	9,8	99,020	5,868	1.11	6,8	6,01	9,3	29,9	4177,0
6	5,1	NA	NA	NA	NA	NA	NA	NA	NA
7	5,1	98,443	8,307	0.85	7,4	12,90	5,8	5,6	231,8
8	5,1	NA	NA	NA	NA	NA	NA	NA	NA
9	6,2	98,404	9,005	0.66	7,3	8,23	11,2	40,9	338,0
10	4,3	NA	NA	NA	NA	NA	NA	NA	NA
11	5,0	98,193	9,692	0.83	7,3	8,16	10,6	32,2	3891,0
12	4,7	NA	NA	NA	NA	NA	NA	NA	NA
13	5,1	98,756	6,657	0.83	7,3	5,60	8,8	33,0	4646,0
14	2,6	NA	NA	NA	NA	NA	NA	NA	NA
15	4,2	98,296	8,248	0.88	7,2	4,90	10,9	24,8	3534,0
16	4,0	NA	NA	NA	NA	NA	NA	NA	NA
17	3,6	97,972	9,777	0.82	7,1	5,80	11,3	23,8	3377,0
18	3,6	NA	NA	NA	NA	NA	NA	NA	NA
19	4,0	99,500	3,196	1.21	7,1	11,79	3,1	14,3	1994,0
20	3,5	NA	NA	NA	NA	NA	NA	NA	NA
21	3,0	99,405	3,743	1.32	7,0	12,71	3,4	16,1	2170,0

# of plot	Soil depth, cm	Dry Matter, %	Loss on Ignition, %	Specific weight, g for 1 ml of soil	PH	P	K	Mg	Ca
						mg nutrient/100 g air-dried soil			
22	3,4	NA	NA	NA	NA	NA	NA	NA	NA
23	4,2	97,937	13,069	0.83	7,1	17,50	21,2	23,7	1126,0
24	5,5	NA	NA	NA	NA	NA	NA	NA	NA
25	3,6	97,945	12,513	0.90	6,9	15,50	18,3	25,8	1021,0
26	3,7	98,184	10,263	0.81	6,8	6,63	14,2	8,7	813,2
27	3,3	NA	NA	NA	NA	NA	NA	NA	NA
28	2,7	96,860	9,633	0.86	6,9	2,87	14,4	11,8	1221,0
29	3,5	97,381	11,528	0.72	6,8	8,20	14,7	20,8	2651,0
30	2,9	NA	NA	NA	NA	NA	NA	NA	NA
31	2,8	97,579	9,715	0.79	6,8	5,30	10,6	22,9	3295,0
32	3,3	NA	NA	NA	NA	NA	NA	NA	NA
33	3,4	97,242	11,229	0.79	6,8	9,90	10,5	24,0	3593,0
34	3,4	NA	NA	NA	NA	NA	NA	NA	NA
35	3,8	98,354	8,300	0.85	6,9	14,34	9,3	22,6	3360,0
36	3,4	NA	NA	NA	NA	NA	NA	NA	NA
37	3,4	98,450	7,761	0.91	6,9	10,79	8,3	24,5	3721,0
38	3,5	NA	NA	NA	NA	NA	NA	NA	NA
39	3,9	NA	NA	NA	NA	NA	NA	NA	NA
40	4,2	97,847	13,051	0.78	6,7	16,60	19,3	23,0	1147,0
41	3,5	NA	NA	NA	NA	NA	NA	NA	NA
42	3,2	NA	NA	NA	NA	NA	NA	NA	NA
43	3,2	98,361	9,409	0.88	6,8	5,10	17,0	10,3	1045,0
44	2,2	NA	NA	NA	NA	NA	NA	NA	NA
45	2,9	97,528	13,947	0.73	6,5	12,60	27,9	14,9	906,8
46	2,7	NA	NA	NA	NA	NA	NA	NA	NA

# of plot	Soil depth, cm	Dry Matter, %	Loss on Ignition, %	Specific weight, g for 1 ml of soil	PH	P	K	Mg	Ca
						mg nutrient/100 g air-dried soil			
47	10,8	93,316	70,910	0.21	6,0	8,30	46,5	77,3	929,5
48	6,2	NA	NA	NA	NA	NA	NA	NA	NA
49	2,4	97,032	17,224	0.59	6,4	10,70	34,0	21,7	2964,0
50	2,0	NA	NA	NA	NA	NA	NA	NA	NA
51	2,3	96,127	23,318	0.49	6,4	11,60	22,7	48,5	6363,0
52	2,3	NA	NA	NA	NA	NA	NA	NA	NA
53	2,6	97,607	14,704	0.62	6,5	13,20	17,5	16,9	1193,0
54	2,5	NA	NA	NA	NA	NA	NA	NA	NA
55	2,6	97,839	12,641	0.78	6,8	5,13	12,8	14,8	1649,0
56	2,3	NA	NA	NA	NA	NA	NA	NA	NA
57	2,3	97,932	14,119	0.67	6,5	15,94	22,0	16,8	1169,0
58	2,2	NA	NA	NA	NA	NA	NA	NA	NA
59	2,7	97,936	13,418	0.69	6,5	16,30	15,8	18,0	1149,0
60	1,6	NA	NA	NA	NA	NA	NA	NA	NA
61	2,0	98,297	7,413	1.06	6,4	6,10	53,1	28,7	317,1
62	1,8	NA	NA	NA	NA	NA	NA	NA	NA
63	1,9	98,357	7,487	0.99	6,4	6,50	54,9	31,6	366,8
64	1,8	NA	NA	NA	NA	NA	NA	NA	NA
65	5,4	97,295	19,209	0.71	5,1	4,90	53,6	29,2	275,4
66	4,0	NA	NA	NA	NA	NA	NA	NA	NA
67	4,0	97,728	14,173	0.79	5,3	5,58	71,5	21,4	197,1
68	4,0	NA	NA	NA	NA	NA	NA	NA	NA
69	2,5	98,399	12,644	0.58	6,5	40,80	22,9	263,4	11510,0
70	2,5	NA	NA	NA	NA	NA	NA	NA	NA
71	2,7	98,496	11,583	0.68	6,5	37,00	17,0	6505,4	11390,0

# of plot	Soil depth, cm	Dry Matter, %	Loss on Ignition, %	Specific weight, g for 1 ml of soil	PH	P	K	Mg	Ca
						mg nutrient/100 g air-dried soil			
72	2,5	NA	NA	NA	NA	NA	NA	NA	NA
73	2,8	96,979	27,708	0.51	4,7	6,92	24,8	52,0	291,0
74	2,9	NA	NA	NA	NA	NA	NA	NA	NA
75	3,1	96,378	29,372	0.57	4,7	7,95	39,7	40,2	379,6
76	2,8	NA	NA	NA	NA	NA	NA	NA	NA
77	2,9	97,807	14,964	0.75	5,3	9,60	35,8	45,0	290,3
78	3,0	NA	NA	NA	NA	NA	NA	NA	NA
79	2,8	97,027	21,425	0.63	5,6	10,60	38,4	51,3	405,4
80	3,1	NA	NA	NA	NA	NA	NA	NA	NA
81	3,0	96,891	22,145	0.55	5,3	7,04	63,0	33,8	332,2
82	3,7	NA	NA	NA	NA	NA	NA	NA	NA
83	3,7	97,464	16,149	0.63	5,4	5,94	74,8	30,8	316,3
84	4,0	NA	NA	NA	NA	NA	NA	NA	NA
85	3,2	97,030	23,659	0.61	5,0	11,32	36,5	31,3	327,4
86	3,2	NA	NA	NA	NA	NA	NA	NA	NA
87	3,3	97,069	25,030	0.58	5,1	2,74	14,4	34,1	324,4
88	4,9	NA	NA	NA	NA	NA	NA	NA	NA
89	2,6	99,356	4,853	0.87	6,6	6,80	7,6	182,9	5699,0
90	2,4	NA	NA	NA	NA	NA	NA	NA	NA
91	2,0	99,029	7,395	0.87	6,5	10,20	9,6	178,9	5457,0
92	2,7	NA	NA	NA	NA	NA	NA	NA	NA

Appendix IX: DCA ordination diagram with all studied plots

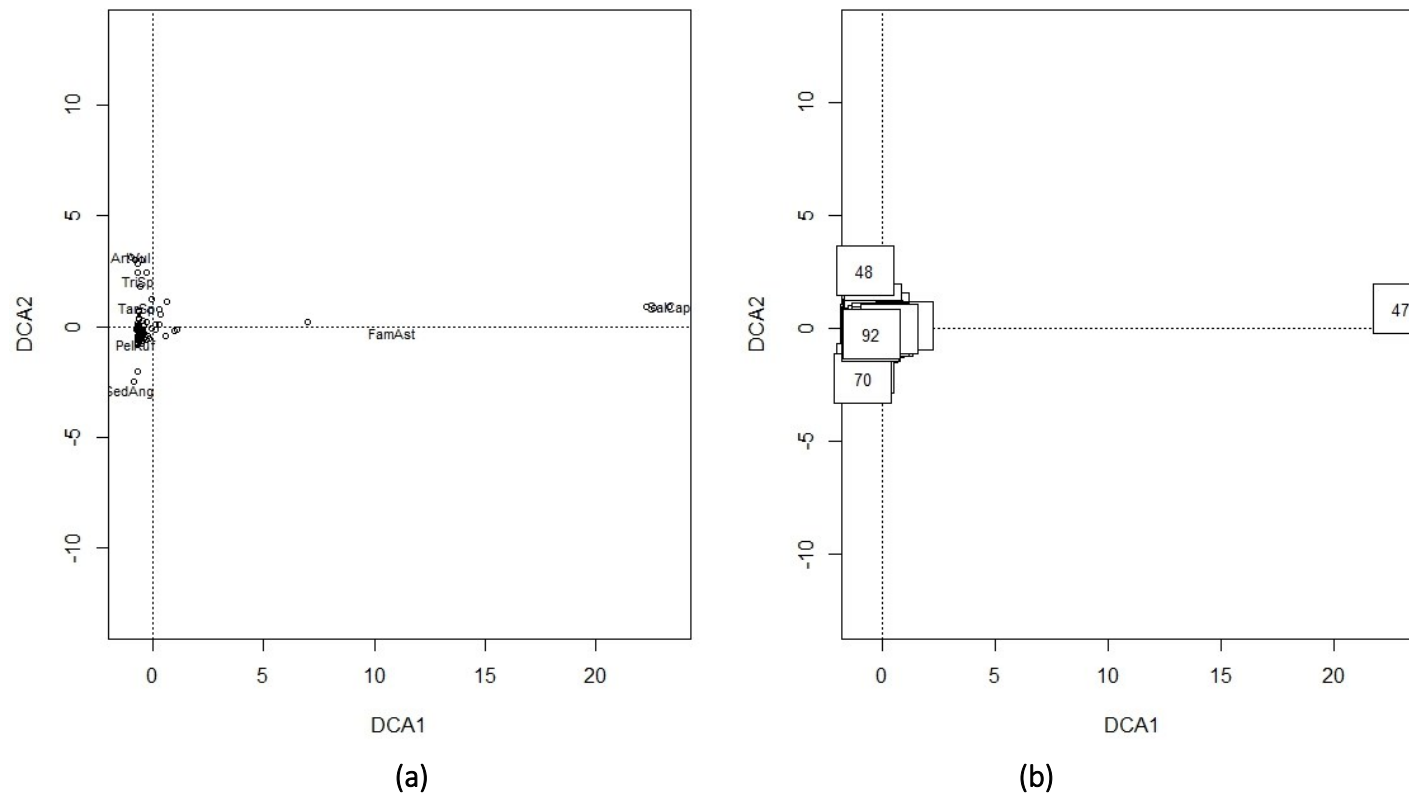


Figure 5. DCA ordination diagram (a) species distribution, (b) plots distribution, on studied EGRs with outlier plot 47

Appendix X: DCA ordination diagram with sedum mat types

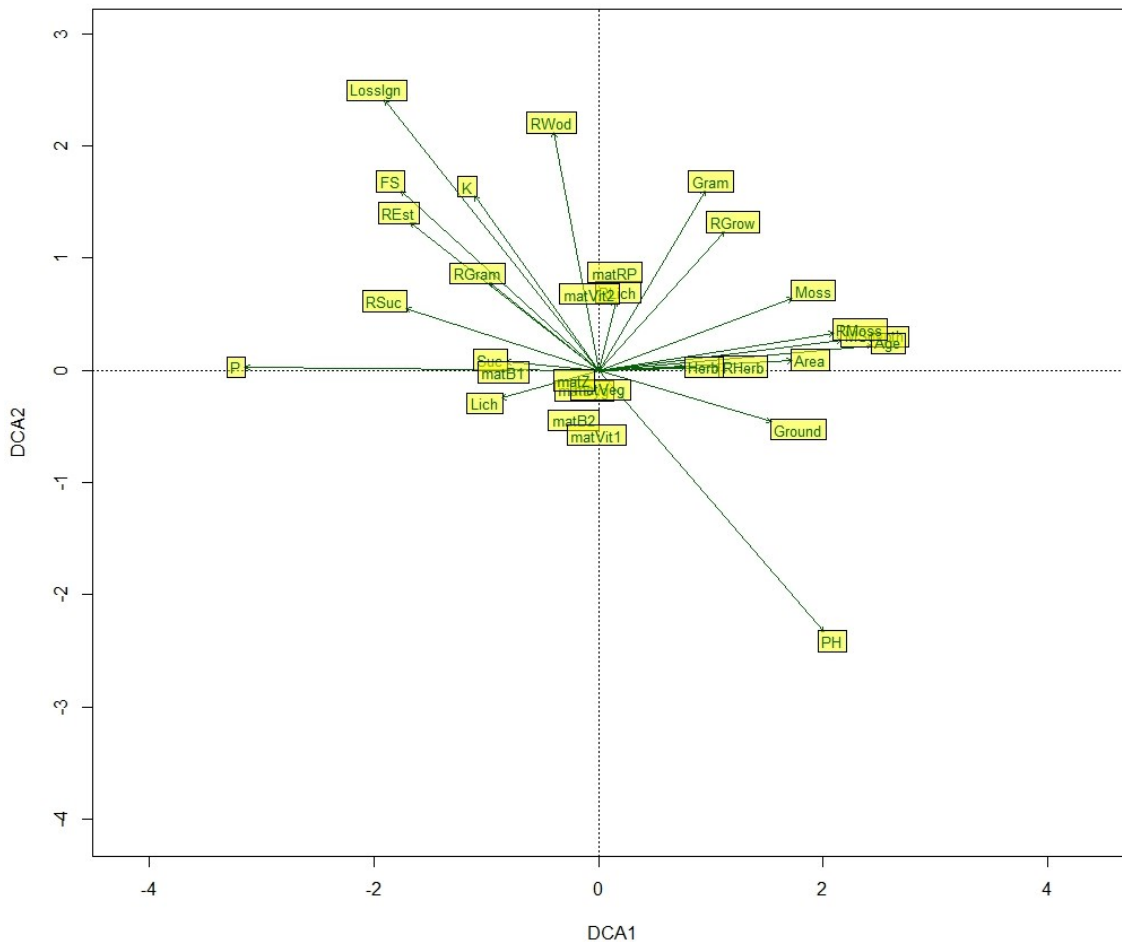


Figure 6. DCA ordination diagram with environmental data as vectors (arrows) and factors (names) without plot 47. LossIgn = loss on ignition, FS = flat roof or with slope, K = potassium, P = phosphorus, Age = age, area = area, MSdepth = mean of soil depth, REst = richness of planted species, Rgrow = richness of found species, Rsuc = richness of succulents, Rmoss = richness of bryophytes, Rlich = richness of lichens, Rgram = richness of graminoids, R woody = richness of woody plants, RHerb = abundance of herbs, Suc = abundance of succulents, Herb = abundance of herbs, Gram = abundance of graminoids, Moss = abundance of bryophytes, Lich = abundance of lichens, Ground = abundance of bare ground, matB1 = type of sedum mat Bergknapp 1, matB2 = type of sedum mat Bergknapp 2, matZ = type of sedum mat Zinco, matRP = type of sedum mat Reiersøl Planteskole, matVeg = type of sedum mat, Veg Tech, matVit1 = type of sedum mat, matVit2 = type of sedum mat, and matBygg = type of sedum mat Bryggros

Appendix XI: Regression pH level and Ca level

$$y = 0,43x + 0,33, r^2 = 0.44, p < 0.001$$

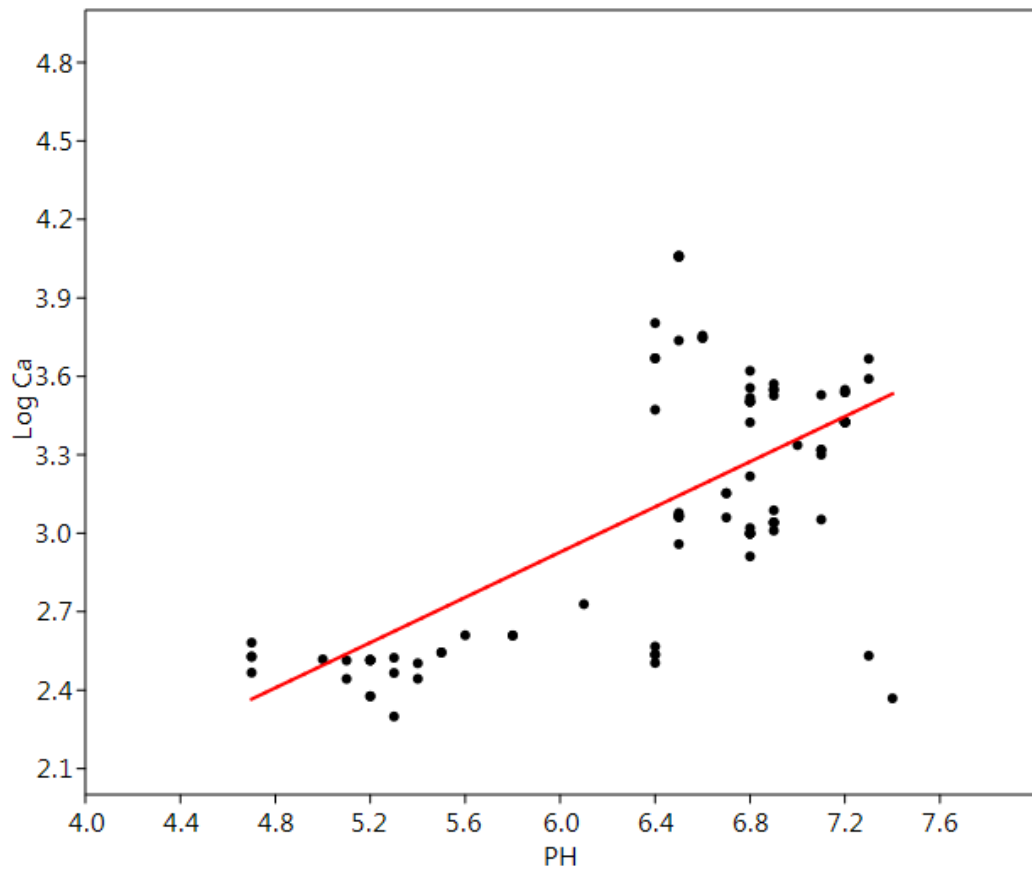


Figure 7. Linear regressions of Ca level on pH level with regression equation, R-squared and p-value on the top of graph

Appendix XII: Regression pH level and loss on ignition

$$y = -3.86x^2 + 5.95x + 4.81, r^2 = 0.64, p < 0.001$$

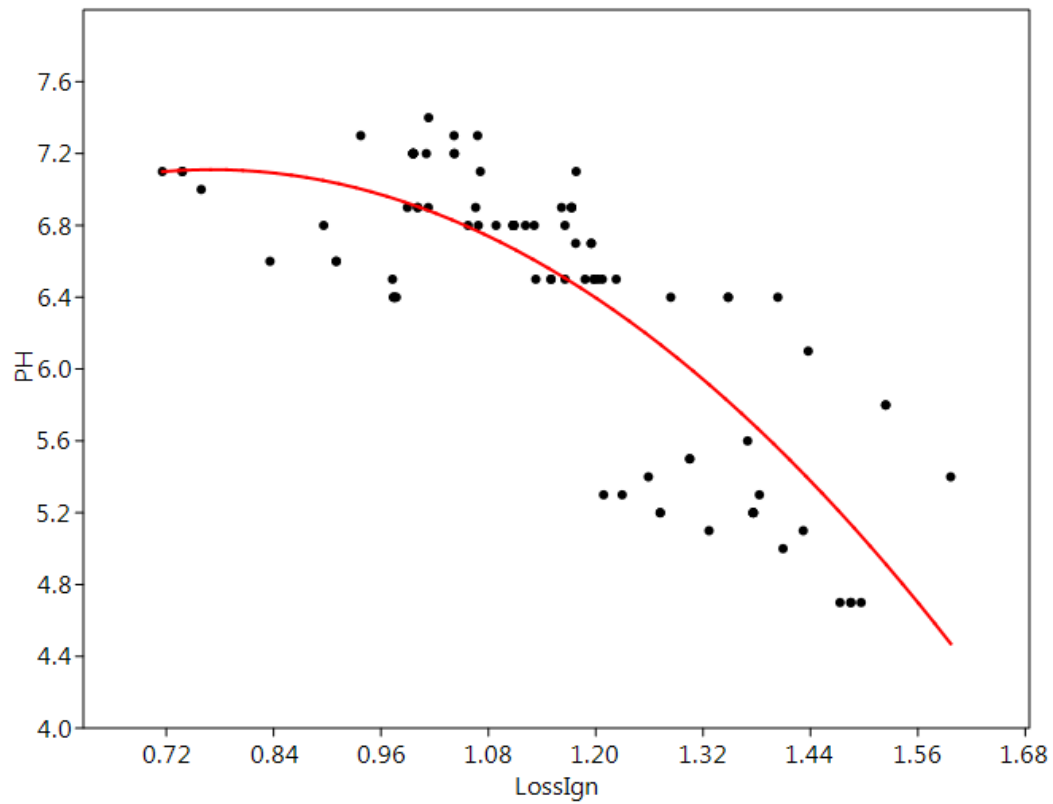


Figure 8. Polynomial regressions of pH level on loss on ignition with regression equation, R-squared and p-value on the top of graph

Appendix XIII: Study limitations

I discover some study limitation for my research:

- Analysis for N was not possible to do, because of not availability in university.
- Sampling for several seasons (at least 2 years) and sampling twice throughout vegetation season, spring and autumn, because the species composition of SES differs from season (Emilsson, 2008).
- It was not enough soil to measure maximum water holding capacity.
- Not possible to compare a nutrient amount with the FLL guide (Forschungsgesellschaft, 2008), because of different analysis methods used.
- Actual risk can be differentiated from cultivars and variations of sedum species, but there is not data to consider that risk (Hanslin et al., 2015).

Appendix XIV: Abundance of individual species from succulent species group

Table 4. *Abundance of individual species of succulent species group (found planted species)*

# of plot	<i>Hylotelephium ewersii</i>	<i>Phedimus hybridus/kamtschaticus</i>	<i>Phedimus spurius</i>	<i>Sedum acre</i>	<i>Sedum album</i>	<i>Sedum hispanicum</i>	<i>Sedum lydium</i>	<i>Sedum rupestre</i>	<i>Sedum sexangulare</i>	<i>Sedum anglicum</i>
1	0	0	15	5	35	5	0	0	25	0
2	0	0	2	5	30	2	0	0	20	0
3	0	0	5	5	15	0	0	0	20	0
4	0	0	5	2	50	5	0	0	15	0
5	0	90	0	0	2	0	0	0	1	0
6	0	15	0	25	50	0	0	0	0	0
7	1	50	0	0	25	0	0	0	0	0
8	30	2	0	30	30	0	0	0	0	0
9	0	25	0	30	40	0	0	0	0	0
10	5	0	0	30	50	0	0	0	0	0
11	2	5	5	40	50	0	0	0	0	0
12	2	5	0	45	55	0	0	0	0	0
13	1	5	0	40	75	0	0	0	0	0
14	2	0	0	15	15	0	0	0	10	0
15	5	0	10	35	30	0	0	0	0	0
16	35	0	10	5	40	0	0	0	0	0
17	20	0	0	15	25	0	0	0	0	0
18	35	0	0	15	15	0	0	0	2	0
19	0	2	5	25	25	0	0	1	5	0
20	0	5	1	5	40	0	0	1	1	0
21	0	10	0	10	25	0	0	2	10	0
22	0	10	1	10	20	0	0	2	15	0

# of plot	<i>Hylotelephium ewersii</i>	<i>Phedimus hybridus/kamtschaticus</i>	<i>Phedimus spurius</i>	<i>Sedum acre</i>	<i>Sedum album</i>	<i>Sedum hispanicum</i>	<i>Sedum lydium</i>	<i>Sedum rupestre</i>	<i>Sedum sexangulare</i>	<i>Sedum anglicum</i>
23	0	0	0	0	70	0	0	0	0	0
24	0	20	0	2	40	0	0	0	0	0
25	0	40	5	2	5	0	0	1	0	0
26	15	40	5	45	35	0	0	0	5	0
27	5	10	2	50	15	0	0	0	10	0
28	0	20	2	10	30	0	0	0	15	0
29	15	2	0	10	20	0	0	0	0	0
30	10	0	0	15	50	0	0	0	0	0
31	10	1	0	20	50	0	0	0	0	0
32	15	0	1	20	20	0	0	0	0	0
33	10	1	0	15	50	0	0	0	0	0
34	15	10	2	15	15	0	0	0	20	0
35	0	20	0	15	50	0	0	0	1	0
36	40	10	0	15	10	0	0	0	0	0
37	2	0	0	20	35	0	0	0	10	0
38	25	5	0	10	45	0	0	0	0	0
39	0	5	1	10	2	0	0	1	0	0
40	0	0	0	1	70	0	0	1	0	0
41	0	5	0	5	70	0	0	0	0	0
42	1	15	5	70	20	0	0	0	5	0
43	0	20	1	50	20	0	0	0	10	0
44	0	45	1	15	20	0	0	0	5	0
45	15	5	10	50	25	0	0	0	15	0
46	0	15	5	50	30	0	0	0	5	0
47	0	0	0	0	0	0	0	0	0	0

# of plot	<i>Hylotelephium ewersii</i>	<i>Phedimus hybridus/kamtschaticus</i>	<i>Phedimus spurius</i>	<i>Sedum acre</i>	<i>Sedum album</i>	<i>Sedum hispanicum</i>	<i>Sedum lydium</i>	<i>Sedum rupestre</i>	<i>Sedum sexangulare</i>	<i>Sedum anglicum</i>
48	5	0	0	10	2	0	0	0	0	0
49	0	35	0	10	30	0	0	0	0	0
50	0	10	0	1	70	0	0	1	2	0
51	0	90	0	2	15	0	0	2	1	0
52	0	85	0	5	20	0	0	1	1	0
53	1	15	5	25	65	0	0	0	10	0
54	5	45	10	5	40	0	0	0	2	0
55	5	15	20	15	35	0	0	0	5	0
56	1	15	1	35	25	0	0	0	1	0
57	10	10	0	10	60	0	0	0	0	0
58	0	1	5	10	90	0	0	0	2	0
59	2	0	1	5	75	0	0	0	0	0
60	1	0	5	5	10	0	0	0	5	0
61	0	0	0	15	25	0	0	0	0	0
62	0	15	0	10	10	0	0	0	15	0
63	0	0	0	40	15	0	0	0	0	0
64	0	0	0	20	45	0	0	0	0	0
65	0	30	0	15	1	0	1	1	0	0
66	0	25	0	45	5	0	1	1	0	0
67	0	5	0	30	2	0	5	1	10	0
68	0	15	0	35	10	0	1	0	2	0
69	0	0	0	15	35	0	2	10	0	60
70	0	0	0	20	0	0	5	5	1	70
71	0	0	0	35	30	2	35	5	2	0
72	0	0	0	35	40	5	20	2	1	0

# of plot	<i>Hylotelephium ewersii</i>	<i>Phedimus hybridus/kamtschaticus</i>	<i>Phedimus spurius</i>	<i>Sedum acre</i>	<i>Sedum album</i>	<i>Sedum hispanicum</i>	<i>Sedum lydium</i>	<i>Sedum rupestre</i>	<i>Sedum sexangulare</i>	<i>Sedum anglicum</i>
73	0	70	0	1	0	0	0	0	15	0
74	0	65	20	0	10	0	0	0	5	0
75	0	80	25	0	1	0	0	0	1	0
76	0	70	0	1	1	0	0	0	0	0
77	0	0	0	30	40	0	0	0	1	0
78	0	2	0	35	30	0	0	0	0	0
79	0	0	0	20	50	0	5	0	1	0
80	0	0	10	30	30	0	15	0	2	0
81	0	15	0	10	0	0	0	0	0	0
82	0	0	0	45	0	0	20	0	0	0
83	0	0	0	45	0	0	10	0	15	0
84	0	2	10	15	20	0	2	0	20	0
85	0	0	50	10	10	0	0	2	1	0
86	0	15	0	15	0	0	15	0	15	0
87	0	0	0	15	15	0	25	0	5	0
88	0	10	2	20	5	0	5	0	1	0
89	0	0	0	35	75	0	0	2	0	0
90	0	2	2	30	75	0	5	5	2	0
91	0	2	1	40	70	0	0	2	5	0
92	0	0	0	45	50	0	0	0	2	0