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Remotely Sensed Estimation of Shrub Encroachment: A Case Study on the Great Alvar, Öland, Sweden.

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Bachelor thesis, 15 credits, in *Physical Geography and Ecosystem Analysis*

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Abstract

The increase of shrub extent in arid and semi-arid environments is reducing the species richness all over the globe. This process of shrub encroachment was found to result from changes in anthropogenic land use, especially from too high or too low grazing intensity.

The Great Alvar on the island Öland, Sweden, is a unique grassland ecosystem with a high species richness. Changes in land use patter lead to shrub spreading, resulting in a reduction of plant and bird species.

The aim of this study is to investigate if the current grazing intensity is effective in halting or reducing the shrub expansion. The past and current shrub extent of a low and a medium grazed area was identified by digitizing the shrub area based on aerial photographs from 2002, 2008 and 2017. Additionally, the growth rate of shrubs was estimated as well as a future prediction of shrub extent.

The shrub coverage of the study plot in 2017 was found to be 30% in the low grazed area and 2.5 % in the medium grazed area. The annual average increase of shrub extent on the low and medium grazed area were 1.2% and 0.2%, respectively. The future prediction, based on a non-spatial model, forecasts a continuous increase in shrubs.

The study results indicate an ongoing increase in shrubs extent, which could lead to a continuous reduction in species richness and in future ecosystem instability on the Great Alvar.

Keywords: Great Alvar, shrub encroachment, species richness, growth rate.

Popular Abstract

Shrub Encroachment, which implies the increase in density, extent and cover of shrub species, is one of the driving processes for grassland changes on Earth. The wide spread increase in shrubs has a negative effect on the species richness and can lead to a complete ecosystem turn over.

The process of shrub encroachment is a result from changes in anthropogenic land use, especially from too high or too low grazing intensity. A change from an intermediate grazing intensity to a low grazing intensity has led to increase in shrub cover for example on the Swedish island Öland.

Öland is home to the Great Alvar which is a grassland ecosystem that can rarely be found elsewhere. The main characteristics of an Alvar are the shallow soils and the high lime content of the soils. Only certain plants can survive in this environment which is why there are plants on Öland that can not be found in the rest of Sweden. The dry and windy climate of Öland is an additional cause for the special vegetation.

Shrub encroachment on the Great Alvar was noticed already 70 years ago. Öland's unique grassland species have been found to decrease since then which is why the aim of this study is to investigate if the current grazing intensity on the Great Alvar is effective in reducing shrub encroachment. This was done by analyzing aerial photographs. The shrub extent was assessed for the years of 2002, 2008 and 2017 and compared afterwards. In addition, the growth rate per year and a future prediction of shrub extent was estimated.

The results show a continuous increase of shrub extent in the 15-year period. Therefore, it has been shown that the current grazing intensity does not reduce shrub encroachment. Possible further decrease in biodiversity can be expected as the future prediction also shows further expansion of shrubs.

Shrub control measures such as manual clearings, periodic fires and an intermediate grazing intensity need to be implemented to reverse the process of shrub encroachment. The understanding of the consequences of shrub encroachment on grasslands needs improvement. Finally, as the effect of climate change on shrub encroachment is unknown, further research is necessary to predict the future ecosystem changes more precisely.

Acknowledgement

I would like to thank my supervisor Veiko Lehsten for his support and guidance throughout my thesis. Additionally, I would like to thank my opponent Nico Valtonen, and my examiners Helena Borgquist and Marko Scholze for their comments and constructive criticism. Special thanks go out to Astrid Zimmermann for answering all my questions regarding the methodology and Roger Gustavsson for letting me interview him.

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1. Introduction

Human habitation of Earth has overseen dramatic change to its land cover through constant modification and transformation of land use. Consequentially, this anthropogenic impact has dramatically altered the Earth's natural environment.
One counter process that has been resulting from the changes in land use management is shrub encroachment. It describes the process of increasing extent, density and biomass of shrubs into arid or semi-arid ecosystems (van Auken 2009). This phenomenon has been seen all over the world, and in the case of the United States (US) has been occurring for the last 160 years (van Auken 2009).

Even though the process of shrub encroachment is a worldwide problem, its consequences on biogeochemical processes, ecosystem services and biodiversity remain unclear (Archer et al. 1988, Knapp et al. 2008). Due to the undesirable impact of shrub encroachment on grazing productivity, it is mainly seen as a negative process and is often associated with land degradation (Belsky 1996). Increase in shrub extent and density is known to reduce the extent of grass plants, its density and diversity, and to alter the biomass allocation (van Auken 2009). However, several studies have shown that it depends on the evaluated factors and location whether shrub encroachment leads to more intense or fewer changes in the ecosystem (Archer et al. 2017; Belsky 1996; van Auken 2009).

In previous decades, it has been more difficult and time consuming to determine the extent of shrub encroachment compared to now. With the improvement of technologies such as remote sensing, it has become more cost and time efficient to monitor shrub encroachment and analyze its development over time (Gautam et. al. 1983). The most commonly used method of determining shrub extent change is by comparing historical aerial images with present ones (Zăvoianu, Caramizoiub and Badea 2004). This positive development should be used globally to improve the understanding of the processes governing shrub encroachment, expand longtime monitoring and advance bush control management (Coops et al. 2006).

On the Swedish island Öland – which this study focuses on – it is clear to see that the unique Alvar ecosystem has been facing shrub encroachment for at least the last 70 years (Wedin 2008). As in other places, the change in land use pattern has been the driving force for this occurrence.
Shrub encroachment, native or invasive, mostly occurs in areas of high intense grazing (Knight, Briggs, and Nellis 1994). Shrubs are spreading in many parts of the US, Australia and Africa where, due to the increase in food production, cattle graze more intensely than they used to (Knapp et al. 2008; Weisberg, Lingua, and Pillai 2007). In case of Öland, the cause of encroachment is reversed. After a long time of continuous grazing, the land use in most parts was changed from cattle use to crop growth. Since crop fields have not been allowed on the Great Alvar, it has led to a reduction or in some parts to the complete absence of disturbance which in turn caused an intensification in shrub spreading (Länsstyrelsen Kalmar Län).

These varying reasons for shrub encroachment show that it is essential not only to focus on the current land use – for reasons of shrub encroachment – but also on the land use history, putting the process into context (Archer et al. 2017).
The Great Alvar is not the only region where a lack of disturbance has caused shrub encroachment. In the Río de la Plata grasslands, in south-central Uruguay, Altesor et al. (2006) found that in an area that was formerly grazed for 25years, the species richness was significantly lower in ungrazed patches compared to moderately grazed area. Another study by Castro et al. (2010), found the species richness to be twice as high in grazed fields compared to fields that had been abandoned for 20 years.

The grassland on the Great Alvar, which covers ¼ of Öland, is a unique ecosystem where endemic plant species occur and a wide range of birds and other animals breed and live (Länsstyrelsen Kalmar Län 2008). Most of these bird species are dependent on open grasslands to protect their eggs during breeding time (Wedin 2008). With an increasing extent of shrubs in that area, it was found that the diversity of birds, fungi, reptiles and insects on Öland has been declining, with some species vanishing completely (Wedin 2008).
Awareness has been rising on the shrub encroachment and its impact on the ecosystem, but it needs further monitoring, analysis and subsidies to counteract the increase of shrubs. As the process has been evolving over a very long period, it will not be possible to eliminate shrub encroachment overnight (van Auken 2009).

With these possible impacts on Öland in mind, the aim of this study is to investigate if current grazing intensity on the Great Alvar is effective in reducing shrub encroachment. The null hypothesis is that if the current grazing conditions are effective, shrub cover on the Alvar will be reduced or will not increase. The alternative hypothesis is that there will be continuous shrub growth on the Great Alvar if current grazing conditions are not adequate.
The above-mentioned aim will be met by fulfilling the following objectives.

1. To remotely determine the areal shrub extent on the Great Alvar in the years 2002, 2008 and 2017.
2. To estimate the shrub survival, growth and die-off rate and compare these with the present grazing intensity.
3. To predict future shrub encroachment with the help of a non-spatial model.

2. Background

2.1 Study Area

The study area of this project is a 1 km by 1 km square on the Great Alvar on Öland (see Figure 2). Öland, which covers an area of 1,342km² (Study plot: 56°19’54.3’’N, 16°28’48.3’’E), is a Swedish island in the Baltic Sea and is located next to Kalmar on the Swedish mainland. It is connected to Kalmar by a bridge and has a total population of 25,846 (SCB 2017).

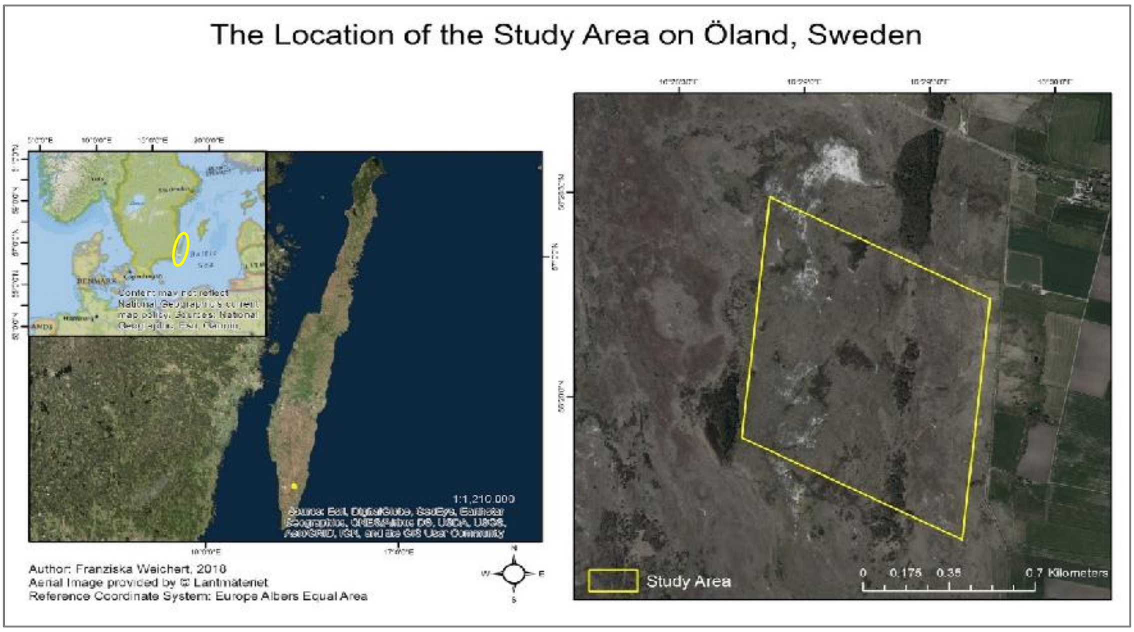

Figure 1: Study plot location on the Great Alvar, Öland. The yellow frame shows the 1 km by 1 km study plot on Öland, and where Öland lies in southern Sweden.

Öland is described as “the sunniest and windiest island” (Forslund 2001, p. 31) in Sweden. It has dry, hot summers, cool springs and mild winters (Forslund 2001). Its landscape is highly influenced by the strong winds. The Baltic Sea functions as a warmth reservoir in winter, which is why Öland has mild winters (Forslund 2001). Even though its annual precipitation lies at 500mm and it is the driest place in the country, during the winter and spring months large water bodies can be found in the Alvar due to the soil’s low discharge capacity (Johansson and Hultén 2009; SMHI 2017). The continuous high winds, dry summers, and wet winters make Öland a place of very special vegetation species which are partly endemic (Johansson and Hultén 2009). Öland’s soil and bedrock conditions add to the difficulties of vegetation growth. The very thin clay-limy moraine that is mainly found in the Great Alvar is on top of limestone (Forslund 2001). Only few robust species can survive or even grow under these conditions.

Another factor, which has been ruling the land cover of Öland, is human introduced grazing. As soon as the first settlements were formed on Öland, cattle were the main field of work with some crop growth at the side (Johansson and Hultén 2009).

This has led to an environment with continuous disturbance, leaving the vegetation with only little competition as the dominant species could not grow big enough to take over other species.
After World War II, fertilizer use was introduced which has led to a drastic change in agriculture use from cattle to crops. This left the Great Alvar almost free from any human disturbances, as crop growth has been prohibited (Forslund and Lager 2008; Wedin 2008).
The dominant native species *Juniperus communis* and *Potentilla fruticosa* thereafter outcompeted more sensitive species such as orchids and are now spreading across the island (Forslund 2001).

2.1.1 Unique Characteristics of Öland

Öland has a unique environment which is called the Great Alvar. An Alvar is an environment with high lime ratio and rather shallow soil (Forslund 2001). The land used to be under the surface of the Baltic Sea. After the last glacial melting, continuous uplifting lead to the formation of the island. This process has occurred in several steps whereby the southern part was already dry 11,000 years ago, whereas the northern part became land 6,000 years ago (Forslund 2001). This explains the differences between the Great Alvar in the south and the less developed Alvar in the North. Overall, the Alvar covers an area of 260km², which is $^1/_4$ of the whole island, and in this extent, rarely found elsewhere on the globe. In Europe only Gotland, small parts of Estonia and Latvia have similar environments (Johansson and Hultén 2009; Länsstyrelsen Kalmar län 2008). Shrub encroachment is a concerning process on Öland as it could endanger the rich diverse wildlife that inhabit the island. Wedin (2008) found, that there has been a decrease in population of several bird species which require the open grassland to provide a better overview to see oncoming predators. On Öland, these and other species are affected by the shrub encroachment, therefore gaining knowledge about the occurring shrub growth rate is essential to conserve the ecosystem.

2.1.2 Present Shrub Species in the Study Area

2.1.2.1 Juniper, *Juniperus communis*

Juniper can be found all over Sweden and is growing between 0.5m and 15m tall (see Figure 3a; Naturhistoriska riksmuseet 2008). It has the ability to grow in a variety of different locations, such as dry, open, rocky and wood sided environments. As these shrubs are sensitive to shade, they are mainly found in open areas as well as in areas with high grazing intensity (Belsky 1996). Juniper encroachment has been occurring in huge parts of the US, Africa, Australia as well as Öland (Weisberg et al. 2007). Due to its needles, it is rarely eaten by livestock, thus enjoying a relatively undisturbed life on the Alvar.

2.1.2.2 Ölandstok, *Potentilla fruticosa*

The other dominant shrub species in the area is the *Potentilla fruticosa* (tok or ölandstok in Swedish; see Figure 3b).

On the Alvar it usually grows up to 30cm and is commonly found in limestone environments (Elkington and Woodell 1963). As juniper, ölandstok is also shade intolerant and therefore occurring in open shrublands. Additionally, it is highly tolerant of extreme conditions such as flooding, frost or dry periods (Elkington and Woodell 1963). Only found on the islands of Gotland and Öland, it does not exist anywhere throughout the rest of Sweden (Naturhistoriska riksmuseet 2003). The plant is rarely eaten by livestock but has been found to be grazed by goats and sheep (Elkington and Woodell 1963).

Figure 2: Occurring shrub species in the study area; a) Juniperus communis, b) Potentilla fruticosa. By a) F. Weichert, b) Naturhistoriska riksmuseet, 2003).

2.2 Shrub Encroachment

The process of native shrub encroachment or alien species invasion results in change in species balance as well as altered biodiversity, water availability and land productivity (Stafford et al. 2017). Generally, it occurs in connection with changes in land use management, specifically with the introduction of high intensity grazing (Archer et al. 2017; Eldridge et al. 2011; Knapp 2008a). High intensity grazing reduces above and below ground grass biomass, cover and extent (Archer et al. 2017). These grasses usually compete against shrub germination and reduce shrub growth (van Auken 2009). When shrubs survive the first life cycle, grasses are incapable of suppressing shrub recruitment (Archer et al. 2017). Additionally, grazers function as a seed distributer which increases the spreading of shrub extent (Archer et al. 2017; van Auken 2009).

Several studies that investigated the impact of grazing intensities on shrub encroachment had found that heavy grazing decreases species diversity whereas moderate grazing lead to an increase in diversity (Collins et al. 1998; Wilson 2006). It was shown that a lack of disturbance (grazing) also leads to a higher shrub density and extent, as they outcompete grasses (van Dyke 2004). Additionally, Altesor et al. (2006) found that there is an increase in summer grasses in grazed areas compared to non-grazed areas.

It is important to note that there is not one single reason that leads to shrub encroachment. It is a highly complex and dynamic process with a range of factors influencing it (Weisberg et al. 2007). Shrub encroachment can be caused by the above-mentioned land use but is also affected by climate, topography, geography, and wild-fire timing (Bond and Midgley 2000).

In Africa it was found that an increase in precipitation and/or temperature has led to shrub encroachment. These shrub species are more robust in an extreme climate compared to most grasses (Stafford et al. 2017). Mean annual precipitation is the main limitation for shrub growth but soil properties or disturbance patterns add to this limitation (Archer et al. 2017).

In case of Öland, the shrub encroachment has started after longtime grazing was halted, reducing disturbances on the Great Alvar. This phenomenon has retained more attention after the 1950's, when the extent of shrubs started to increase heavily (Rosén and van der Maarel 2000). To reverse this process, a so-called Life Project was conducted on Öland to clear several areas of encroachment. It lasted four years (from 1996 to 1999) and had a total budget of 1,763,818€, where 50% was subsidies by the EU (Forslund 1999). During this project, an area of 6,840 hectare (Ha) of the Great Alvar was restored, grazing regimes were reintroduced, where farmers get paid up to 150€/Ha to graze their cattle on the Alvar, and continuous plant, bird and insects monitoring is being conducted (Forslund 1999; Rosén and Bakker 2005). The selected study plot is outside of the cleared area with the ambition, if a continuous shrub growth is found, to show that bush management should be extended over the whole of the Great Alvar.

2.2.1 Impacts of Shrub Encroachment

Grasslands are one of the most endangered ecosystems on earth which is why it is extremely important to identify consequences of shrub encroachment and start bush control in areas that need conservation of endemic or rare species (van Dyke 2004). The consequences are highly dependent on the location and ecosystem functioning and therefore can result in positive or negative ecosystem productivity (Eldridge et al. 2011; van Auken 2009). Since shrub encroachment is mainly occurring in grazing areas, it is seen as a negative process as it reduces grazing productivity and therefore livelihood of those depending on it (Archer et al. 2017). Other studies have shown that shrub encroachment can also increase niches for new animal species and increase carbon and nitrogen pools (Archer et al. 2017; Throop and Archer 2008). These varying outcomes are the reason that shrub encroachment needs further evaluation and can not be generalized (Archer et al. 2017).

2.2.1.1 Positive

Knapp et al. (2008b) found, that above ground net primary production can increase up to a fourth fold in shrub environments compared to grasslands. This results in a higher biological productivity even in ecosystems with poor soil conditions (Eldridge et al. 2011).

In addition, as evergreens take up carbon throughout the year and not only in summer months, encroachment of these shrubs can positively affect the carbon budget and energy balance at a global scale (Archer et al. 2017; Knapp et al. 2008a).

2.2.1.2 Negative

Overall, there is a reduction in species richness following shrub encroachment (Archer et al. 2017; Knapp et al. 2008a). Few shrubs in a grassland can enhance biodiversity, but the shrub density usually crosses a species-specific threshold which leads to a reduction in species richness (Archer et al. 2017; Sirami et al. 2009).

Several studies that investigated the juniper encroachment (mainly in the US), found that the increase in juniper density and extent has led to a decrease in species richness (see Figure 4; Hoch, Briggs and Johnson 2002; Knapp et al. 2008a; Weisberg et al. 2007). Within 40 years, a closed canopy juniper shrubland can be established leaving almost no space for grasses to survive (Hoch et al. 2002).

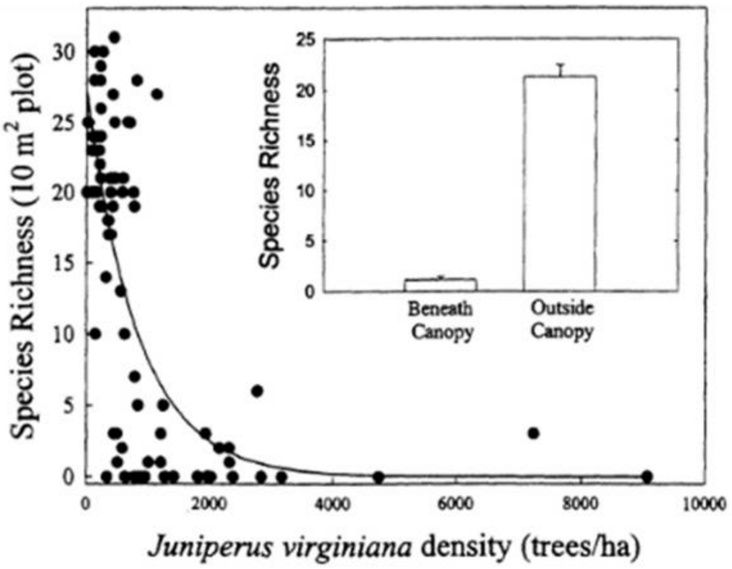

Figure 3: The relationship between juniper density and species richness in a 10 m³ circular plot. The dots indicate the density of juniper on the x-axis, and the species richness on the y-axis. Additionally, species richness underneath the canopy and outside of it is shown. From Hoch et al. 2002, reprinted with permission.

Reduction in certain tall grasses is leading to a decline in plant and bird species that favor these types of grasslands (van Dyke 2004). As grassland bird species are sensitive to vegetation structure, it is often seen that some of these birds do not return to the encroached area (van Dyke 2004). This has also been experienced in the Great Alvar, where for example $^{2}/_{3}$ of wader birds have not returned to Öland after 1995, when the shrub encroachment was wide spread (Länsstyrelsen Kalmar län).

Another factor that can not be neglected is that due to the all year photosynthetic activities of the evergreen, water use has increased, which in times of water scarcity in many countries, can have huge impacts on grazing, and even water availability for the population living in that area (Knapp et al. 2008a).

2.2.2 Future of Shrub Encroachment

2.2.2.1 Prevention

Current restoration measures are rare due to uncertainties in ecological consequences (Weisberg et al. 2007). It was agreed that too high or too low grazing intensity is a trigger of shrub encroachment which is why it is the first factor that needs to be adjusted. Intermediate grazing level is crucial to be complied as it has been shown to improve species richness in grasslands (Altesor et al. 2006). There are several chemical and mechanical prevention measures that can be used, but overall, they are most successful if they are combined (van Auken 2009). Manual clearing is time consuming but most effective, especially in combination with periodical fires and grazing (van Auken 2009). As young shrubs, especially juniper, grow fastest, appropriate management is needed to eliminate the shrubs before further encroaching occurs (Rosén and Bakker 2005).

2.2.2.2 Prediction

Overall, it is agreed that the sustainable management of ecosystems such as grasslands is the key conservation goal (Archer et al. 2017; van Auken 2009). To reverse the process of shrub encroachment in the future, a better understanding of the past and current causes and dynamics is required (van Auken 2009). It is essential to investigate how future impact of climate change will affect the growth of shrub encroachment. When looking at juniper, which is known to be a drought resistant shrub, it is possible that it will have even stronger encroachment rates in the future, leading to further ecosystem instability (Knapp et al. 2008a). Additionally, altered carbon storage and nutrient cycling needs investigation as their consequences remain unclear (Knapp et al. 2008b).

Finally, it is essential to understand that encroachment will not stop after one bush control measure is implemented, like during the Life Project on Öland, but is a continuous process of shrub removal, grazing management and possibly fire reintroduction (Lukomska, Quaas and Baumgärtner 2010). Only long-term management can result in a positive restoration of the unique grasslands (Willems 2001). Although it will be a difficult and expensive process; the implementation of location specific management is fundamental to succeed in retaining sustainable ecosystems in grazed grasslands; helping to maintain a healthy ratio between grass species and woody plants in future generations (Archer et al. 2017; van Auken 2009).

3. Methodology

The methodology of this case study follows widely the protocol of the study conducted by A. Zimmermann (2017), examining the encroachment of *Rosa rugosa* on Kieler Ort, Germany. The growth rate of shrubs was analyzed there, too which is why the calculations were reproduced in this case study. A case study was found to be most appropriate research strategy to explain the complex process of shrub encroachment at the local scale of the Great Alvar (Yin 2014).

3.1 Data

The data for this study, which included aerial photographs over the study plot in late spring of 2002, 2008 and 2017, were provided by Lantmäteriet. These years were chosen because of the higher image quality compared to other years. Additionally, this study was conducted to focus on possible shrub encroachment without interfering shrub management such as the Life Project, therefore the analysis period started after 1999.
The years of 2008 and 2017 were available as color aerial photographs in “lyr”-files with a resolution of 0.25m² per pixel. As they were provided as “lyr.” layers, it was not possible to adjust the lightness and contrast of the images for better identification. The image from 2002 was retrieved as a TIF. Raster and was also available in color and a resolution of 0.25m² per pixel. All images were already orthorectified and therefore no georeferencing was needed.

3.2 Digitizing

Before the digitizing process was performed, all images were projected to the Europe Albers Equal Area reference coordinate system, because it preserves the area which was most important for this study.
During the process of digitizing, the areal extent of shrubs was established (Appendix A). This is a manual way of creating a polygon for each shrub by hand instead of automatically classifying the pixels. There were areas with a very high density in shrubs which were marked as on big polygon since it was, due to the resolution, not possible to digitize each shrub individually. Automatic classification was not tried due to differences in the quality of the analyzed aerial photographs, and time limitations for this project.

3.3 Field Trips

For this study, two field trips were conducted. The first one, in the beginning of the study (10th of April 2018), was used to get an overview over the area and its shrub species. Additionally, a local farmer (R. Gustavsson) who owns parts of the field, which is included in the study plot, was interviewed.

This interview was performed and recorded with the aim to get detailed information about the situation of shrub encroachment in the past and the grazing intensity in the plot area (Appendix B). Since the Great Alvar is part of the "allemansrätt"; R. Gustavsson (2018) explained that every farmer that owns field connected to the Great Alvar, is allowed to have 10%-15% of their cattle grazing on it. Therefore, it was not possible to get precise numbers of the grazing intensity on the study area. Overall, there was a low grazing intensity until the late 1990's, with an increased amount cattle from the 1990's until now (Gustavsson 2018, pers. comm.). These varying numbers can be explained with the decrease in economic value from the 1960's on (Gustavsson 2018, pers. comm.). After the Life Project was finished in 1999, subsidies from the commune made it more attractive to graze cattle on the Great Alvar again (Rosén and Bakker 2005).

The second field trip, which was conducted on the 22nd of April 2018, was used for validation of the newest digitized layer (2017).
The digitized shrubs were compared with the collected ground truth and checked if any shrubs were overlooked or mistaken with any other type of vegetation such as grasses, mosses or water.
Other studies used confusion matrix to determine accuracy based on randomly selected points in the study area but since the study plot was small, it was possible to identify each shrub individually (Foody 2002).
Field preparation included the aerial image of 2017 with the digitized shrub layer printed in DIN-A2 to have a detailed overview on where and how many shrubs there were. During the field work, the navigation was done with a GPS app on a smartphone and further orientation by natural landmarks with the help of the map. This field work was done by two people, each working on one half of the study plot.
All wrongly digitized shrubs were crossed out and additional shrubs that were not digitized were marked. It is important to mention, that due to the aerial image resolution of $0.25m^2$, some shrubs, especially ölandstok, could not be identified and were therefore not marked as missing if the shrubs were smaller than the image resolution. After the trip, the falsely digitized shrubs were erased from the layer and missing shrubs were added. Any incorrect digitized or missing shrubs that could be identified in 2002 and 2008 were taken away or added there, too.
The adjusted layers where then used to analyze the growth rate of shrubs over the 15-year period and in the future.

3.4 Analysis of Shrub Expansion

The final digitized shrub layers from 2002, 2008 and 2017 were used to define the changes between the start and end of the two resulting periods, 2002-2008 and 2008-2017. To be able to compare the shrub extent, the start and end year of each period were 'overlaid' in Arc Map 10.5. Two fields were added to the resulting attribute table, where 1) showed the area of each shrub part and 2) indicated the change of the shrub part within one period varying between stayed, disappeared or newly established.

After investigating the periods, it became clear that there are several different cases of change. (Figure 5). The three most common forms of change are the (a) complete elimination of shrubs, (b) new establishment and (c) expansion (Figure 5). Other, more complicated cases were found in the partial die-off (d), where parts of a shrub area expanded but some parts died-off, and the joining of several shrubs due to their proximity (e).

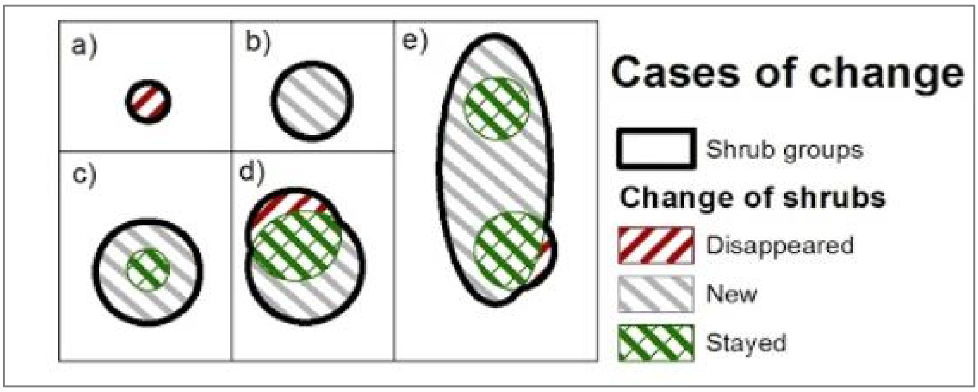

Figure 4: Identified cases of shrub change on the Great Alvar: a) shrub disappeared/ eliminated; b) new shrub establishment; c) expansion of a shrub; d) partial die-off and new establishment of a shrub; e) combining of shrubs due to expansion and proximity (with or without shrub die-offs), adapted from A. Zimmermann (2017) with permission.

For further analysis, all shrubs that were spatially connected were combined to one shrub group (see Figure 5). This step was necessary to distinguish between elimination, partial die-off, new establishment and expansion per shrub over each period. The overlaid layer was used to merge all spatially connected shrub polygons into one big polygon (shrub group) with the 'dissolve' tool. Afterwards, the dissolved and overlaid layers were spatially joined to add a unique shrub (shrub group) ID for each shrub part.

Before continuing with the growth analysis, the study area was spilt into two areas where one part was more grazed and manually cleared (farmers own property) than the other part. Now the low grazed study plot had an area of 770,000m² and the smaller medium grazed part (230,000m²) was kept separately for further comparison of the difference in shrub extent and growth over time depending on grazing intensity.
The final attribute table for each period with all shrub parts, their shrub group ID, change indicators and area was exported to Excel. The information of the total area that stayed, expanded, newly established, eliminated or died-off for each period in the low and medium grazed area were summarized (see Appendix C and D).

3.5 Shrub Growth Rate Calculations

To calculate the survival-, expansion-, new establishment-, lateral die-off- and lateral expansion rate, the shrub part area values from each period were taken from the last step.
The survival rate, which is built on the growth factor, is based on the area that stayed unchanged throughout the period over the total area in the beginning of the period to the power of 1 over the investigated period. The annual survival rate was therefore calculated with equation [1].

survival rate: $r_s = \left(\frac{Fs(t_n)}{F(t_0)}\right)^{\frac{1}{(t_n - t_0)}}$ [1]

Where: $F(t_0)$: Shrub area at the start of the investigated period
$Fs(t_n)$: Area of shrubs that has stayed unchanged by the end of the investigated period
$(t_n - t_0)$: Number of years within the investigated period

The expansion rate was calculated by adding the total area of survived and expanded over the unchanged area to the power of 1 over the investigated time. The following rates are based on the growth rate which is why the -1 is needed in the end of the calculation. This rate was calculated with equation [2].

expansion rate: $r_e = \left(\frac{Fs(t_n) + Fe(t_n)}{Fs(t_n)}\right)^{\frac{1}{(t_n - t_0)}} - 1$ [2]

Where: $Fe(t_n)$: Area of shrubs that expanded by the end of the investigated period

Equation [3] is used for the new establishment rate. Similar to the expansion rate, this one added the establishment area and subtracts the expansion in the end.

new establishment rate: $r_n = \left(\frac{Fs(t_n) + Fe(t_n) + Fn(t_n)}{Fs(t_n)}\right)^{\frac{1}{(t_n - t_0)}} - 1 - r_e$ [3]

Where: $Fn(t_n)$: Shrub are that was new established by the end of the investigated period

To estimate the areal rate of expansion and die-off per shrub, the lateral expansion [equation 4] and die-off rate [equation 5] were calculated. These equations were based on the area of a circle since shrubs tend to grow in circular form.

lateral expansion rate: $r_{le} = \frac{\left(\frac{Fs(t_n) + Fe(t_n)}{\pi}\right)^{\frac{1}{2}} - \left(\frac{Fs(t_n)}{\pi}\right)^{\frac{1}{2}}}{t_n - t_0}$ (for $Fe(t_n) > 0$) [4]

lateral die-off rate: $r_{ld} = \frac{\left(\frac{Fs(t_n)}{\pi}\right)^{\frac{1}{2}} - \left(\frac{Fs(t_n) + Fd(t_n)}{\pi}\right)^{\frac{1}{2}}}{t_n - t_0}$ (for $Fd(t_n) > 0$) [5]

Where: $Fd(t_n)$: Area of shrubs that had died by the end of the investigated period

The future prediction of shrub encroachment on the Great Alvar was based on the equations [1-3]. An average of each rate over both periods was calculated [2002-2017]. The formula for future shrub extent is based on the equations for the rate of survival, expansion and new establishment, and the sum of these equals the new total area of shrubs on the plot [equation 6]. In this study, the next 20 years will be predicted to show a near future trend of shrub encroachment on the Great Alvar.

area of shrubs: $F(t_n) = F(t_0) * (r_s * (1 + r_e + r_n))^{(t_n - t_0)}$ [6]

Where: $F(t_n)$: Shrub extent at the end of a selected period

4. Results

4.1 Expansion of Shrubs in the Study Area

The validation after the second field trip showed that 4,407 shrub polygons were correctly identified, 50 shrubs were added, four were taken away as they were either water or grasses and five shrub areas were reduced in size.

The shrub extent in the whole study area has increased in the period of 2002-2017 (see Figure 6). In case of the low grazed area the shrub cover was 11.9% in 2002, in 2008 it was 19.6% and 30% in 2017. This results in an average increase in shrub cover of 1.2% per year. The extent increase was higher in the period between 2002 and 2008 with 9,878m² per year compared to an increase of 9,165m² per year between 2008 and 2017. The medium grazed area on the eastern side had a shrub extend of 0.33%, 0.86% and 2.5% in 2002, 2008 and 2017, respectively. The increase in shrub extent was 200m² per year for the first period (2002-2008) and 431m² per year in the second period, 2008-2017. Here the average rate of encroachment per year was 0.2%.

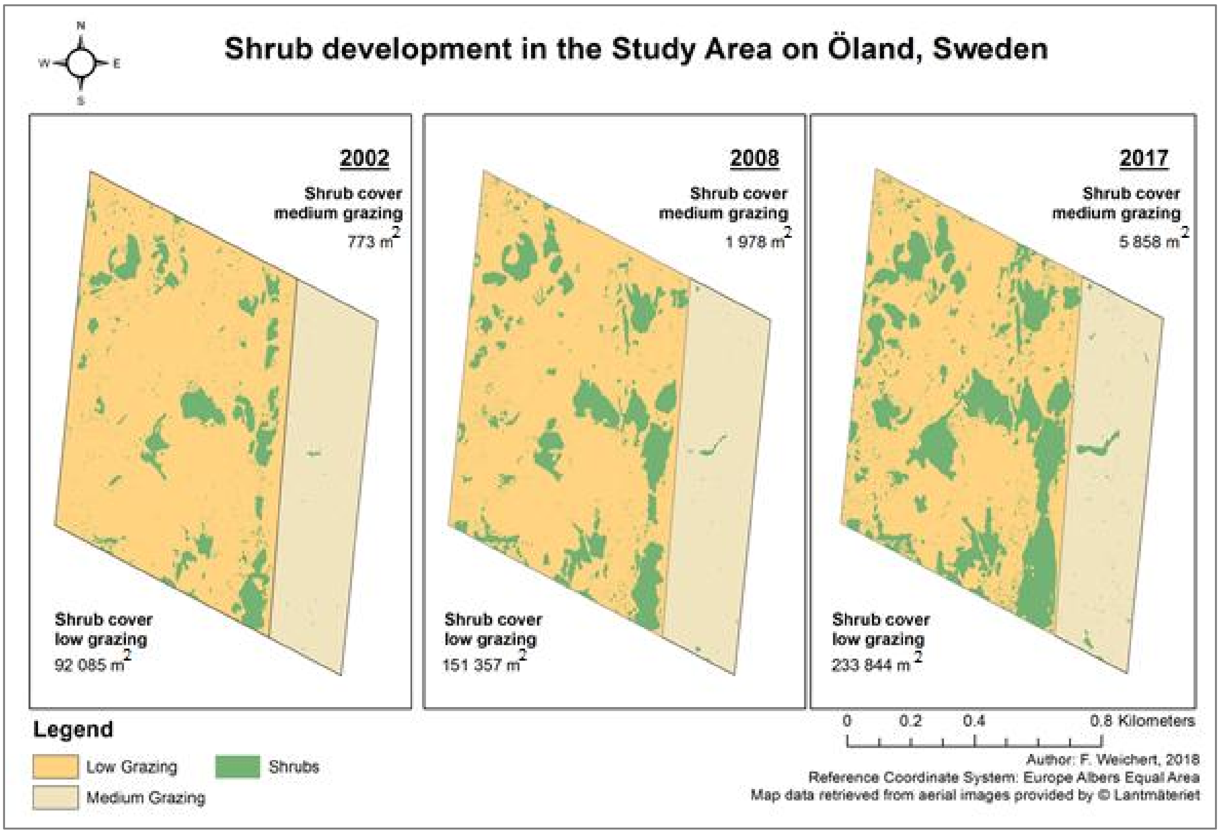

Figure 5: Shrub extent in the years of 2002, 2008 and 2017. The green cover are the shrubs, light orange on the left side indicates the low gazed area and dark sand colored area on the right side represents the medium grazed area.

4.2 Growth Rate of Shrubs

4.2.1 Past Growth Rate

The percentage of shrub area in the low grazed area that survive per year was almost 100% over the investigated period (see Table 1). The rate of change per year for the expansion, establishment, lateral die-off and lateral expansion was higher in the first period (2002-2008) compared to the second period (2008-2017) (see Table 1).

Table 1: The change rates for shrubs in the low grazed area on the Great Alvar. The overall areas per period were calculated for the survival-, expansion-, and establishment rate whereas for the lateral rates, the average of all shrubs was used.

Rate	Survival [%/year]	Expansion [%/year]	Establishment [%/year]	Lateral die-off [cm/year]	Lateral expansion [cm/year]
Per Period:					
2002-2008	96.91	8.90	0.68	- 11.2	24.2
2008-2017	99.56	4.99	0.41	- 2.1	11.3
Average:					
2002-2017	98.24	6.94	0.55	- 6.7	17.8

The survival of shrubs in the medium grazed area is slightly lower than in the low grazed area (see Table 2). On the contrary, the expansion and new establishment of shrubs is higher in the medium grazed area. The average lateral die-off (-6cm/year) and average lateral expansion (15cm/year) are similar compared to the average values in the low grazed plot (see Table 1).

Table 2: The change rates for shrubs on the study area with medium grazing intensity on the Great Alvar. The overall areas per period were used to calculate the survival-, expansion-, and establishment rate whereas for the lateral rates, the average of all shrubs was used.

Rate	Survival [%/year]	Expansion [%/year]	Establishment [%/year]	Lateral die-off [cm/year]	Lateral expansion [cm/year]
Per Period:					
2002-2008	94.11	15.99	5.51	- 9.4	20.2
2008-2017	98.17	12.07	2.85	- 2.7	9.9
Average:					
2002-2017	96.14	14.03	4.18	- 6.0	15.0

4.2.2 Future Prediction

The future prediction based on a non-spatial model for the low grazed values show a continuous increase in shrub area within the next 20 years. The areal shrub prediction in 2037 based on the period of 2002-2008 is 777,909m², based on the period of 2008-2017 is 613,431m² and based on the average between 2002-2017 is 694,660m² (see Figure 7). This shows that there will be a complete shrub closure by 2037 or shortly after since the low grazed plot area is 770,000m².

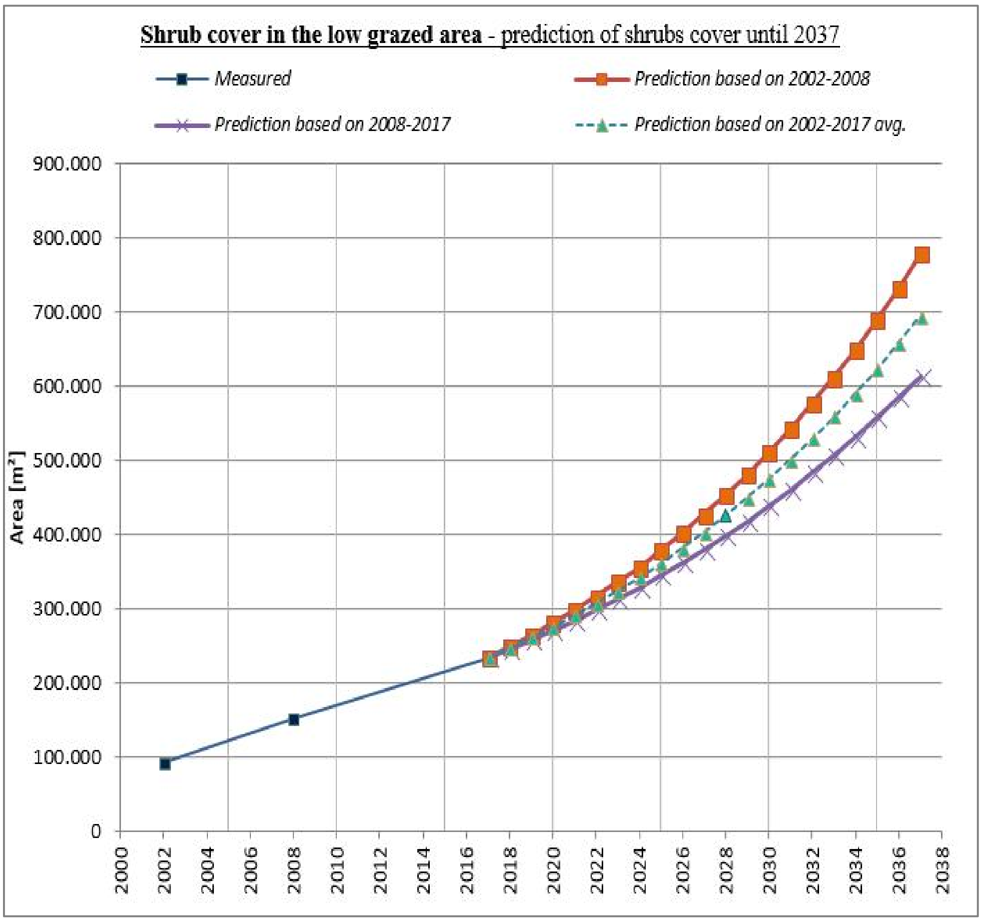

Figure 6: Measured and predicted shrub extent in the low grazed plot from 2002 to 2037. The dark blue line (with squares) is the measured area, the purple prediction is based on the period of 2008-2017, the dotted light turquoise line (with triangles) shows the prediction based on the period between 2002-2017 and the orange line predicts the shrub extent based on the period between 2002-2008.

The future prediction of the medium grazed plot is showing a sharper increase in shrub extent until 2037. The areal shrub prediction in 2037 based on the first period (2002-2008) is 85,583m², based on the period of 2008-2017 is 65,400m² and based on the average between 2002-2017 is 75,737m² (see Figure 8).

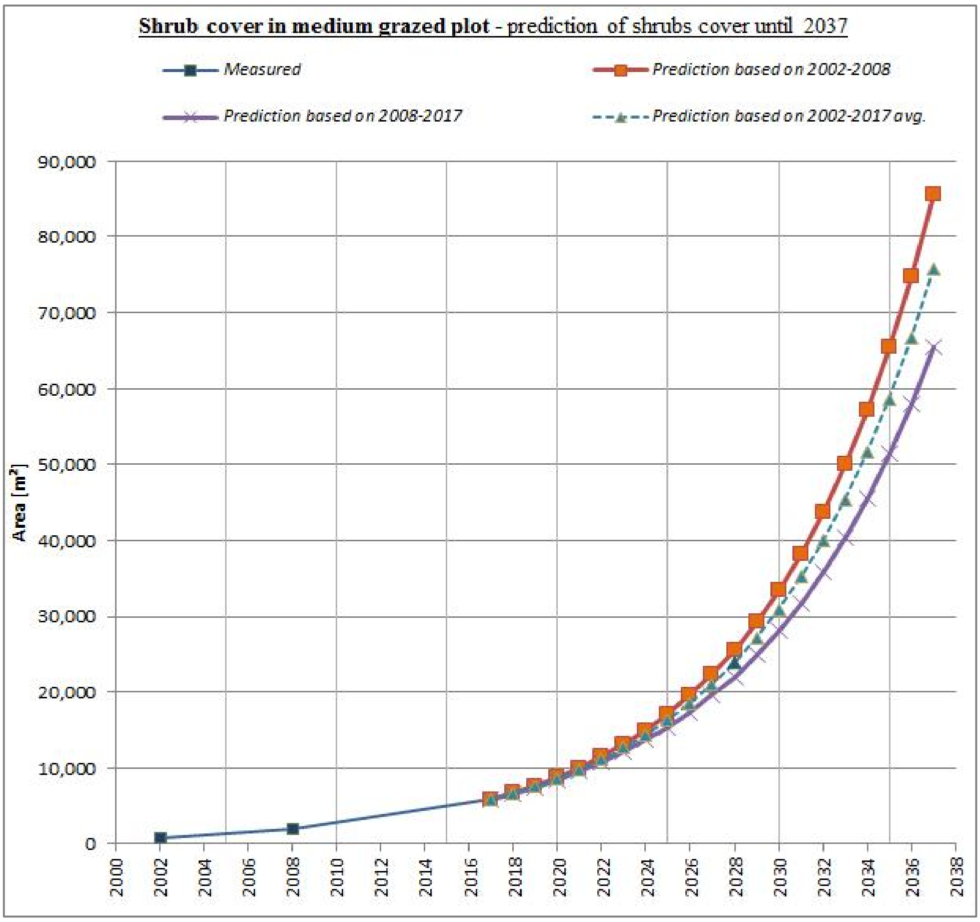

Figure 7: Measured and predicted shrub extent in the medium grazed plot from 2002 to 2037. The dark blue line (with squares) is the measured area, the purple prediction is based on the period between 2008-2017, the dotted light turquoise line (with triangles) shows the prediction based on the period between 2002-2017 and the orange line predicts the shrub extent based on the period between 2002-2008.

4.3 Validation

Both low and medium grazed predictions, based on the average of both periods and based on the first period, were validated against the measured shrub extent of the second period. The predictions show a general overestimation compared to the measured shrub extent in 2017 (see Figure 9).

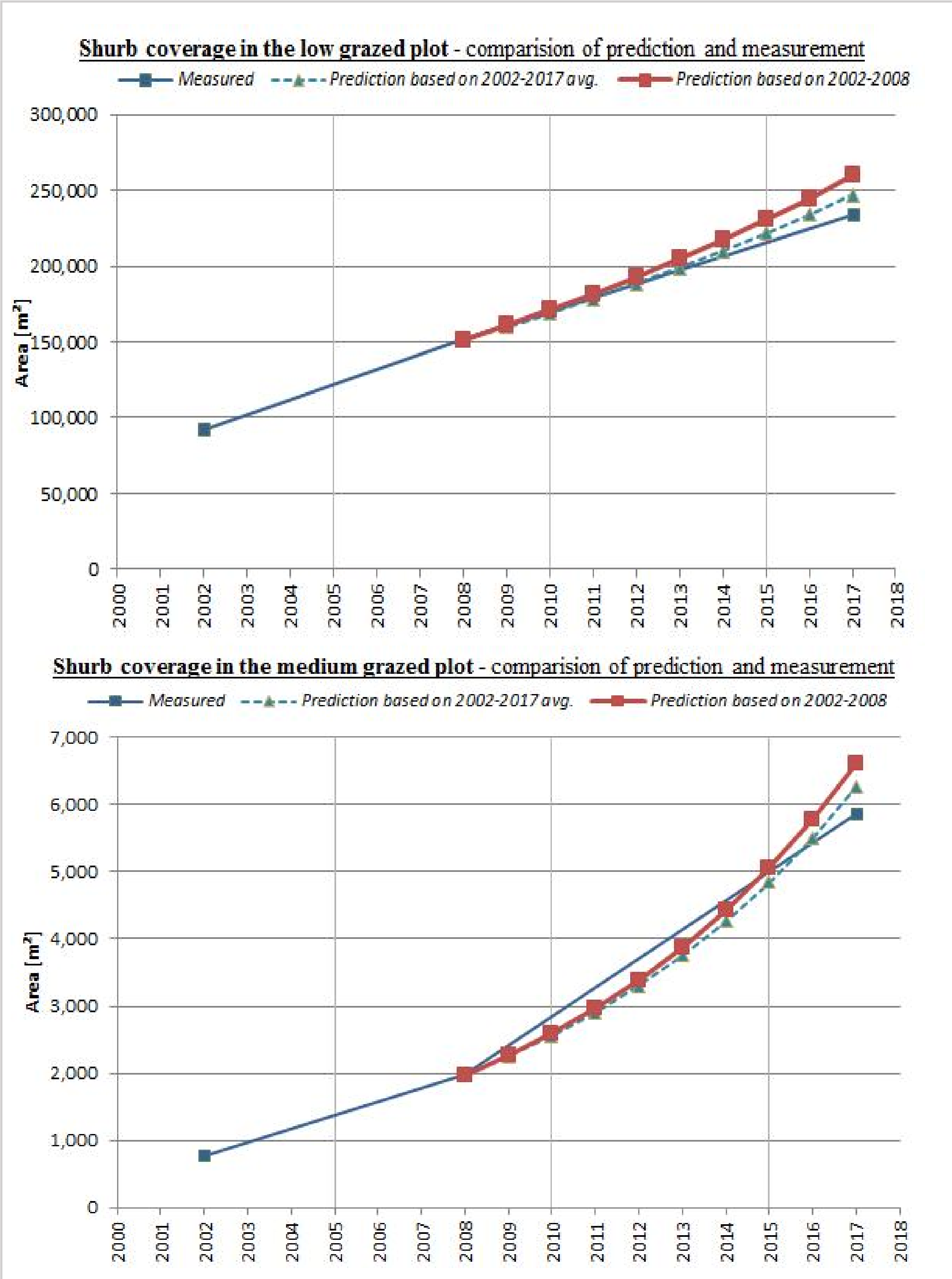

Figure 8: Comparison of fit of the averaged (2002-2017; dotted green line with triangles), and values from the first period (red line with squares) with the measured result of the second period (dark blue line); for both low grazed plot (top) and medium grazed plot (bottom).

5. Discussion

5.1 Expansion of Shrubs in the Study Area

The results show a clear increase in shrub extent in the whole study area over the period of 2002 and 2017, indicating that the current grazing intensity is not enough to reduce shrub cover expansion in that area. The increase in shrub cover of 1.2% per year for the low grazed and 0.2% per year for the medium grazed plot is consistent with the results estimated by Barger et al. (2011) who found, that the rate of encroachment can vary between 0.1%-2.3% per year. As most case studies focus on one encroaching shrub species, it was difficult to find other comparable encroachment rate values.

The insufficient disturbance intensity is continuously leading to shrub encroachment on the most parts of the Great Alvar, possibly resulting in further reduction in species associated with grasslands (Archer et al. 2017). The small shrub cover extent on the farmer's own property (medium grazed) can be used as an indicator, that if there is an adequate ratio of cattle per hectare, it is possible to retain a lower shrub extent. Since this is dependent on the location, it is essential for future management to gain knowledge over quantity of cattle and sheep grazing on the Great Alvar and their impact on the shrubs.

The results of the study should motivate Kalmar commune and local famers on Öland to continue shrub management on the Great Alvar. The Life Project was a start, but since continuous shrub encroachment is evident, it is essential to clear more areas of shrubs and keep them intermediately grazed.

5.2 Growth Rate of Shrubs

The high survival rate of shrubs in the whole study area indicates that the grazing is not able to destroy existing shrubs. The medium grazed area had a slightly lower survival rate which can be explained by the higher grazing intensity and manual shrub and tree cutting done by the farmer on his own property (Gustavsson 2018, pers. comm.). Additionally, the reduced lateral die-off rate in both areas in the second period show that once the shrubs have grown bigger, they are less likely to be eaten by cattle or sheep.

The average expansion rate of encroachment of 6.94% per year in the low grazed plot is higher than the one found by Hoch et al. (2002), which was 5.8%. There are several factors such as different grazing intensity, shrub density or accuracy that could be the reason for the higher rate found in this case study. The expansion, new establishment and lateral expansion rates were all lower in the second period than the first which can be explained by the upper threshold theory (Weisberg et al. 2007). This theory explains that encroachment is highest in earlier stages but declines with time when a certain shrub density or resource threshold is approached (Archer et al. 2017; Fensham, Fairfax and Archer 2005).

As both dominate species (juniper and ölandstok) are light sensitive, the expansion into denser areas is lower due to the avoidance of proximity (Archer et al. 2017; Belsky 1996; Elkington and Woodell 1963; Knapp et al. 2008b). This trend therefore explains the much higher expansion and new establishment rates in the medium grazed area, where the overall cover is extremely low, and shrubs can grow without interfering with each other.

The non-spatial model indicates an ongoing increase of shrub extent for the whole area in the future. If no further bush control is conducted, the low grazed area could be completely covered in shrubs by 2040. The low grazed area has a gentler increase of shrub extent due to the avoidance of proximity of shrubs, compared to the medium grazed plot. As the validation shows an overestimation trend for all predictions, it is essential to treat these predicted values with care.

5.3 Errors and Uncertainties

A possible source of error or inaccuracy is the process of digitizing. It is difficult, due to human subjectivity, available aerial image resolution and color differences of each image, to digitize the correct outline of each shrub (area). Additionally, as the shrub counting during the second field trip was done by two people, it is possible that there were some differences in identifying missing or mistaken shrubs. Finally, due to the resolution of $0.25m^2$, it was not possible to digitize smaller shrubs, which were mostly young ölandstok. This has generally led to an underestimation of shrub extent and therefor also in growth rate estimation and future prediction.

The prediction has some uncertainties due to the missing spatial factor. The non-spatial model includes overlapping of neighboring shrubs, as it presumes a continues shrub expansion per year, even though, shrubs stop growing if they are too close to other shrubs. The continuous yearly average expansion and die-off leads to another inaccuracy of the model since the growth of shrubs can vary from year to year. Additionally, as the model does not take changing environmental factors such as temperature, precipitation or atmospheric CO_2 concentration into consideration, it is not certain at which rate the shrub extent will grow in the future. Finally, since shrub encroachment is an unwanted process on the Great Alvar, future bush management will possibly reduce the shrub extent and conserve the unique environment on Öland.

Classification tools to establish land cover would have been more time efficient than digitizing but had too high uncertainties in success to be taken into consideration for this project (Fuller, Smith and Devereux 2003). The three images were very different in quality and color and therefore might have resulted in an undesirable result.

5.4 Improvements

An even higher resolution is likely to improve the accuracy of digitized shrubs compared to reality. A spatial model is likely to predict more accurate values for the shrub extent in the future compared to the non-spatial model.

If the study would have been conducted over a bigger area, classification and an accuracy assessment should be included. Juniper could have been classified separately with a software that distinguishes juniper from other vegetation (Weisberg et al. 2007). Additionally, there are several different ways to assess accuracy in studies like these, but it has been found that the use of several different ones could improve the result of the assessment as they focus on different factors (e.g. User -, Producer accuracy, Cohen’s kappa) (Foody 2002). Moreover, a comparison of an area that had been cleared by the Life Project between 1996 and 1999 with the study plot of this thesis could have helped to further investigate the impact of shrub management on encroachment. An additional in-depth analysis of the relationship between species richness and shrub cover on Öland will be necessary to justify future shrub management.

5.5 Further Research and Future Perspective

As the increase in shrub plants have been found to reduce the species richness and grass species, it is essential to reverse the process on the Great Alvar, to conserve endangered and endemic species (Eldridge et al. 2011; Forslund and Lager 2008; Hoch et al. 2002; van Auken et al. 2009). An intermediate grazing will counteract shrub encroachment, but encroachment can not be controlled without further shrub management such as manual clearings and fires (Collins and Wallace 1990). It was found that annual clearing is most effective in conserving the species richness, which should be taken into consideration on the Great Alvar to preserve its unique environment (Nkambule et al. 2017).

Further research is needed to clarify post-encroachment dynamics, identify factors that limit shrub encroachment, and estimate how the process alters biogeochemical cycles (Archer et al. 2017; Pascala et al. 2001). Additionally, it is essential to investigate how the change in air temperature, precipitation frequency and intensity and atmospheric CO_2 concentration will affect shrub encroachment (Knapp et al. 2008a; Stafford et al. 2017). Vegetation models that include the complex dynamics of an ecosystem and their interaction with the climate should be used to estimate the future structure and distribution of grasslands and shrub areas depending on predicted climate changes (Scheiter and Higgins 2009).

It is highly possible that the future climate predictions of increasing droughts, milder winter and more intense precipitation will favor shrub encroachment and therefore increase ecosystem instability (IPCC 2007; Knapp et al. 2008b; SMHI 2018). To avoid this, immediate action is needed.

6. Conclusion

The purpose of this study was to find out whether current grazing on the Great Alvar is effective in reducing shrub encroachment. In this case study, the null hypothesis has to be rejected. The aim was met as the results show a clear increase in shrub extent over the investigated period, especially in the low grazed area. Due to the richness in grassland species on Öland, it is essential to take measures against shrub encroachment. If it continues, several, partly endemic plant and animal species will be lost, and the unique environment will undergo a complete ecosystem turnover (Archer et al. 2017; Wedin 2008).
Future research should be conducted to:

a) improve understanding of the process of shrub encroachment
b) gain knowledge over climatic factors that will affect encroachment
c) investigate the consequences of past encroachment
d) predict the future distribution of grassland and shrub land

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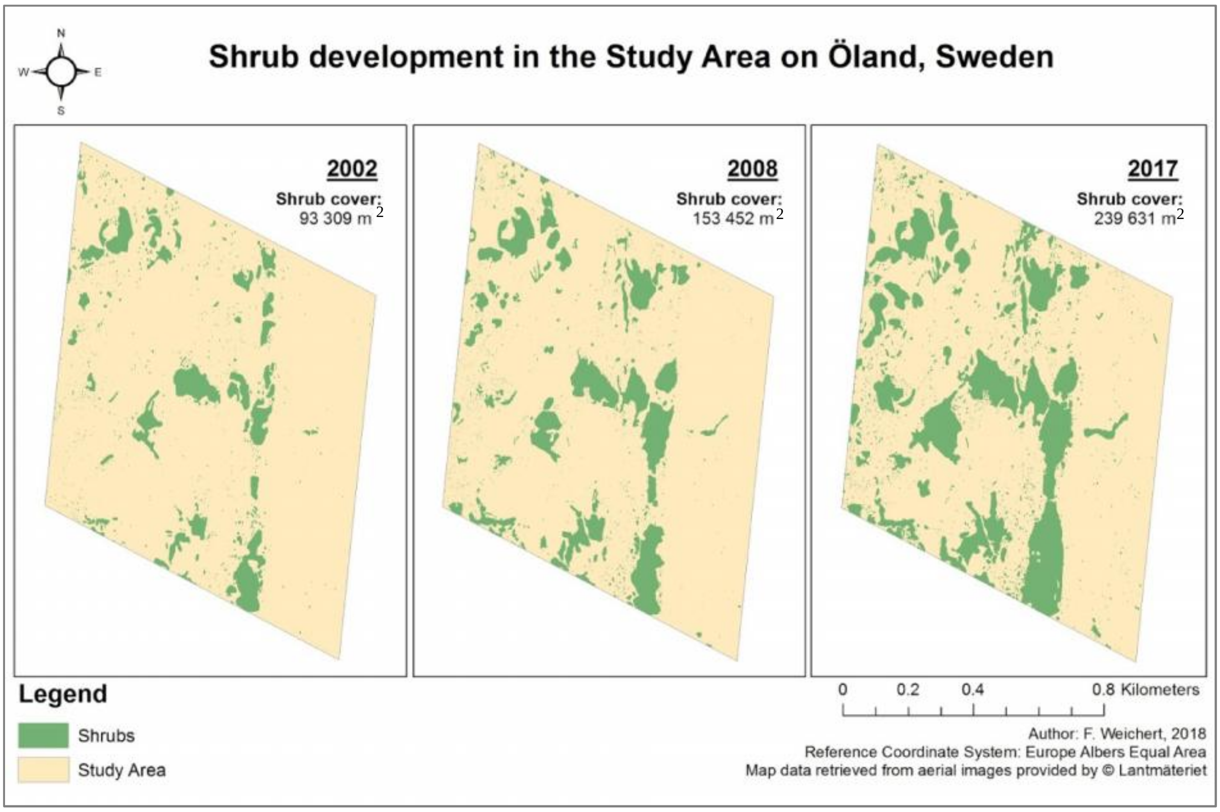
Appendix:

Appendix A

Shrub Expansion over the Whole Study Area



Appendix B

Interview Protocol

R. Gustavsson (2018) gave permission for:

- the interview to be recorded
- his name to be use
- the information used in public

Questions

- How long have you been a farmer on Öland?
    - Hur länge har du varit bonde på Öland?
- How many cows graze on your property?
    - Hur många kor betar på din egendom
- Since when is shrub encroachment a problem on the Great Alvar?
    - Sedan när är förbuskning ett problem i alvaret?
- What could possibly be reasons for shrub encroachment
    - Vad är orsakerna till det?
- Which shrub species are taking over the landscape?
    - Vilken arter verkar ta över?
- Which prevention measures have been taken and are they sufficient in reducing shrub encroachment?
    - Vad har man/d gjört för att forhindrar förbuskning
    - Är dessa förebyggande åtgärder till radlinga?
- What other prevention measure could possibly be taken into consideration in the future?
    - Vilka andra förebyggande åtgäreder kan vidtas i framtiden?
- Do you think that shrub encroachment has an impact on the biodiversity here?
    - Tror du att det påverkar biologiska mångafalden?

Appendix C

Analysis of Shrub Growth in the Low Grazed Study Plot

	2002-2008 Area [m²]	2008-2017 Area [m²]
Overall		
Start of Period	92,085.92	151,357.95
End of Period	151,357.95	233,844.5
Died	7,340.66	6,061.26
Eliminated	1,610.19	1,384.29
Died-off	5,730.47	4,676.97
Survived		
Stayed	84,745	146,118.69
New	66,612.69	88,250.81
Expanded	60,645.08	80,090.03
New established	5,970.62	8,160.79

Appendix D

Analysis of Shrub Growth in the Medium Grazed Study Plot

	2002-2008 Area [m²]	2008-2017 Area [m²]
Overall		
Start of Period	773.91	1,978.33
End of Period	1,978.33	5,858.69
Died	268.03	302.25
Eliminated	149.6	89.57
Died-off	118.43	212.68
Survived		
Stayed	505.87	1,676.07
New	1,472.45	4,182.61
Expanded	923.35	2,998.47
New established	549.1	1,184.14