Potential Carbon Storage and Albedo Change due to Reforestation of Pasture in Scania.

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Abstract

Using reforestation for climate change mitigation is complex due to the multiple impacts forest has on climate. This study analyses the effectiveness in using reforestation on pasture in Scania (south Sweden) as a tool for climate mitigation. The potential carbon storage in biomass and the impact on land surface properties that determine the absorption of radiation (albedo) was assessed. To answer the research questions, a GIS analysis and a literature study was performed. Due to the small area of pasture in Scania, the potential carbon storage is estimated to be relatively low. The carbon storage capacity of different categories of forest was estimated to be of the same magnitude. However, it was found that the carbon storage capacity of the type of forest found in national parks was slightly lower than of coniferous forest. The results from the literature study show that pasture, deciduous forest and coniferous forest have an annual mean albedo of 0.305, 0.190 and 0.144, respectively. It was also noticed that, between the classes, the winter albedo varied the most. The sum of the negative radiative forcing caused by carbon sequestration due to reforestation and the positive radiative forcing caused by the resulting albedo change, indicated a marginal negative net radiative forcing. Based on these results, it was not possible to determine whether reforestation on Scanian pasture is an effective climate mitigation tool. Further studies must be performed to better understand how carbon storage and albedo is related, but also to understand the magnitude of other climate related aspects such as aerosols. Also, how climate change will influence these effects needs to be further investigated, as it can influence the effectiveness of reforestation as a tool for climate mitigation.

Table of content

Introduction

Using forestation for climate change mitigation is complex due to the multiple impacts forest has on climate (Spracklen et. al. 2008). As a part of the carbon cycle, terrestrial plants take up carbon via photosynthesis and store it in biomass. Carbon in dead organic matter from plants is transferred to soils through litterfall, root death, root exudation and root transfers to symbionts. Some of the carbon is stored as soil carbon but most of it is released to the atmosphere via respiration, leaching, disturbances, etc. Also, anthropogenic activities, such as combustion of fossil fuels and land use change, leads to that carbon is released (Chapin et. al. 2011; IPCC 2007). To clarify, land use conversions from high-carbon systems (i.e. forests) to low-carbon systems (i.e. pasture) increases the flux of carbon to the atmosphere (House et. al. 2012), whereas the opposite increases the uptake of carbon and contributes to reducing the concentration of atmospheric carbon (Spracklen et. al. 2008).

In a report from the Swedish Board of Agriculture (Swedish: Jordbruksverket) (2013a) the interest of using pastures and meadows for other purposes than feeding cattle is identified. For example, they point out an increasing demand for biomass for production of fossil-free energy but also mention the usage of renewable material in products. This interest is in line with both the targets set by the EU RES directive which promotes the usage of energy from renewable resources (European Parliament 2009) and the Paris Agreement (United Nations 2015) that encourages the parties to aim to reach the peak of greenhouse gas emissions as soon as possible. All these targets mirror a concern for climate change caused by a steady addition of anthropogenic carbon dioxide to the atmosphere since the beginning of the industrial era. In the IPCC report *Land Use, Land-Use Change and Forestry* (2000) it is noted that in addition to reducing greenhouse gas emissions, forestation (i.e. reforestation and afforestation) can help to mitigate the growth rate of atmospheric carbon dioxide concentrations through carbon sequestration.

Figure 1 is a simplified schematic of the biogeochemical and biophysical effects that occur in association with forestation. As seen in Figure 1, reforestation leads on one hand to an increased uptake of atmospheric carbon dioxide (biogeochemical effect), but on the other hand to a lower albedo (biophysical effect) (Spracklen et. al. 2008). Albedo is a dimensionless fraction used to measure reflective properties of land surfaces. It is measure on a scale from 0 to 1 where an albedo of 0 corresponds to a black body that absorbs all incident radiation, while an albedo of 1 corresponds to a white body which reflects all incident radiation (Svirezhev 2008). As forest in general has a lower albedo than pasture, and therefore absorbs more radiation, a land use change from pasture to forest leads to a positive feedback effect (Betts 2000; Kirschbaum et. al. 2011; Kurtén et. al. 2003; House et. al. 2012).

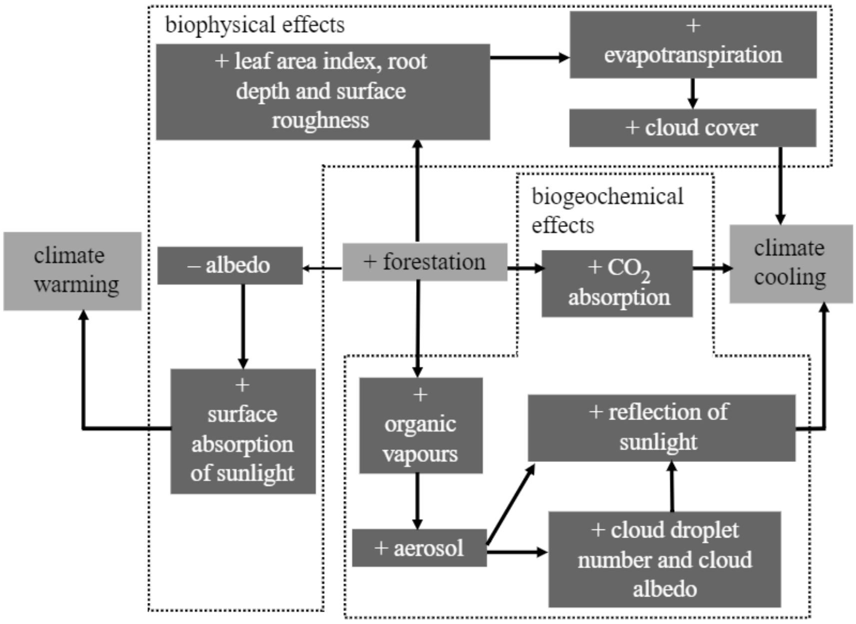


Figure 1
An illustration of the impacts of forestation on climate. *Source*: Spracklen et. al. (2008).

Radiative forcing is a metric used to measure the imbalance in the radiative budget of the Earth's climate system. A negative radiative forcing corresponds to a cooling effect on the climate while a positive radiative forcing corresponds to a warming effect (IPCC 2001, Chapter 6; IPCC 2007, Chapter 2). This metric makes it possible to calculate the magnitude of the biophysical and biogeochemical effects, for example, caused by reforestation. The magnitude of the radiative forcing of biogeochemical and biophysical effects, in relation to each other, has been studied in previous reports (Bala et. al. 2007; Betts 2000; Kurtén et. al. 2003; Spracklen et. al. 2008). However, the results can be inconsistent. House et. al. (2012) show that planting trees at northern high latitudes, that frequently are snow covered, lowers albedo and thus causes local warming that counteracts the cooling effect of the CO_2 uptake. Additionally, Bala et. al. (2007)

suggests that reforestation in temperate regions has only minor benefits and in high latitude areas, it is even counterproductive. Contrastingly, Pongratz et. al. (2011) states that the general climate response of reforestation is a net cooling effect and thus reforestation could be an effective climate mitigation tool, even at high to midlatitudes. Likewise, Betts (2000) and Kurtén et. al. (2003) state that the biochemical effects of carbon sequestration negate the positive albedo feedback and thus, reforestation should lead to a negative radiative forcing. Thus, the relative strength of biophysical and biogeochemical processes associated with reforestation is still uncertain.

Analysing the benefits of reforestation on pasture in Scanian (south Sweden) is of interest due to an observed loss of biodiversity in these areas. In general, pasture contains high biodiversity, both of plant and animal species and provides critical ecosystem services such as, for example, pollination (Wiegand 2008; Brauman 2008). The high biodiversity occurs due to an intermediate disturbance created by management such as mowing and grazing (Underwood 2008). However, according to the Swedish Board of Agriculture (2013a), the number of grazing animals in Sweden no longer corresponds to the area of pasture and thus, these areas loses its high biodiversity. Therefore, together with the background presented in the preceding paragraphs, it is relevant to examine reforestation as an alternative purpose of Scanian pasture.

Purpose

This thesis aims to study and analyse how reforestation on pasture in Scania would affect carbon storage and albedo, and if reforestation on Scanian pasture is an effective tool for climate mitigation. The purpose is also to analyse if and how carbon storage and albedo would differ depending on forest type. As mentioned in the introduction, it is interesting to study and analyse the benefits of reforestation on pasture in Scanian due to an observed loss of biodiversity in these areas.

Research questions

- How would carbon storage and albedo be affected if Scanian pasture were to be reforested?
- What is the influence of forest type on carbon storage and albedo?
- Is reforestation of Scanian pasture an effective tool for climate mitigation?

Limitations

I will perform a quantitative analysis of reforestation on pasture in Scania. Focus will be to study the coniferous forest and deciduous forest types. The effectiveness of reforestation as a tool for climate mitigation will be determined based on the net radiative forcing of atmospheric carbon uptake resulting from increased biomass and albedo change due to changed land surface properties. Hence, other effects from reforestation such as organic vapours, aerosols and LAI (Fig 1.) will not be included in this study.

I will not study quantitatively what impact reforestation would have on nature values and biodiversity. Moreover, the analysis will only include carbon stored in biomass, hence soil carbon storage will not be studied.

Method

The method of this study consists of two parts, an analysis in ArcMap 10.5.1 and a literature study. Directly, there is no ethical dilemma with this study. However, indirectly it could give consequences if the results would influence policymakers. The methodology is presented in the following paragraphs.

ArcMap 10.5.1

ArcMap 10.5.1 is a main component of the software ArcGIS. It is used to edit, create, view and analyse geospatial data. The program is launched by ERIS and available to download via ERIS' webpage [https://www.esri.com].

In this study, ArcMap 10.5.1 was used to calculate the average of carbon stored in biomass for each of the five forest types; coniferous forest, mixed forest, deciduous forest, forest in national parks and all forest. To do so a combination of data from the Swedish Forest Agency (Swedish: Skogsstyrelsen) and the Swedish Environmental Protection Agency (Swedish: Naturvårdsverket) were used.

Forest- Biomass (Skogliga grunddata- Biomassa)

The *Forest- Biomass* was obtained from the Swedish Forest Agency's (2014) data portal. The data is based on statistics from Lantmäteriet and the Swedish University of Agricultural Sciences and presented as a raster layer with a pixel level of 12.5 x 12.5 meter. The raster layer presents AGB (aboveground biomass) in units of ton dry matter per hectare (ton DM/ha) in Swedish forests. To clarify, this includes stem wood, branches and tops, but stumps and roots are not included (Swedish Forest Agency 2014).

Swedish ground cover data (Svenska Marktäckedata)

From the Swedish Environmental Protection Agency's data portal (Swedish Environmental Protection Agency n.d.a), the vector layer *Swedish ground cover data* was downloaded. This layer includes distribution and information of landscape classes, such as pasture, clear cut, cultivated fields and mixed forest, in Scania. The data is based on satellite data from Landsat™, obtained between 1999 and 2001, together with data from Lantmäteriet, the Swedish University of Agricultural Sciences, the Swedish Meteorological and Hydrological Institute, Statistics Sweden (Swedish: Statistiska centralbyrån), Geological Survey of Sweden (Swedish: Sveriges geologiska undersökning), the Swedish Environmental Protection Agency and the County Administrative Board (Swedish Environmental Protection Agency 2000).

Protected areas, national parks (Skyddade områden, nationalparker)

Another vector layer from the Swedish Environmental Protection Agency named *Protected areas, national parks* was used. This layer consists of the 29 parks that were Sweden's national parks in 2018. The data is based on data from the Swedish Environmental Protection Agency together with data obtained at field studies (Swedish Environmental Protection Agency n.d.b).

Work process in ArcMap 10.5.1

In the vector layer *Swedish ground cover data*, polygons representing forest were selected. These polygons were exported into a new layer, named “All_Forest”. The same procedure was used to create the layers “Deciduous_Forest”, “Coniferous_Forest” and “Mixed_Forest”, but with other polygons selected. The polygons that were selected to create each layer are presented in Table 1 (see Table 3 in Appendix for the original version in Swedish). Also, a layer containing forest in national parks was created by using the layer *Protected areas, national parks* as clipfeature to clip the layer “All_Forest”. The output layer was named “National_Parks”.

Table 1
The polygons that were selected to create the layers “All_Forest”, “Deciduous_Forest”, “Coniferous_Forest” and “Mixed_Forest”. See Table 3 in Appendix for the original version in Swedish.

Layers	All_Forest	Deciduous_Forest	Coniferous_ Forest	Mixed_Forest
Polygons	Coniferous forest not on lichen ground > 15 meters	Deciduous forest not on mire or exposed bedrock	Coniferous forest not on lichen ground > 15 meters	Mixed forest not on mire or exposed bedrock
	Coniferous forest not on lichen ground 7–15 meters	Deciduous forest on exposed debrock	Coniferous forest not on lichen ground 7–15 meters	Mixed forest on exposed bedrock
	Coniferous forest on exposed bedrock	Deciduous forest on mire	Coniferous forest on exposed bedrock	Mixed forest on mire
	Coniferous forest on mire	-	Coniferous forest on mire	-
	Mixed forest not on mire or exposed bedrock	-	-	-
	Mixed forest on exposed bedrock	-	-	-
	Mixed forest on mire	-	-	-
	Cutting area	-	-	-
	Deciduous forest not on mire or exposed bedrock	-	-	-

	Deciduous forest on exposed bedrock	-	-	-
	Deciduous forest on mire	-	-	-
	Young forest	-	-	-

Further, the raster layer *Forest- Biomass* was resampled from the ordinary cell size of 12.5 x 12.5 meters to 100 x 100 meters and transformed into a point layer. To obtain the biomass representing forest in Scania the point layer was intersected with the layer “All_forest”. In the output layer's attribute table statistics were shown for the field presenting the biomass for each point. The mean value was noted. This procedure was repeated with each of the layers "Deciduous_Forest", "Coniferous_Forest", "Mixed_Forest" and “National_Parks” (subsets of “All_forest”). The working process used in ArcMap 10.5.1 is presented in Figure 2.

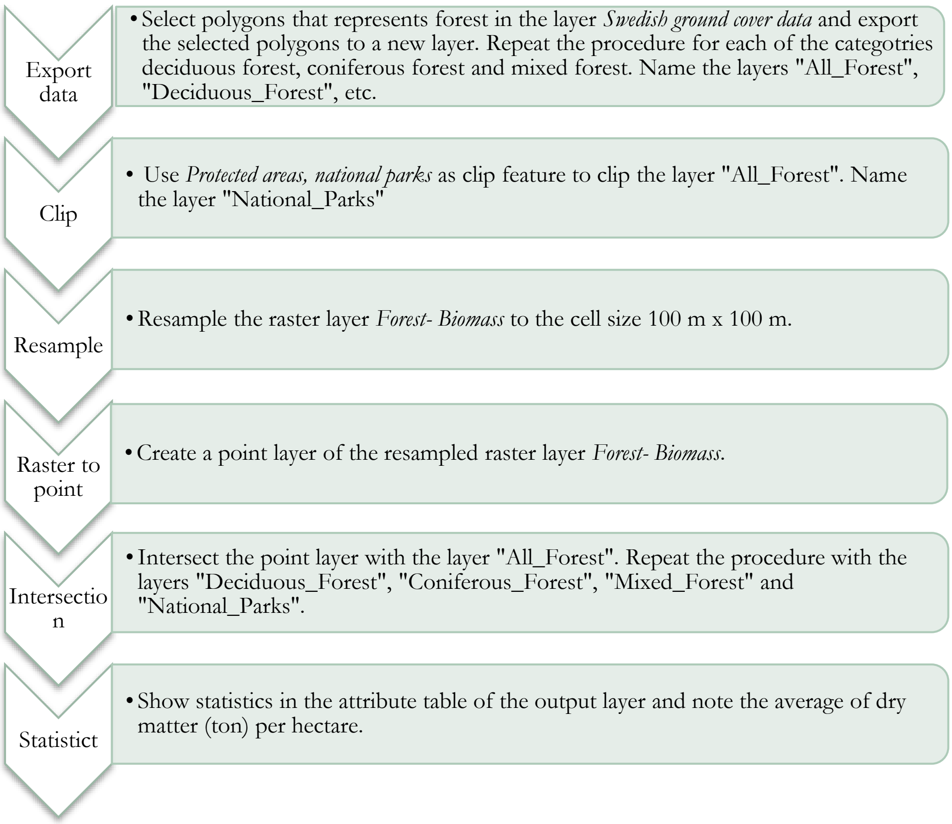


Figure 2
A schematic illustration of the working process used in ArcMap 10.5.1.

Also, the polygons Åkermark (cropland) and Betesmark (pasture) were selected and exported into two separate layers. The total area of cultivated fields and pasture was noted from the respective attribute table. Also, from the layer "All_forest" the total area of forest in Scania was noted.

A conversion factor of 0.5 (Alriksson & Eriksson 1998) was used to convert the output value of mean aboveground dry matter biomass per hectare (ton DM/ ha) to mean carbon storage in AGB per hectare (ton C/ ha). To convert from mean AGB carbon storage per hectare to mean carbon storage in total biomass per hectare (ton C/ha), the ratio 0.733:0.267 for AGB: belowground biomass, was used (Sinacore et. al. 2017). Thereafter, the mean carbon storage in total biomass per hectare was combined with the calculated areas of cultivation, pasture and all forest in Scania to calculate the respective total potential carbon storage.

Literature study of albedo

The literature study was preformed to get an overview of albedo of the main landscape classes present in Scania and relevant to this study, namely pasture (represented by grassland), boreal needleleaf forest and temperate broadleaf forest. The literature study was performed in April and May 2019 using the database Web of Science ™ Core Collection. Table 2 presents the process used when performing the literature study.

Table 2

The process used when performing the literature study in Web of Science ™ Core Collection.

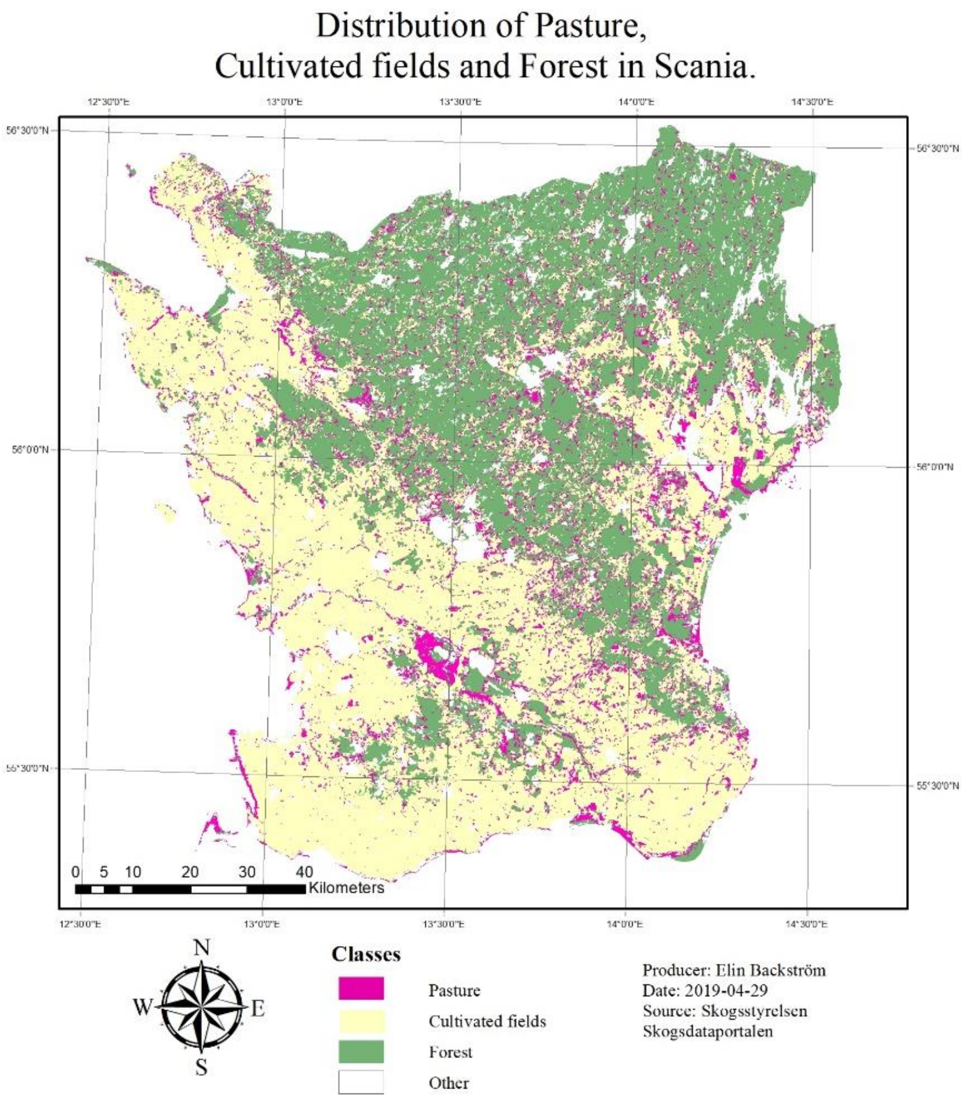
Data base, Date	Keywords	Limitations	Results	Selection 1. Based on relevance of title.	Selection 2. Based on if the article includes useable data.
Web of Science, 26-04-2019	albedo AND conifer* OR "evergreen" OR deciduous* OR "broadleaf*" OR grass* OR pasture* OR meadow* OR "needleleaf*" OR boreal* OR temperate* AND "northern hemisphere" OR europe OR fennoscandia OR scandinavia	Articles, results with the keyword albedo in the title.	115	13	3

This search gave 115 results of which 3 articles were used. Using the snowball method further relevant articles were found. From literature study a total of 8 articles were used. The selection of articles was based on that they should include albedo for grassland, boreal needleleaf or temperate broadleaf forest. Based on the eight references, a mean albedo of coniferous forest, deciduous forest and pasture at different seasons and annually was calculated.

Results

Results from the analysis in ArcMap 10.5.1

The area of forest in Scania was determined to be approximately 417 000 ha. The area of pasture in Scania was determined to be approximately 95 000 ha and the area of cultivated fields in Scania was determined to be approximately 500 000 ha. The map in Figure 3 presents the distribution of these three classes.



Figur 3

The distribution of the classes pasture, cultivated fields and forest in Scania.

The estimated mean carbon storage for all forest types was 71 t C/ha. Based on the forest area and the estimated mean carbon storage for all forest types, the carbon stored in Scanian forest was calculated to approximately 30 MtC.

The potential carbon storage in forest biomass of pasture and cultivated fields, if these areas were to be reforested, was estimated to be approximately 7 MtC and 35 MtC, respectively. In Figure 4, the carbon storage of the three classes is presented and compared with annual emission from the transport sector in Scania (RUS 2018).

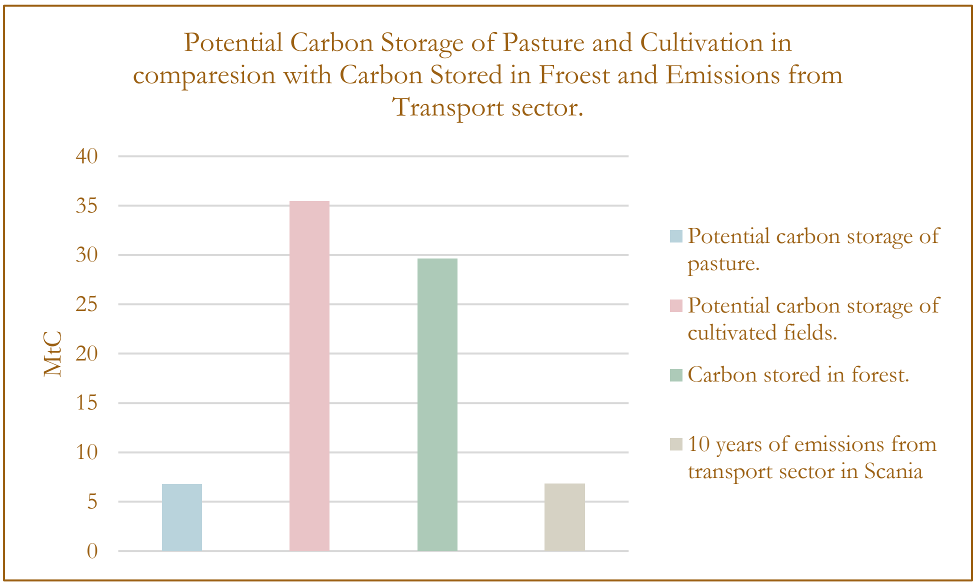


Figure 4

The potential carbon storage of pasture and cultivation by reforestation on Scania pasture. This, in comparison with the estimated storage of carbon in forest and 10 years of emissions from the transport sector in Scania. The statistics of emission from the transport sector in Scania is taken from the National Emission Database (RUS 2018).

The bar chart in Figure 5 shows each of the forest types: all forest, deciduous forest, mixed forest and forest in national park's potential carbon storage (MtC) by reforestation on Scanian pasture. Coniferous forest has the highest potential carbon storage of 7.4 MtC while forest in national parks has the lowest of 6.3 MtC. The numbers are calculated based on the total area of Scanian pasture (95 000 ha) and the estimated carbon storage of the respective forest type (see Table 4 in the Appendix).

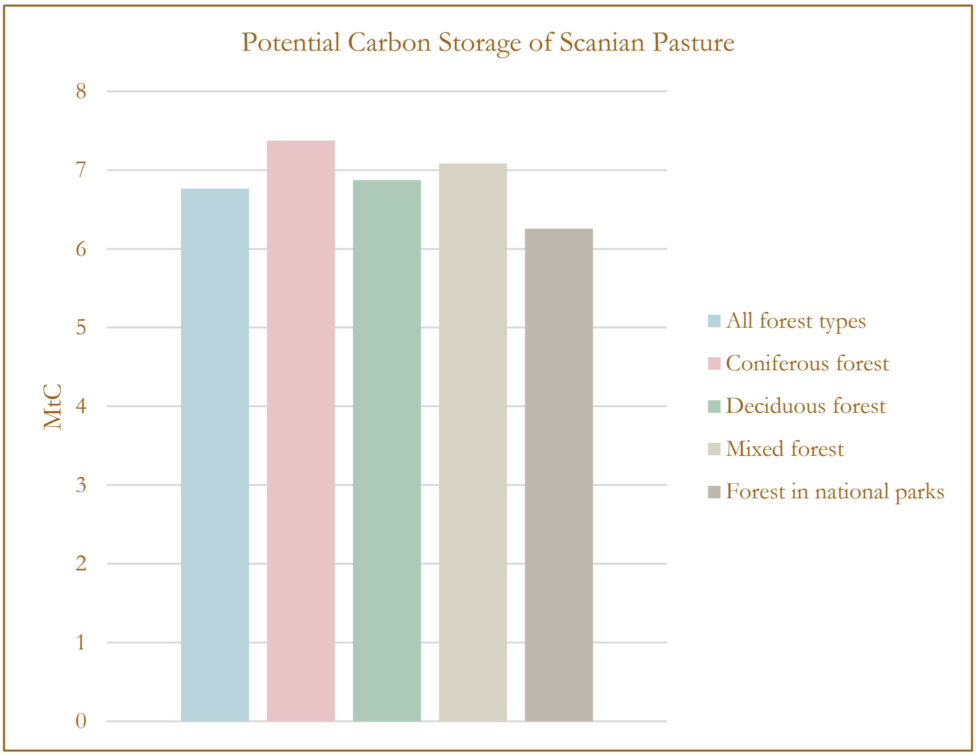


Figure 5
The potential carbon storage by reforestation of Scania pasture for each of the categories all forest types, coniferous forest, deciduous forest, mixed forest and forest in national parks.

In total the category forest in national parks, consisting of the forest-covered area in the three national parks in Scania: Söderåsen, Dalby Söderskog and Stenshuvud, is dominated by deciduous forest (71%). Coniferous forest equals to 4% and cutting area (defined as fields with trees and shrubs with a height of 2 meters and lower) equals 18%. The pie chart in Figure 6 presents the percentages of the coverage of the different forest types in the national parks in Scania.

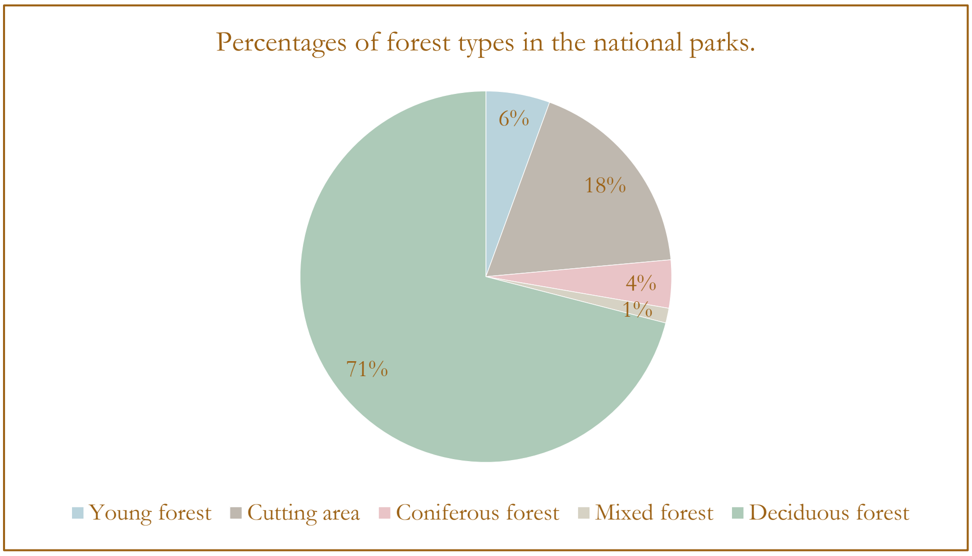


Figure 6
The percentage of the different forest types in the national parks in Scania.

Results from Literature Study- Albedo

Based on the eight references Betts & Ball (1997), Budyko (1974) see Otterman (1977), Cherubini et. al. (2017), Cox et. al. (1999), Essery (2013), Hollinger et. al. (2010), Milly & Shmakin (2002) and Oke (1987) it was found that pasture has the highest mean albedo of 0.305 followed by deciduous forest of 0.190 and coniferous forest of 0.144. The biggest variation between the classes occurs in winter. The mean albedo of deciduous forest in winter is approximately half of the winter albedo of pasture, while the corresponding value of the coniferous forest is approximately one-third of the winter albedo for pasture. The graph in Figure 7 is based on the results from the literature study which are presented in Table 5 in the Appendix.

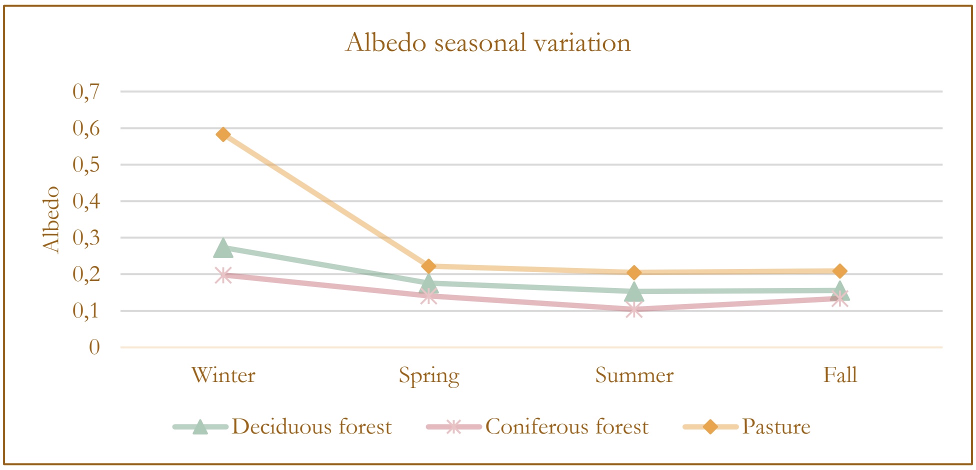


Figure 7
The seasonal variation of albedo for deciduous forests, coniferous forests and pasture. The graph is based on the references presented in Table 5 in Appendix.

Discussion

Potential Carbon Storage in Biomass

The first research question aimed to explore how carbon storage in Scania would be affected if all areas currently used for pasture were to be reforested. The results showed that, the carbon storage in Scania could potentially increase with 6.3 to 7.4 MtC, depending on forest type (Fig. 5). However, when comparing these numbers with the potential carbon storage by reforestation on cultivated fields and the estimated carbon storage of Scanian forest it is noticed that the potential carbon storage of pasture is relatively low due to the relatively small area of pasture in Scania (Fig 3.). Due to the large area of cultivated field the potential carbon storage of cultivated fields is five times larger than that the potential carbon storage of pasture. If all Scanian pasture were to be reforested the corresponding average carbon storage in forest biomass, would equal to approximately 10 years of carbon emission from the transport sector in Scania.

However, both reforestation on pasture and on cultivated fields are problematic. As mentioned in the introduction a reforestation on pasture would conflict with the high biodiversity of pasture and ecosystem services (Wiegand 2008; Brauman 2008), while reforestation on cultivated fields may conflict with for example food security and socioeconomic aspects. Also, it should be noted that soils in Scania have been classified to be the best soils in Sweden and thus are of great importance for the Swedish agriculture (Kungliga lantbruksstyrelsen 1971). Additionally, reforestation affects the aesthetic aspect of the landscape. A conversion from pasture to forest could affect the impression of the landscape and accordingly affect recreational aspects.

The results indicate that the carbon storage capacity of the different forest types is of the same magnitude. However, the carbon sequestration of forest in national parks is significantly lower than of coniferous forest, with the carbon storage capacity of forest grown in national parks corresponding to merely 80% of the capacity of coniferous forest. The slightly lower carbon storage of forest in the national parks could partly be explained with that this forest is dominated by deciduous forest (71%), which is the forest type with the second lowest carbon storage capacity. But this does not fully explain the results because if the lower carbon storage capacity of deciduous forest would have been the single explanation, the carbon storage of deciduous forest would be lower than the carbon storage of forest in national parks as the forest in national parks is mixed with other forest types with higher carbon storage capacity. Hence, there must be an additional reason for the lower carbon storage of the national parks. In production forests the management is reasonably designed to maximise biomass production at the same time as it is likely that the national parks have been preserved due to low productivity soils. Further explanations could be different types of disturbances, tree density or tree age (Cooper 1983; Luyssaert et. al. 2008; IPCC 2007; Vauhkonen & Packalen 2019).

Additionally, even though the carbon storage capacity of the different forest types was determined to be of the same magnitude the value for biodiversity and the ecosystem services of them would not be the same. For example, managed forest has low biodiversity due to uniform stands that can be efficiently managed with maximised harvest, while forest with higher diversity of habitats, i.e. forest in national parks, will be more species-rich. In terms of ecosystem services, forestry yields harvest but at the expense of recreational opportunities provided by the uncut forest (Chapin et. al. 2011). Biodiversity preservation and ecosystem services of different forest types are additional aspects that must be considered in association with reforestation.

Albedo Change due to Reforestation

Regarding albedo, the results indicate that reforestation of pasture with either deciduous forest or coniferous forest would lead to a mean annual surface albedo change from 0.305 to 0.190 and 0.144, respectively. Also, the result shows that albedo of the landscape classes pasture, coniferous forest and deciduous forest differ the most in winter. This since the forest masks the snow in wintertime, which leads to a lower winter albedo than for pasture which is open and therefore has a more complete snow coverage (Robinson & Kukla 1984; Betts & Ball 1997). However, it is likely that the winter albedo will be less pronounced in a warmer climate as higher temperatures will result in receding snow coverage in the wintertime (SMHI 2018; Spracklen et. al. 2008; Gibbard et. at. 2005) in Scania. Therefore, future winter albedo can be expected to be more similar to the albedo in fall and spring. If so, reforestation would have greatest influence on mean annual albedo if it would be of coniferous forest. This as mean surface albedo of pasture and deciduous forest only differed significantly in wintertime (Fig 7.).

Net Radiative Forcing

This thesis estimated an average potential carbon sequestration of 71 tC per hectare in Scanian forest. This carbon sequestration leads to a negative radiative forcing at the same time as the lowering in albedo contributes to a positive radiative forcing (Spracklen et. al. 2008). According to Betts (2000), the albedo reduction resulting from a land use change in Scania from cropland to boreal forest leads to a positive radiative forcing that corresponds to carbon emissions of 60 tC/ ha (see Betts 2000, Table 2 and Figs 1a and 2a.). The sum of these radiative forcing results in a minimal negative net radiative forcing equivalent to (-71-60=) -11 tC/ha. Comparing the results of this study with earlier studies', it appears that the weight of biophysical and biogeochemical processes is still unclear. Some studies suggest that reforestation leads to a negative radiative forcing (Betts 2000; Kurtén et. al. 2003), while others find the opposite (Bala et. al. 2007; House et. al. 2012; Spracklen et. al. 2008). My results indicate a marginal negative net radiative forcing, (i.e. a slight cooling effect), as the potential carbon uptake exceeds the equivalent carbon emissions due to lowering of albedo, which indicates that reforestation is an effective tool for climate mitigation.

The effect that climate change will have on these processes associated with reforestation is not fully understood. Climate change affects the biogeochemical and biophysical processes in multiple ways. Some processes will affect the uptake of atmospheric carbon, for example, CO_2 fertilization, warmer temperature and a longer growing season in the northern hemisphere due to a warmer climate (IPCC 2007). While other processes will act to affect albedo. For example, a warmer climate will lead to earlier snow melt (SMHI 2018), which means that the warming effects caused by snow-covered surfaces being masked by forest will decrease Simultaneously, a receding snow coverage in the wintertime will lead to lower annual albedo and a positive feedback to climate (Bonan 1992; Gibbard. et. al. 2005; Spracklen et. al. 2008).

An aspect related to reforestation that has not been considered in this thesis is the albedo effect caused by forest aerosol emissions (Fig 1.). The results from the Spracklen et. al. (2008) and Kurtén et. al. (2003) studies indicate a negative radiative forcing of forest aerosol emission that is of the same order of magnitude, but opposite, to estimated positive radiative forcing of albedo (Kurtén et al. 2003; Randerson et al. 2006). Accordingly, the aerosol effect could be an aspect of importance when determining the potention of climate mitigation through reforestation. Especially in a warmer climate, the aerosol effect might be of importance and according to Spracklen et. al. (2008) it might even be dominant. This as organic vapours and therefore aerosols (Fig 1.) will be driven by higher temperatures and the effects from snow-covered surfaces masked by vegetation will decrease. However, due to all the mentioned uncertainties, it is not possible to determine whether reforestation on Scanian pasture is an effective tool for climate mitigation or not. Thus, further studies that aim to determine the total net forcing of all effects caused by reforestation are needed.

Error sources

The estimated carbon storage in biomass per hectare of forest is based on statistics of biomass in Scanian forest. This includes a source of error since biases in the Scanian forest will cause a bias in the estimations. For example, if the Scanian forest consists more of old that young forest the estimated biomass and carbon storage will be biased high, and vice versa.

Further, there are some uncertainties in the albedo values presented in Figure 7. This, as the some of the numbers presented in Table 5 in Appendix, which the numbers in Figure 7 are based on, only have one significant figure while the numbers in Figure 7 are presented with three significant figures. This way of presenting the values in Figure 7 gives a false accuracy but is done to more clearly show the differences in albedo of the classes.

The area of pasture in Scania that was determined from the analysis in ArcMap 10.5.1 differ a lot from statistics from the Swedish Board of Agriculture (n.d.). Therefore, it is interesting to discuss the cause of this difference and potential error sources. In an email conversation, the Swedish Environmental Protection Agency (2019, personal communication, 26th-29th of April) explained that in *Swedish ground cover data* (2000) the category "pasture" was created based on a topographical map from Lantmäteriet. In this map, everything that was defined as something other than pasture, i.e. parking lots and sports field, was excluded from the class "other open land". This method contains a risk that area that do not belong to the category "pasture" has been incorrectly classified as pasture. In addition, the *Swedish ground cover data* is based on a 25 x 25 meters pixel image but in the version used for this study this is generalised to 2 hectares which means that pasture fields with an area less than 2 hectares can have been excluded or enlarged to 2 hectares (Swedish Environmental Protection Agency 2019, personal communication, 26th-29th of April). Despite this, the Swedish Environmental Protection Agency (2014) defines the accuracy of cultivation and pasture in the *Swedish ground cover data*, as high.

The statistics from the Swedish Board of Agriculture (n.d.), which presents a total area of pasture of 56 424 ha for 1999, is based on the Swedish farming register (Lantbrukregistret LBR). Until 1999 the register was based on annual surveys in which the farmers reported the area of pasture, cultivation, forest and other fields that they managed. Additionally, the system for registration was designed so that farmers that managed less than 2 ha of cropland were excluded from the statistics, without considering the area of pasture or forest (Swedish Board of Agriculture 2019). Apparently, both the *Swedish ground cover data* and the statistics from the Swedish Board of Agriculture have their uncertainties. Yet, the fact that the area differs as much as it does is an important source of error of results of this work.

An additional source of error is the age of the *Swedish ground cover data*. This becomes clear when studying the categories of forest types in the national parks. In Söderåsen, and partially in Stenshuvud, forest areas have been classified as cutting area, but as these areas are within the borders of the national parks there should not be any cutting fields. In the product description (Swedish Environmental Protection Agency 2014), cutting areas are defined as fields with trees and shrubs with a height of 2 meters and lower. Moreover, it is reported that the category “cutting area” often is mixed with the category “young forest” which could be the reason behind the misclassified areas in the national park of Stenshuvud. In Stenshuvud there are fields that are being grazed (sverigesnationalparker.se n.d.b). These fields could have possibly been classified as cutting areas if they contain shrubs and trees with a height of 2 meters or lower, as the definition of cutting areas. For Söderåsen these areas classified as cutting areas could occur since Söderåsen became a national park first in 2001 (sverigesnationalparker.se n.d.a), which means that data in the *Swedish ground cover data* was obtained just before Söderåsen become a national park. In an email conversation, also the Swedish Environmental Protection Agency (2019, personal communication, 22th-23th of May) pointed out the year that Söderåsen become a national park as an explanation for these cutting areas. But they also added restoration measures as a possible reason. For example, plantations of coniferous forests that have been harvested to be afforested with deciduous forest or overgrown pasture that one has restored.

When preforming the literature study, I evaluated the reliability of the articles mainly based on where they had been published and if they had been cited by other works but I also considered other aspects that could affect the reliability such as the results, layout and language.

Conclusions

To conclude, this study has shown that the potential carbon storage by reforestation on pasture is relatively low (Fig 4.). This is due to the fact that the area of pasture in Scania is not very large. The carbon storage capacity of the different forest types was of the same magnitude, but with small variations. The causes of these variations are not fully understood but could be, for example, forest species, age, management or tree density. However, biodiversity preservation or ecosystem services of the forest types would not be the same.

Moreover, it was found that pasture has the highest annual albedo while coniferous forest has the lowest. It was also shown that albedo of the landscape classes pasture, coniferous forest and deciduous forest is significant higher in wintertime. Due to climate change's projected impact on snow coverage, it is likely that it is the winter albedo that will change the most in a warming climate.

Whether reforestation is an effective tool for climate mitigation depends on the magnitude of biophysical and biogeochemical effects. The result from this thesis indicates a small negative net radiative forcing (i.e. a cooling effect), though, it is marginal and earlier studies oppose each other (Bala et. al. 2007; Kurtén et. al. 2003; Pongratz et. al. 2011; Spracklen et. al. 2008). It should be noted that besides uptake of atmospheric carbon and albedo change, there are additional effects caused by reforestation that this study has not considered (Fig 1.). Also, there are questions marks regarding what impact climate change will have on these effects. Thus, further studies and climate models that contain all the effects and processes are needed. Due to the uncertainties mentioned here, it is not possible to determine with certainty the effectiveness of reforestation as a tool for climate mitigation, though the results indicated a marginal negative (i.e. cooling) net radiative forcing.

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Appendix

Table 3
Original version of Table 1. The polygons that were selected in ArcMap 10.5.1 to create the layers "All_Forest", "Deciduous_Forest", "Coniferous_Forest" and "Mixed_Forest".

Layers	All_Forest	Deciduous_Forest	Coniferous_ Forest	Mixed_Forest
Polygons	Barrskog ej på lavmark > 15 meter	Lövskog ej på myr eller berg i dagen	Barrskog ej på lavmark > 15 meter	Blandskog ej på myr eller berg i dagen
	Barrskog ej på lavmark 7–15 meter	Lövskog på berg-i-dagen	Barrskog ej på lavmark 7–15 meter	Blandskog på berg-i-dagen
	Barrskog på berg-i-dagen	Lövskog på myr	Barrskog på berg-i-dagen	Blandskog på myr
	Barrskog på myr	-	Barrskog på myr	-
	Blandskog ej på myr eller berg i dagen	-	-	-
	Blandskog på berg-i-dagen	-	-	-
	Blandskog på myr	-	-	-
	Hygge	-	-	-

	Lövskog ej på myr eller berg i dagen	-	-	-
	Lövskog på berg-i-dagen	-	-	-
	Lövskog på myr	-	-	-
	Ungskog	-	-	-

Table 4

The average ton dry matter per hectare and ton carbon per hectare for the classes all forests, coniferous forest, deciduous forest, mixed forest and forest in national parks.

	ton DM/ ha (AGB)	ton C/ ha (AGB)	ton C/ ha (total)
All forest	104	52	71
Coniferous forest	113	57	77
Deciduous forest	106	53	7
Mixed forest	109	54	74
Forest in national parks	96	48	66

Table 5

The albedo of deciduous forest, coniferous forest and grassland depending on seasonality.

Forest type (season)	Betts & Ball (1997)	Hollinger, et. al. (2010)	Cox, et. al. (1999)	Milly & Shmakin (2002)	Cherubini, et. at. (2017)	Budyko (1974) see Otterman (1977)	Essery (2013)	Oke (1987)	Mean albedo	Comments
Coniferous forest/ evergreen needleleaf- Winter (November- March)	Pine: 0.150 spruce: 0.108 (with snow)	-	0.2	-	0.2	0.45 (forest with stable snow cover)	0.1- 0.25	0.05- 0.15	0.2 (0.198)	Vary between 0.05- 0.25. 0.45 differ from the other values as it is higher.
Coniferous forest/ evergreen needleleaf- Spring	-	0.084	0.14	0.11	0.1- 0.2	0.25 (forest with unstable snow cover	0.1- 0.2	0.05 -0.15	0.1 (0.141)	Vary between 0.05- 0.25.

(April- May)						in spring)				
Coniferous forest/ evergreen needleleaf- Summer (June- August)	Pine: 0.086 spruce: 0.081 (without snow)	0.079	0.14	0.11	0.1	0.14	0.1	0.05- 0.15	0.1 (0.104)	Vary between 0.079- 0.14.
Coniferous forest/ evergreen needleleaf- Fall (September- October)	-	0.089	0.14	0.11	0.05- 0.15	0.30 (forest with unstable snow cover in autumn)	0.1	0.05-0.15	0.1 (0.134)	Vary between 0.05- 0.15. 0.3 differ from the other values as it is higher.

Deciduous forest/ broad-leaved trees- Winter (November- March)	0.214 (Aspen, with snow)	-	0.3	-	0.1–0.4	0.45 (forest with stable snow cover)	-	0.15 (bare)	0.3 but 0.2 if 0.45 is excluded. (0.273, 0.229)	Wide range of the values. Vary between 0.1- 0.45.
Deciduous forest/ broad-leaved trees- Spring (April- May)	-	0.145	0.13	0.13	0.1–0.3	0.25 (forest with unstable snow cover in spring)	-	0.2 (leaved)	0.2 (0.176)	The four columns to the left present values between 0.12- 0.145. The two columns to the right present values of 0.1- 0.3 and 0.25.

Deciduous forest/ broad-leaved trees- Summer (June-August)	0.156 (Aspen, without snow)	0.152	0.13	0.13	0.1-0.15	0.18	-	0.2 (leaved)	0.2 (0.153)	A narrow range of values. Vary between 0.1-0.18.
Deciduous forest/ broad-leaved trees- Fall (September-October)	-	0.146	0.13	0.13	0.05-0.2	0.25 (forest with unstable snow cover in autumn)	-	-	0.2 (0.156)	Vary between 0.05- 0.25. The four references to the left vary between 0.12- 0.146.

Grassland-Winter (November-March)	0.75 (with snow)	-	0.7	-	-	-	0.2–0.4	-	0.6 but 0.7 if the range 0.2- 0.4 is excluded (0.583, 0.725)	A wide range of values. Vary between 0.15- 0.8. 0.7- 0.8 differ as it is higher than the rest.
Grassland-Spring (April- May)	-	0.209	0.19	0.20	-	-	0.2–0.3	0.26	0.2 (0.222)	Vary between 0.19-0.3.
Grassland-Summer (June-August)	0.197 (without snow)	0.181	0.19	0.20	-	-	0.2	0.26	0.2 (0.205)	Vary between 0.181-0.2.

Grassland-Fall (September-October)	-	0.197	0.19	0.20	-	-	0.2	0.26	0.2 (0.209)	A narrow range of values. Vary between 0.19- 0.2.