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Comparing net primary productivity between continuous cover and rotation forestry management in Sweden

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Abstract

Forests are important ecosystems worldwide and in Sweden, where over half of the land is forested. Forestry management strategies significantly impact ecosystem productivity and carbon sequestration. This study focuses on comparing two prevalent forestry management strategies: Rotation Forestry (RF), which uses clearcutting as the prevalent timber extraction method, and Continuous Cover Forestry (CCF), which extracts timber by individual tree selection, thus, always maintaining the tree cover. While RF is favoured for its economic benefits, CCF performs better at preserving ecosystem services and biodiversity. The aim of this thesis is to assess the difference in Net Primary Productivity (NPP) and their trends over the years 2001 to 2023 between RF and CCF across Sweden. Using satellite-based NPP observations, data from 49 pairwise forest sites managed under RF and CCF were analysed. Statistical tests revealed no significant difference in average NPP between the two strategies, as well as no difference in NPP trends over the study period. These findings contradict the hypothesis that CCF would exhibit higher NPP and a more statistically significant trend than RF due to carbon sequestration declines under RF management. However, limitations of this study exist, including uncertainties in the satellite-based dataset used, the relatively short study period to display any impacts of the management strategies, and absence of clearcutting phase in RF management study sites. Nonetheless, this study emphasizes the importance of further research to maximize the economic benefits and ecosystem services of forestry in Sweden and abroad.

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1 Introduction

Forests are important ecosystems worldwide, providing diverse ecosystem services, such as timber, food, carbon sequestration, water, soil and air purification (Harrison et al., 2010). In the European Union, Sweden is the country after Finland with the largest share of forested area, with 63% of land covered by forest in 2021 (European Commission, 2024). In 2015, Sweden provided 10% of timber products, including logs, pulp and paper of the global market (Swedish Forest Agency, 2015). As over half of the country is forested, forestry is an important economic sector, which makes Sweden a favourable place for forest-related studies.

Actively managed forests not only maintain carbon stocks better but also have greater climatic benefits in the long run compared to unmanaged forests (Nabuurs et al., 2007). However, timber forestry often conflicts with other forest ecosystem services, such as carbon storage, pest regulation, cultural services, as well as biodiversity protection (Pohjanmies et al., 2017). The extent and impact of these disputes also depends on the forest management type applied, as it may result in different climatic benefits due to the complexity of carbon stocks in the ecosystem and timber harvesting (Smyth et al., 2014). The management strategy rotation forestry (RF), also called even-aged or clearcut management, is a maintenance of mainly even aged individual tree stands, with the final timber extraction being clearcutting (Roberge et al., 2020). As of 2020, it was and remains the dominating forestry management strategy in Sweden (Felton et al., 2020; Manner et al., 2023). A different management strategy is continuous cover forestry (CCF), which is a term covering a variety of practices, where timber extraction is carried out by individual tree selection and the main goal is to always contain a tree cover (Roberge et al., 2020). Since the 1950s, when clearcutting became the dominant practice (Roberge et al., 2020), most forests of Fennoscandia became impoverished in structural diversity, as well as fragmented (Kuuluvainen et al., 2012). Hence, studies suggest that CCF might be a better management strategy for preserving the beforementioned ecosystem services, resilience against disturbances, and biodiversity (Hertog et al., 2022), as well as in maintaining carbon storage in the short term (Davis et al., 2009). On the contrary, RF is found to be favoured in maximizing sustainable yield and providing higher economic benefits than CCF (Eyvindson et al., 2021; Tahvonen & Rämö, 2016).

Yet, the effect of different forest management strategies on carbon sequestration and forest productivity is still not extensively studied. Net primary productivity (NPP), estimated as autotrophic respiration subtracted from the carbon assimilation rate of photosynthesis, is an important indicator of the forest's health (Davis et al., 2009). The NPP of the forest stand depends on the tree species and age, as well as the response to climatic factors and nutrient availability (Davis et al., 2009; Houghton, 2003). A study by Gower et al. (2001) found that boreal forests of Sweden and Finland range in NPP from 215 to 462 g C/m^2/year NPP is found to have a rapid increase within young trees, reach a peak growth in middle aged forests and slowly decline with age thereafter (He et al., 2012). Moreover, even though the impact of management strategies on forest productivity has been studied, the extent of it is uncertain (Lundmark et al., 2016). Davis et al. (2009), analysed the effect timber harvest has on the net ecosystem productivity, and suggested that on average, forests had lower carbon storage in response to clearcutting events, as opposed to other management strategies. Furthermore, the effect of CCF on the forest carbon balance in relation to the RF management strategy has been studied by Lundmark et al. (2016), for a Norway spruce stand in central Sweden using model simulations. It was found that changes in carbon stock were very small between the two management strategies, hence, the strategy choice was insignificant in regards to the climatic benefits in the long run. Nevertheless, growth of the forests under both scenarios was assumed to be equal, which might not always be the case.

A Swedish Forestry Act implemented in 1993 aims to expand the selection of forest management strategies in order to attain a larger variety of ecosystem services from the forests, as opposed to letting rotation forestry be the dominating strategy (Roberge et al., 2020). However, as the changes in NPP due to different forest management strategies remains uncertain, more research is needed to better motivate the choice of a preferred forest management strategy.

1.1 Aims and Hypothesis

Therefore, the main aim with this thesis is to study the difference in NPP between RF and CCF forestry management strategies across Sweden. Moreover, the second aim of the study is to analyse whether there is a difference in the NPP trend 2001-2023 between the two different management strategies.

The hypothesis of the study is that CCF sites would have higher average NPP and a larger positive trend than that of RF forestry, as older growth forests generally have higher NPP (He et al., 2012), and carbon sequestration declines under RF management (Davis et al., 2009).

2 Background

A review article on CCF and RF concluded that more research is needed to properly compare the two management strategies, especially in forests composed of multiple species (Kuuluvainen et al., 2012). It has also been argued that RF providing higher economic benefits than CCF is a misconception, and that the economic performance of CCF can be increased when applying different economic setups and growth models (Kuuluvainen et al., 2012). The selected management strategy also depends on the initial forest stand, as it is found that RF management is most economically beneficial when used in a mature, even-aged forest stand, whereas afterwards clearcutting, to improve regeneration, CCF is preferred (Tahvonen et al., 2010). An economic advantage of CCF can be observed by it providing more log than pulp wood as opposed to RF, due to harvesting being carried out from above (Eyvindson et al., 2021). Furthermore, CCF assumes regeneration, whereas RF relies on manual tree planting, which has high costs, although, the natural regeneration may not always be successful (Eyvindson et al., 2021).

While it is important to compare the two strategies in order to maximize benefits of the forestry, a study done extensively on multifunctionality of Finnish forests found that excluding any forest management strategy (as in choosing only one method) would in the end negatively impact overall all forests’ multifunctionality (Eyvindson et al., 2021). Limiting the use of forest management strategies to either only CCF or only RF would likely reduce economic value of the forest and ecosystem services that it provides (Eyvindson et al., 2021). Moreover, a pilot study on CCF managed forests in Sweden found that not only the method but also the intensity of harvesting has an effect on the productivity of the harvester, with tree stem volume increasing with decreasing harvesting intensity, resulting in a better yield (Manner et al., 2023). A study on forest management intensity impact on mushroom yield in Catalonia’s pine forests suggests that mushroom productivity increases with increased forest management intensity (de-Miguel et al., 2014), regardless of the chosen strategy. Another study also concluded that to mitigate the conflicts between timber extraction and forest ecosystem services, a variety of forest management strategies is needed (Pohjanmies et al., 2017). Some studies are developing methods that do not comply with neither of the two management strategies, a third option referred to as any-aged management, where a forest land owner chooses between different management approaches, rather than sticking to one (Pukkala et al., 2014). Following the results of these studies, it could be concluded that many factors should be taken into consideration when choosing the appropriate management strategy, and implementing both CCF and RF across different forests might be more beneficial for the forest ecosystem, rather than choosing one. As CCF is still not a widely used strategy neither in Sweden nor worldwide, longer implementation and more studies are needed to fully understand its impacts on the landscape and forest ecosystem (Eyvindson et al., 2021).

3 Methods

3.1 Study area

In order to fulfil the study aims, I used coordinates of forests with different management strategies across Sweden and collected their annual NPP 2000-2023 from satellite-based observations. The study is conducted at sites located across Sweden. The country has a large north-south extent with a considerable change in climatic conditions, dividing the country into three main vegetation zones (Swedish Forest Agency, 2015; Roberge et al., 2020). The boreal zone covers the largest part of the country and is dominated by coniferous forests. Remaining smaller zones include alpine in the north and nemoral zone of mostly deciduous forests in the south (Swedish Forest Agency, 2015; Roberge et al., 2020). The dominating tree species in Swedish forests are Norway spruce (Picea abies), Scots pine (Pinus sylvestris) and birch (Betula pendula, Betula pubescens), accounting for 40 %, 38 % and 12 % of the forest cover respectively (Roberge et al., 2020; Forests and Forestry in Sweden, 2015). In 2014, approximately half of all forest area was owned by private owners and 25% by forestry companies (Roberge et al., 2020).

3.2 Study site selection

To acquire study sites with different forest management strategies, an open source database containing most of the Swedish forestry trials, called “Silvaboreal” was utilized (Silvaboreal, 2024). The database is owned by the Swedish University for Agricultural Sciences and maintained by cooperating with 15 different organizations, such as The Swedish Forest Agency (Skogsstyrelsen), The Forestry Research Institute of Sweden (Skogforsk) and the largest forest owner in Sweden Sveaskog (Silvaboreal, 2024). The database includes data (in particular location) of various forest sites that are classified by their management type and ownership. The available information for each forest site includes: ID, tree species, forest owner and contact person, point coordinates of the forest location and year of the implemented management strategy. The latter could not accurately indicate the age of the forest, as age of the seedlings could differ. Moreover, some forest sites included a description of the site, however, the provided information and its amount varied a lot.

I selected sites that are managed with the CCF and RF management strategies. Firstly, a CCF site was selected, which always started with the word “Hyggesfritt”. The requirements that needed to be fulfilled for the site to be included were:

- the forest had to extend 500 meters in each direction from the coordinate point, as the acquired satellite-based NPP observation had a spatial resolution of 500 m;
- there should be no urban areas, water bodies or other forest management strategies within the site extents, in order to accurately compare sites covering the whole area.

These requirements were tested by using Google Maps satellite imagery of 2024. As the aim of the study was to compare the management strategies, a pairwise site of RF management, identified with the name “Produktion”, was selected right after, taking the closest forest site that fulfilled the same requirements. The site acquisition always started with the CCF forests, as less of these were available. All of the available CCF sites from the database were tested for suitability. In total, 49 forest pairs matching the criteria were selected, 98 forest sites, displayed in Figure 1.

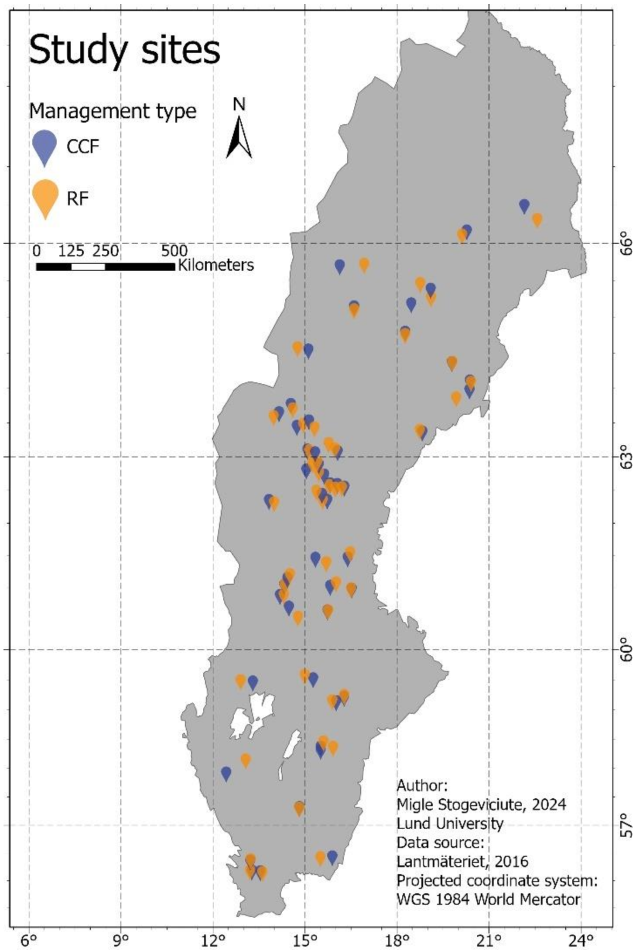


Figure 1. Study sites across Sweden, continuous cover forestry (CCF) in blue and rotation forestry (RF) sites in orange.

3.3 Data

The NPP data (g C/m²/year) was acquired from the NPP product (MOD17A3HGF v061) based on data from the MODIS (Moderate Resolution Imaging Spectroradiometer) sensor, which is on board the Terra satellite launched in 1999 (Running & Zhao, 2021). This is a gap-filled annual product provided at 500-meter spatial resolution. The annual NPP product is based on the 8-day MODIS Gross Primary Production (GPP) estimated with a light use efficiency model and constrained due to vapor pressure deficit and air temperature conditions (Running & Zhao, 2021). The model uses predicted daily GPP from MODIS satellite-derived fraction of absorbed photosynthetically active radiation (FPAR), as well as other estimates of PAR and other surface meteorological variables (Running et al., 1999). Maintenance respiration and growth respiration costs are then subtracted from GPP in order to acquire annual NPP values (Figure 2). Here, the primary input for estimating maintenance and growth respiration is the annual maximum leaf mass(Running et al., 1999). Hence, many complexities of carbon balance in specific ecosystems are simplified while computing this NPP dataset (Running & Zhao, 2021).

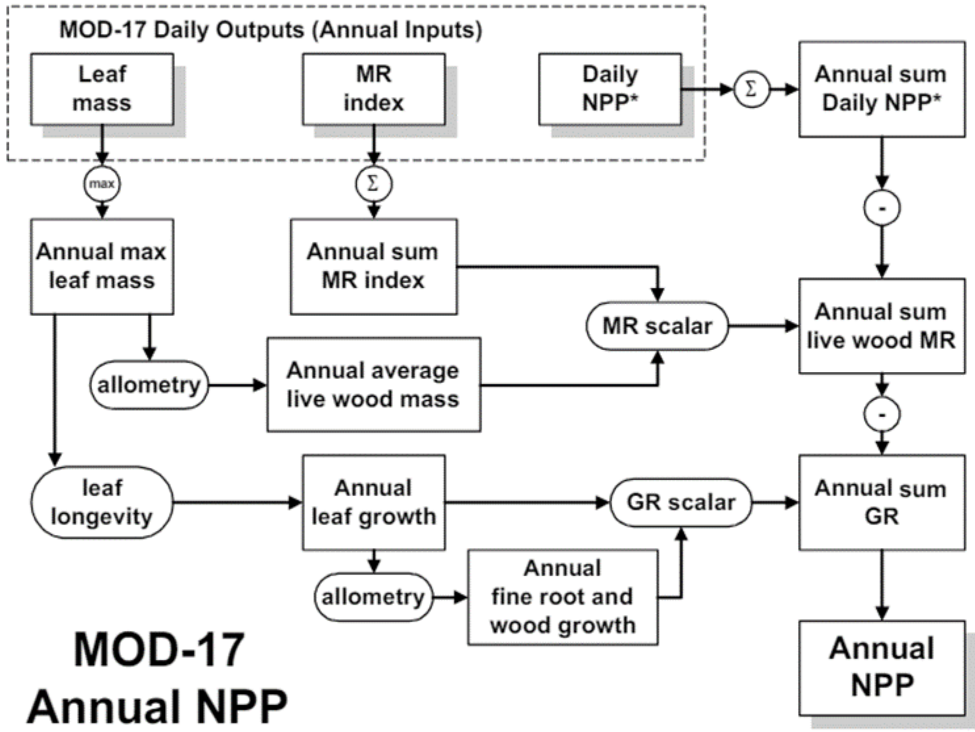


Figure 2. A flow chart, illustrating the data flow in the annual part of the MOD17 model algorithm for annual NPP product estimation (Running et al., 1999). MR is maintenance respiration and GR is growth respiration.

To download the data, MODIS global subset tool TESViS (Terrestrial Ecology Subsetting and Visualization Services) was used (ORNL DAAC, 2018). The coordinates of the study sites were imported using WGS84 coordinate system and the extent of the area selected as 0 km in order to acquire one-pixel value. Data were collected for the years 2001-2023. All data were checked to validate that no clearcutting occurred during the selected time span, but none of the sites were excluded. This was done visually, by plotting scatterplots of the data and checking whether there is a decrease from the mean of around 300 g C/m^2/ year, which would indicate an extraction of timber, decreasing the forest productivity.

3.4 Statistical analysis

In order to compare the average NPP values of the different forest management strategies, averages over the full time series were calculated for each site. The averages of CCF and RF sites were then tested for normal distribution separately, using Shapiro-Wilk test, level of significance α set to 0.05. If data was normally distributed, a pairwise t-test was selected, if data was not normally distributed, a Wilcoxon signed rank test was carried out.

To test if there is difference in the trend 2001-2023 between the management strategies, the linear trends and their respective coefficients of determination (R^2) were first extracted for each site using an ordinary least square linear regression. All R^2 and slope values of the CCF and RF sites were then separately checked for normal distribution. An appropriate statistical test, either a pairwise t-test for normally distributed data or a Wilcoxon signed rank test for non-normally distributed was then implemented.

4 Results

4.1 Differences in NPP averaged site-wise between CCF and RF

NPP values for CCF sites range between 388.8 and 876.0 g C/m²/year, for RF sites between 378.6 and 852.6 g C/m²/year and both mean values are very close at 561.5 g C/m²/year for CCF and 563.4 g C/m²/year for RF (Figure 3). CCF and RF pairwise sites' average NPP values plotted against each other (Figure 4) display a relatively good fit of the trend, with R^2 being 0.78.

The normal distribution tests show both CCF and RF averages being normally distributed, with CCF p-value being 0.10, and RF averages test p value being 0.07. Hence, a pairwise t-test was carried out between the averages of the two forest management strategies, resulting in $t = -0.28$, critical two-tail $t = 2.01$. As t falls within the critical t: $-2.01 < -0.28 < 2.01$, the null hypothesis is accepted, indicating no significant difference in NPP averaged site-wise between the two forest management strategies.

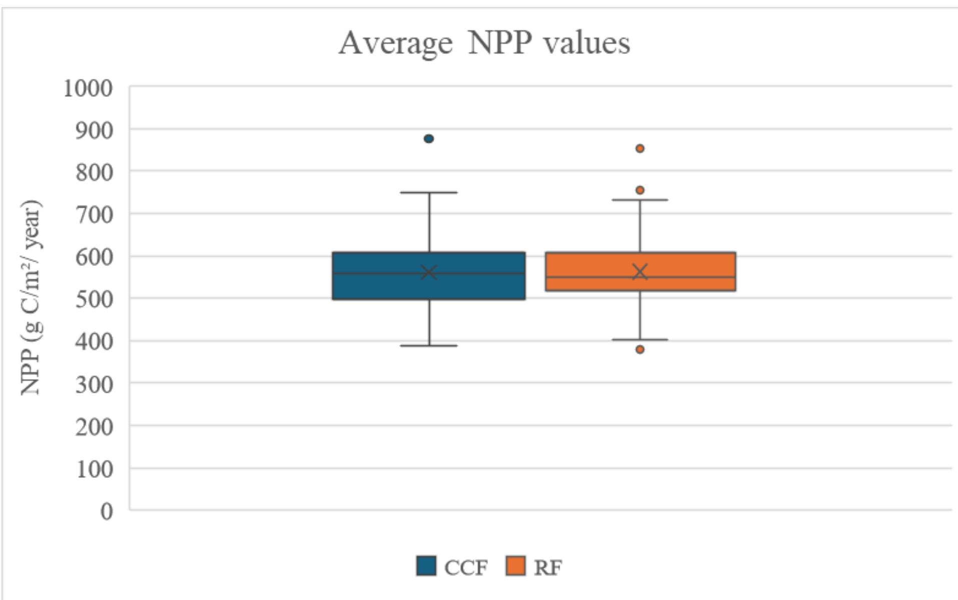


Figure 3. Average NPP value distribution between continuous cover forestry (CCF) and rotational forestry (RF) management strategies. Displayed in the box plot as dots are outliers (defined as laying 1.5 times the length of the box), vertical lines are the error bars, the bottom and upper edges of the boxes are the lower and upper quartiles respectively, X is the mean and the line inside the box is the median.

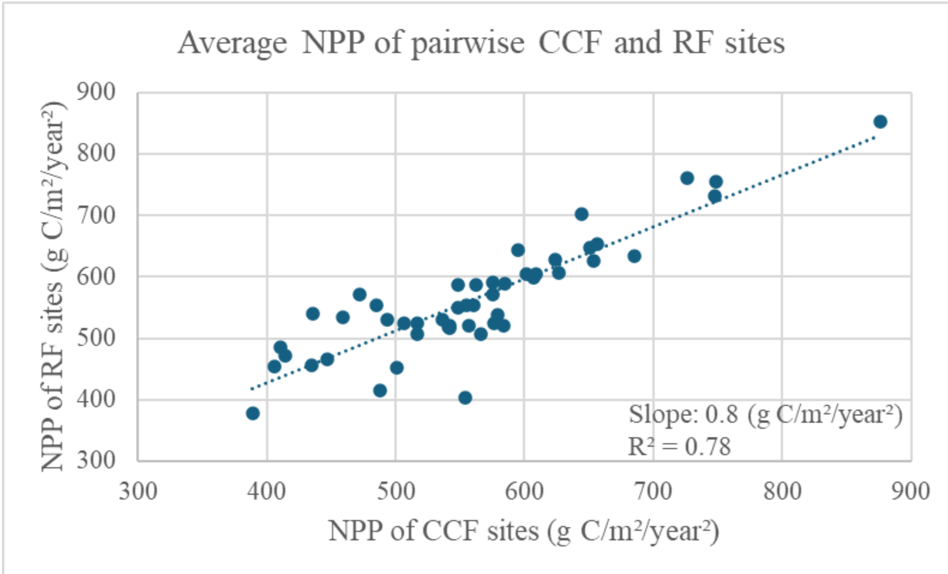
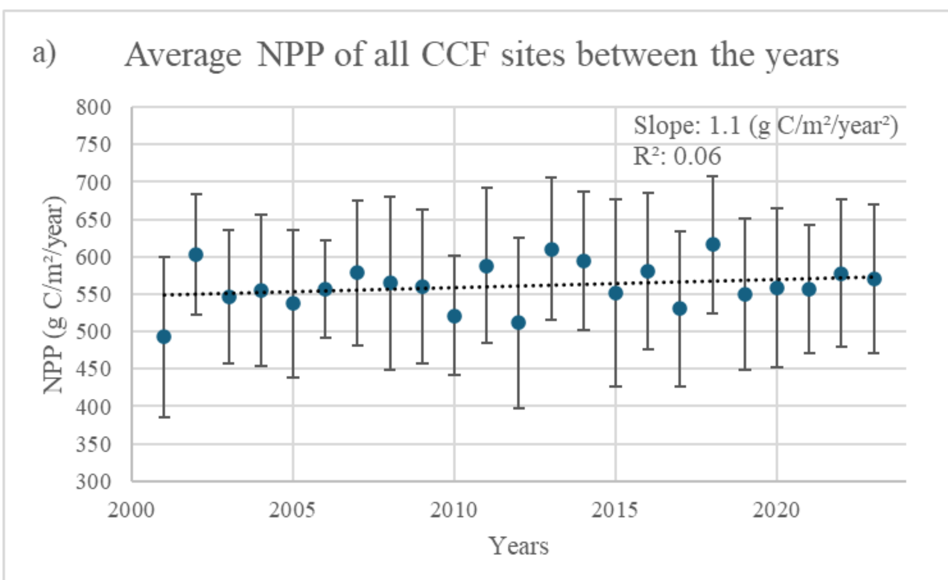


Figure 4. Scatter plot of average NPP values of pairwise continuous cover forestry (CCF) and rotational forestry (RF) management strategy sites.

4.2 Differences in trends 2001-2023 between CCF and RF

Time series in NPP averaged per year 2001-2023 for the CCF and RF sites are displayed in Figure 5 a) and b). The overall trend in NPP is very similar between both datasets, showing a slight increase from around 550 in 2001 to around 570 g C/m²/year in 2023. The data points from CFF sites have a slightly closer value range as the R^2 is 0.06, as opposed to R^2 being 0.05 of RF. Significance values F of the regression analysis for the trends are 0.26 and 0.31 respectively, both above significance level 0.05, showing no significant trend for neither of the averages.



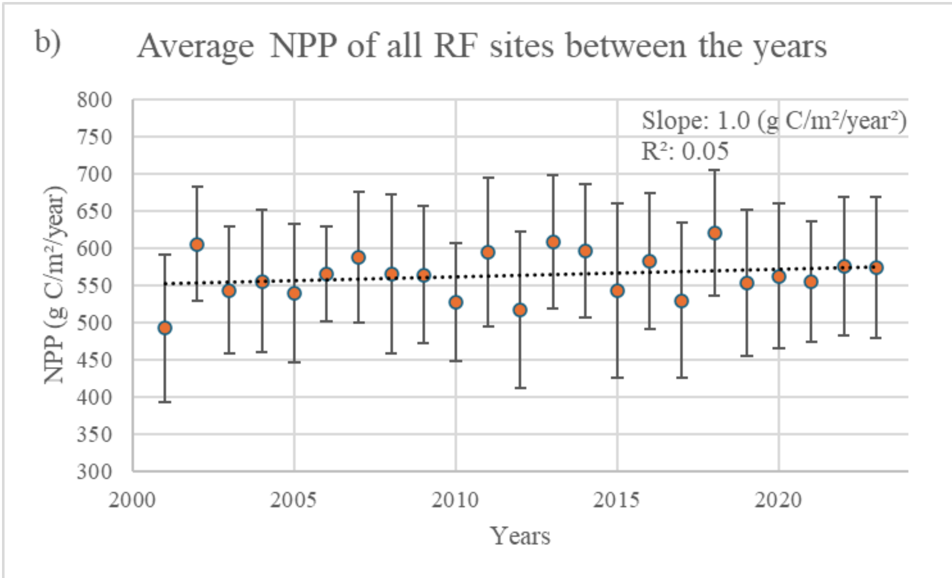
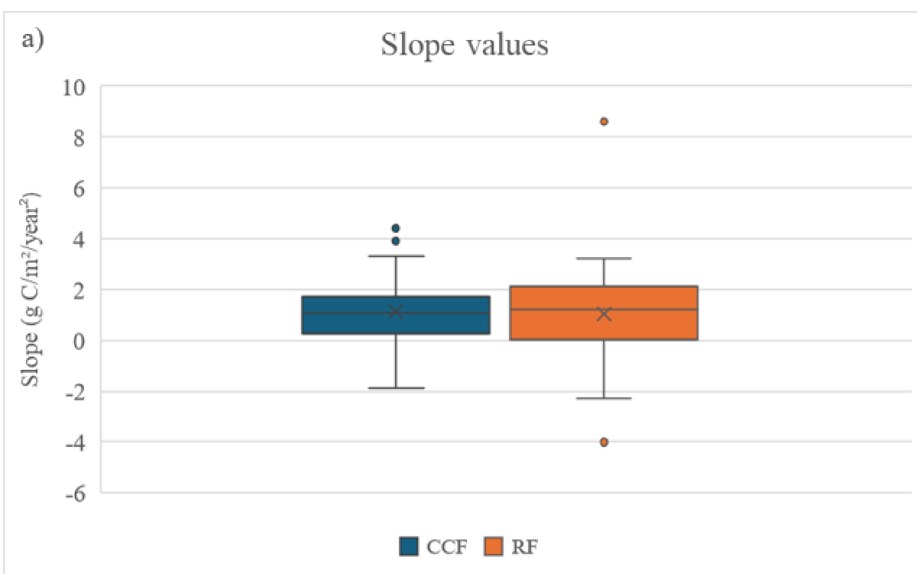


Figure 5. Times series of net primary production (NPP) averages over the 49 a) continuous cover forestry (CCF) sites and b) the rotational forestry (RF) sites over the years 2000-2023. Included is also the ordinary least square linear regression trends, their respective slopes and coefficients of determination (R^2).

Moreover, the variation of slope and R^2 values of all sites are displayed in Figure 6 a) and b) respectively. In both instances, RF sites have a wider value range. For slope, the majority of the values are positive for both datasets, with similar means of 1.1 for CCF and 1.0 g C/m²/year^2 for RF, values ranging from -1.9 to 4.4 g C/m²/year^2 for CCF sites and from -4.0 to 8.6 g C/m²/year^2 for RF sites (Figure 6 a)). For R^2 values, the value range is from 0.0 to 0.19 for CCF sites and from 0.0 to 0.28 for RF sites, mean values being 0.07 for CCF and 0.09 for RF data (Figure 6 b)).

The variation of slope values between pairwise CCF and RF sites (Figure 7) is substantial, with slope values differing between the pairwise sites a lot, R^2 value of the trend being very low at 0.01.



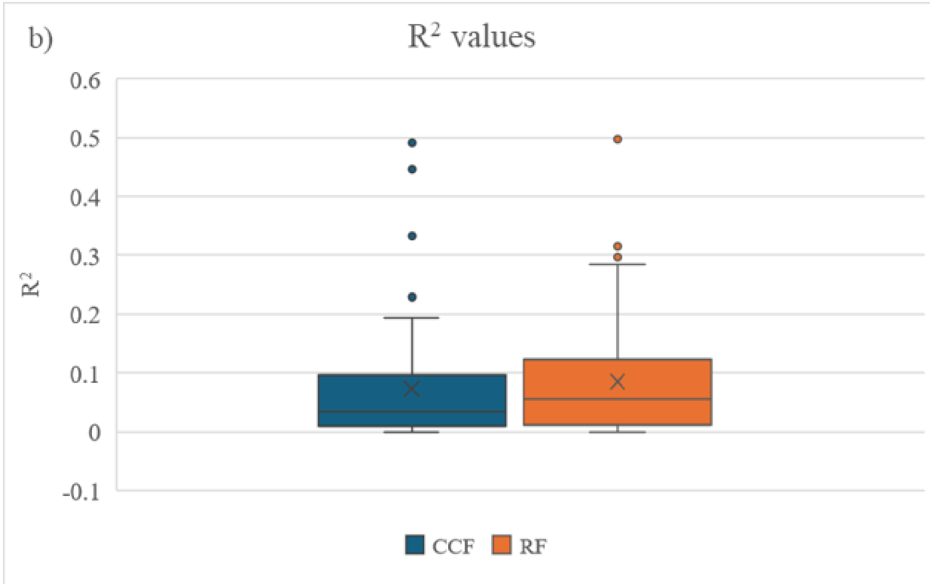


Figure 6. a) Slope and b) R^2 value ranges for continuous cover (CCF) and rotational forestry (RF) management strategies' sites. Displayed in the box plot as dots are outliers, vertical lines are the error bars, the bottom and upper edges of the boxes are the lower and upper quartiles respectively, X is the mean and the line inside the box is the median.

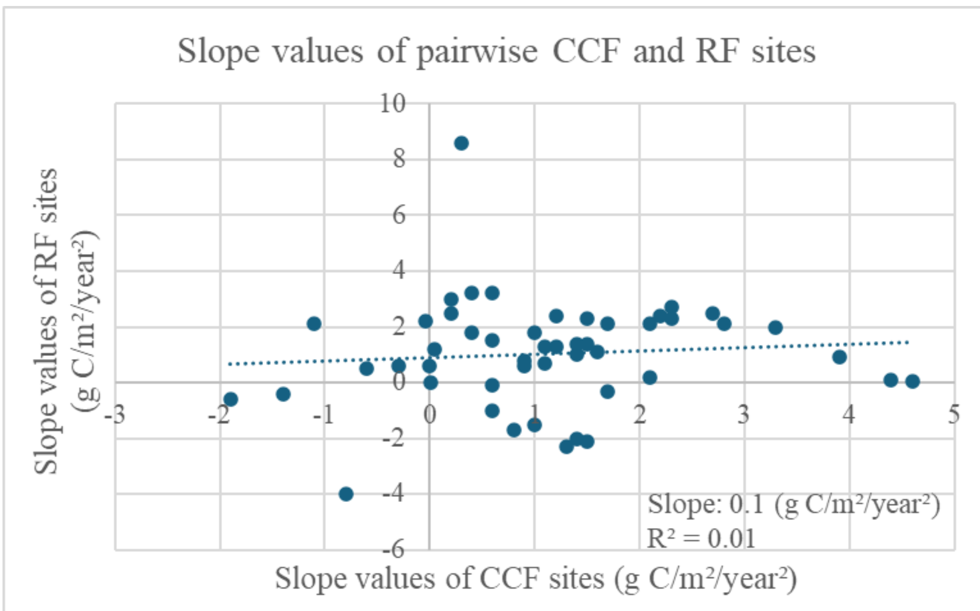


Figure 7. Slope variation of pairwise continuous cover (CCF) and rotation forestry (RF) management strategies sites.

The Shapiro Wilk normality test carried out for slope and R^2 values indicates that only CCF slope data has a normal distribution ($p = 0.34$). Therefore, Wilcoxon signed rank tests were implemented for testing difference in the trend 2000-2023 of the management strategies. For slope, p resulted in 0.84, and for R^2 the $p = 0.19$. As both results are higher than significance level 0.05, both null hypotheses were accepted, showing no significant difference between the sites in regards of trends and their R^2 values.

5 Discussion

5.1 Differences in NPP between CCF and RF management strategies

To begin with, the thesis hypothesis was rejected, as the CCF and RF management strategies did not have a significant difference in their ecosystem productivity and trend. Average NPP values of both management strategies were very similar, in pairwise sites as well as total averages, mean values being very close at 561.5 g C/m²/year for CCF and 563.4 g C/m²/year for RF, although CCF management had a slightly larger range of values. The values were a bit higher than those found by Gower et al. (2001): 215 – 462 g C/m²/year, however, the years of measurement, data source and area extent were different in this study. Forests under both management strategies in this study were equally productive. This might be due to no sites with clearcutting since 2001 were included in the study. Therefore, it is not entirely representative to compare full impacts of both management strategies. Additionally, the time period of the chosen management strategy implementation varied between the sites, and it could be assumed that the age of the forests also varied, which makes the study more representative within forests of different characteristics. However, this also means that some stands could have been under the specific management strategy for an insufficient amount of time to display any effects (Tahvonen et al., 2010).

Regarding the trend, both slope and R^2 values of CCF and RF had no significant difference between them, both trends being very similar. Even though CCF had a higher R^2, it was only by 0.01, which is a very small difference. The variation in NPP between the years followed the same pattern in both management strategies, meaning that other factors had an influence on the productivity of the forests, potentially climatic variables. The majority of slope values were positive, meaning in almost all of the study sites the NPP trends were positive. This could be explained by the forests growing older and sequestering more carbon, as mature growth forests generally have larger NPP values due to carbon uptake over the years (He et al., 2012). Other explanations could also be global warming impacts or the effect of CO_2 fertilization. However, the pairwise site comparison displayed a large variation in slope values, meaning that pairwise sites of different managements varied in their trends. R^2 values for both management types were very low, ranging from 0.00 to 0.28. Moreover, R^2 values of RF sites had a larger variability, possibly indicating a larger interannual variability than that of CCF sites, being more vulnerable to climate variation. However, as the significance tests of the trends showed no significance, and as the R^2 value displays how well can the model fit the data points, it can be concluded that there is no strong trend between the years.

While Davis et al. (2009) found that carbon sequestration and therefore forest productivity declines under RF management as compared to CCF management, this was not the result of this thesis, as there was no significant difference between the strategies and carbon uptake in NPP values displayed an increasing trend over the years. Nonetheless, it is important to point out that a significant effect on forest carbon storage are the harvesting events (Davis et al., 2009), which were not a part of this study. Therefore, while this thesis and Davis et al. (2009) produced different results, the methodology of the studies was different, meaning other discussed variables could have had an impact on the results. Furthermore, it has been shown in Sweden that forest stands similar in age and species composition had only small differences in carbon balances between the two different management strategies of CCF and RF (Lundmark et al., 2016). Despite that, the study was done in order to compare how a specific forest stand with only one tree species would react to different management, whereas the study sites in this thesis varied in their growth and composition. Arguably, when comparing forests of different ages and species, different management strategies could still have different outcomes (Eyvindson et al., 2021).

5.2 MODIS NPP Dataset

The limitations of the MODIS NPP dataset are found within remote sensing, as the main errors are connected to the retrieval of the satellite data due to cloud and/or aerosol contamination (Running & Zhao, 2021; Endsley et al., 2023). It is important to note that this issue is most prominent in tropical regions where there is a higher cloud concentration (Running & Zhao, 2021), as well as it was a larger issue in previous MOD17 versions, and this has been improved in the version 6.1 (Running et al., 1999), that is used in this study. Another source of error for the dataset is misclassification of land cover classes, as it is an important input in the model (Running & Zhao, 2021). Studies have suggested that the MODIS vegetation maps are accurate within 65-80%, however, accuracy increases with higher area size and homogeneity (Running & Zhao, 2021; Friedl et al., 2010). Hence, for this thesis, as the study sites are rather small, there is an increased chance of land cover misclassification, especially as the dataset is aimed to fit on a global scale and not Sweden exclusively.

The dataset has been validated using in situ carbon and water flux tower measurements as well as other ecosystem models (NASA, 2023). This validation procedure has been developed by Running et al., (1999). Currently, the dataset has reached the highest stage 3 validation, which is developed by the Committee on Earth Observation Satellites (CEOS), The Land Product Validation Subgroup (LPV) (NASA, 2021). It implies that the model is validated by using in situ or other relevant reference data, uncertainties are investigated and evaluated by many peer-reviewed articles globally (NASA, 2021).

Regarding use of MODIS dataset in forest ecosystems, several studies have utilized the dataset in Sweden or similar forest environments, comparing the model output with in situ flux tower data, finding that in general, the results are relatively accurate but some improvement is still needed, especially when working on smaller scales (<500 m) (Cai et al., 2021; Endsley et al., 2023; Hu et al., 2023; Olofsson et al., 2007; Tang et al., 2015; Wang et al., 2017). Cai et al. (2021) tested MODIS GPP dataset using data from 8 flux towers in the Nordic region, 6 of which were located in Sweden and found that the accuracy of the dataset was generally high, $R^2 = 0.83$. On the contrary, Wang et al. (2017), tested the MODIS GPP dataset across 6 biomes which also included evergreen needleleaf, deciduous and mixed forests, and found that the model performance in general was rather poor, and that it can be improved by using a different FPAR input. Moreover, a similar study evaluating MODIS GPP as well as the NPP product across 8 different ecosystems found that the products tend to overestimate values at sites with lower productivity and underestimate at sites with high ecosystem productivity (Turner et al., 2006).

5.3 Limitations and uncertainties

Some of the study limitations lie within the chosen methodology. It is rather difficult to compare the two management strategies as the time span of comparison is only 23 years, when all forests were in the growing phase. A longer time span and more sites could provide more accurate results, especially as the harvesting outcome in RF is the complete loss of tree cover, and in this case, it is unclear whether any clearcutting was carried out in any of the RF sites previously. However, the NPP dataset did not have a longer data time span, and acquiring a longer observation based dataset at this spatial resolution was not feasible. This is another limitation, as having other datasets for comparison would have improved the accuracy of the study. Further, having in situ measurement data from flux towers, as done by Cai et al. (2021) to validate the satellite-based dataset would have provided a better insight not only into the productivity of the forests, but also the extent to which remote sensing can be used within this topic. A drawback of this is that there are not enough flux towers, especially located in CCF stands, in Sweden to cover as large temporal and spatial variability as in this study.

Regarding the study site acquisition, the Silvaboreal database worked generally well. However, there is uncertainty about the size of the forest sites. In most cases it is difficult to tell whether the extent of the forest is homogenous in the management strategy, therefore, homogeneity was assumed, that could have had an impact on the results. Moreover, the NPP dataset could have misclassified the land cover of some of the forest sites, as they were rather small, as well as had errors related to extensive cloud cover (Running & Zhao, 2021).

6 Conclusion

To conclude, the thesis hypothesis was rejected, as the continuous cover forestry and rotational forestry management strategies did not have a significant difference in their ecosystem productivity and trend. There were small positive trends in NPP 2001-2023 for both strategies, but they were not significant. This study has limitations in regards to possible errors of the used satellite-based NPP dataset, too short of a time span to study the long-term effects of both management strategies, and missing clearcutting phase of the RF management. As forests' multifunctionality increases when properly managed, more research is needed of both management strategies in order to maximize not only the economic benefits of forestry, but also forests' ecosystem services and biodiversity.

In the future, this study could be improved by including in situ flux tower NPP measurements, in order to compare with MODIS dataset values. Additionally, tree species could be taken into consideration, as well as doing a pairwise comparison of different management sites where tree species and age were the same, as done by Lundmark et al. (2016). Furthermore, a longer time span could be taken in order to see the long-term effects of both management strategies, preferably after clearcutting has taken place in an RF site at least once.

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