Are large clearcuts the only way to manage forests?

A study of economic performance and deadwood production of various silviculture systems

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Master's thesis • 30 credits
Swedish University of Agricultural Sciences, SLU
Southern Swedish Forest Research Centre
Skogsbruk med många mål
Alnarp 2023

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Credits:	30 credits
Level:	Second Cycle A2E
Course title:	Master thesis in Forest Science
Course code:	EX0985
Programme:	Skogsbruk med många mål
Course coordinating dept:	Southern Swedish Forest Research Centre
Place of publication:	Alnarp
Year of publication:	2023
Cover picture:	**C**learcut in Dalarna. Photo: Haidi Andersson
Illustrations:	All figures and tables are the work or the author unless stated.
Keywords:	CCF, continuous cover forestry, clearcut, biodiversity, RFM, even-aged forest, Net present value.

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Abstract

Our forests are a natural resource which is needed for many purposes. Their importance and different values are expressed in the Swedish legislation, where production and environmental goals are set as equal. To many it is not sufficient, there has been a debate regarding how forests are managed and the practice of clear-cutting for decades. Rotation forest management (RFM) is often set against continuous cover forestry (CCF).

Economy is not the only driver when it comes to forest management, but alternative regimes will not be used on a larger scale if they are not compatible with silviculture used today. This study aims to investigate if it is possible to apply a different management with the same or better financial result, and at the same time benefit biodiversity. Biodiversity was measured by the amount of deadwood and financial value with net present value (NPV).

Data from eight clearcuts exceeding 20 ha in size, six in northern and two in southern Sweden, were used to simulate one rotation in Heureka PlanWise DSS. The scenarios were rotation forest management (RFM), continuous cover forestry (CCF), leaving a part unmanaged in combination with RFM, fertilizing every ten years, a combination of CCF and RFM, fertilizing and CCF and dividing the site in three parts clearcutting the site with 10-year intervals.

The conclusion was that both CCF and intensive forestry had a higher NPV than RFM. The result varied with site index, tree composition and location in the country, with higher NPV for sites in northern Sweden with lower site index. The measured volume of deadwood was highest when leaving a third of the site unmanaged and two thirds with RFM for all sites except one in northern Sweden and came at a high cost with a much lower NPV for all sites.

The result shows that it is possible to manage our forests without taking up large clearcuts with the same, or even better, financial result. Depending on the property owners` goals one or several management regimes could be used resulting in a more varied landscape and at the same time benefit biodiversity and resilience in a changing climate.

Keywords: uneven-aged forestry, continuous cover forestry, CCF, clearcut, deadwood, RFM, even-aged forest, Net present value, Heureka.

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Abbreviations

CCF	Continuous cover forest
CGS	Chequered-Gap-Shelterwood-System
DSS	Decision support system
FSC	Forest Stewardship Council
NO	Nature conservation unmanaged
NPV	Net present value
NS	Nature conservation managed
PEFC	The Programme for the Endorsement of Forest Certification
RFM	Rotation forest management
SFA	Swedish Forest Agency
Swedish NFI	Swedish National Forest Inventory
UM	Unmanaged

1. Introduction

Forestry has played a significant role for the Swedish economy in the past century and has contributed to the welfare we now have (Brännlund, et al., 2010). Today the forest sector account for 9–12 % of the Swedish industry when it comes to occupation, export, and revenue (Föreningen Skogen, 2020).

There is an ongoing debate regarding how our forests are managed and the practice of clear-cutting. Some of its critics have been Zaremba (2012), Röstlund (2121) and in the documentary “Slaget om skogen” (2021). In debate articles (Samebyar, 2020; Muonio Sameby, 2021) the people of Sapmì have criticized the practice of large clear-cut areas and rotation forest management (RFM). They see clear-cut forestry as a threat to herding reindeers and their traditional way of life. The use of large clear-cuts and even-aged forests are set against other management regimes like continuous cover forest (CCF) or managing with single-tree selection. Hannerz, et al. (2017) found that the preference for CCF methods is based on people’s dislike for clearcut areas more so than to benefit biodiversity.

The forestry sector on the other hand has the failure of the dimensional loggings of the 20th and early 21st century in mind, which left damaged low productive forests in the north of Sweden as a result, when assessing CCF. There is also a concern that CCF will have a negative effect on the raw material supply, that the share of timber will increase, and pulpwood and biofuel decrease. Hannerz et al. (2017) states that if up to 10-20 % of the Swedish forests are managed with CCF it will have no or negligible effect on the overall raw material supply in the country.

The reasons to choose CCF as a management strategy could be to create a variation, for preservation or cultivation of natural and cultural values or for recreational purposes. It could also be a choice for a site where natural regeneration is more suitable (Appelqvist, et al., 2021). Economy is not the only driver when it comes to forest management, but the alternative regimes will not be used on a larger scale if they are not compatible with the regimes used today (Puettmann, et al., 2015).

Since research has primarily focused on RFM more knowledge and long-term trials with alternative methods is required to be able to compare different management regimes (Puettmann, et al., 2015; Mason & Kerr, 1999). The need for more information regarding CCF and readily available data from different trials is also highlighted by Mason, et al. (2022).

One way to compare different management regimes with current knowledge is using a forest decision Support System (DSS). Heureka forest DSS is developed as a tool for long term planning where different treatment models can be selected for the stand. Here growth, biodiversity and financial result can be assessed (Wikström, et al., 2011; Eggers & Öhman, 2020).

Figure 1. A 46,4-hectare clear-felled area in Dalarna.

1.1. Rotation Forest Management (RFM)

With RFM the stands are final felled in rotations with a clearcut larger than 0,25 ha as defined by the Swedish Forest Agency (SFA) (Appelqvist, et al., 2021). After a clear-cut, the stand is regenerated using planting, natural regeneration and seeding, tended to with cleaning and thinning creating a more or less even-aged forest (Heinonen, et al., 2020; Lundqvist, et al., 2014).

According to the Swedish National Forest Inventory (NFI) if a clearcut area exceeds 20 ha it is considered as a large clearcut. About 30% of the clearcuts in northern Sweden and 5% in southern Sweden qualifies into this category (Fridman & Kempe, 2012).

The average clearcut has the size of 4,3 ha, larger in the north of Sweden (6,9 ha) and smaller in the south (2,7 ha) (Anon., 2019).

1.2. Continuous Cover Forest (CCF)

Continuous Cover Forestry is a collective term for several different silvicultural systems that have the goal to manage with multiple objectives in common. A canopy cover is maintained during regeneration and the aim is to work without clear-felling. Natural regeneration is preferred with species suited for the site creating forest of mixed species. All forestry operations are performed considering diversity of the stand and site variations working with existing site limitations, not using fertilizer, herbicides, or scarification (Mason & Kerr, 1999).

To define silviculture systems without clearcutting and building a platform where different regimes can be discussed and reliable research produced the SFA, and the Swedish University of Agricultural Sciences (SLU) has together established a set of definitions. This group of management regimes has no clearings larger than 0,25 hectare on productive forest land and will not be managed with clearcutting over time. Other criteria are to always have trees higher than ten meters in height and a tree density in an area exceeding the minimum regeneration requirement for productive forestland according to the Forestry Act 5§, figure 2 (Appelqvist, et al., 2021).

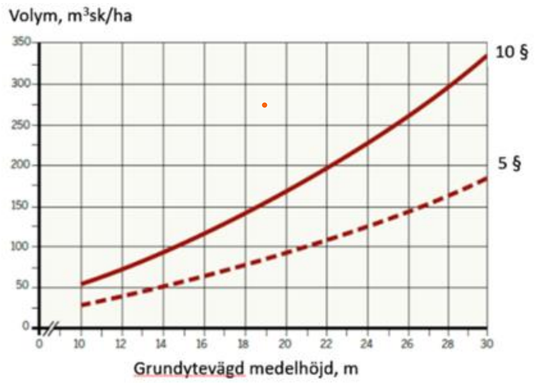

Figure 2. Lower limit for volume and basal area weighted mean height according to the Forestry Act 5§. (Appelqvist, et al., 2021).

An overstorey can be removed down to twenty-five stems per hectare when regeneration has reached the height of 2,5 meters, after it has reached ten meters all the overstorey can be removed. 2,5 meters of height in the regeneration is also the limit for a new gap to be taken up next to the previous (Appelqvist, et al., 2021).

Converting an even-aged forest into an uneven-aged stand managed with single tree selection, is a slow process that can take 100-150 years states Lundqvist, et al. (2014). These difficulties are also recognized by O´Hara, but he points out that an even-aged stand can also be a natural state due to lack of disturbances. Considering biodiversity, it might be sufficient with a two-aged or a less complex multilayer forest structure, this might give as much biodiversity as a fully multi-layered forest (O´Hara, 2001).

Laiho et al. (2011) on the other hand concludes that there are possibilities to start a CCF management in a birch or pine forest with understorey of spruce. They see that natural regeneration is not a problem in most forest.

Uneven-aged forestry is the management regime used for simulations in this study.

1.3. A selection of CCF methods

1.3.1. Uneven-aged forestry

This requires a forest with trees of all heights without any distinctions and fewer tall trees than smaller. A sufficient regeneration is more important than site index and moisture conditions (Appelqvist, et al., 2021). The treatments are with selective felling, which will result in an uneven-aged forest. This can be a management for all forests if they have trees of all heights and a large enough standing volume (Lundqvist, et al., 2014). It is suitable for stands consisting of Norway spruce (*Picea abies*) and European beech (*Fagus sylvatica*). For other tree species like Silver birch (*Betula pendula*) more light and larger clearings are required (Hannerz, et al., 2017) (Lundqvist, et al., 2014).

It takes 150-200 years for a tree in an uneven-aged stand to reach full grown state. Harvest could be with longer intervals (20-25 years) or shorter (5-10 years) depending on site index and standing volume. With the longer interval a larger volume per hectare can be harvested. This requires higher ingrowth of trees and there might be a higher risk for storm felling. The shorter interval has the negative effect with machines working in the forest more often with an increasing risk for root rot and soil compacting (Lundqvist, et al., 2014).

Chrimes (2004) concludes that with a lower number of stems per hectare the periods between harvest should be prolonged not to lose increment. The greatest growth is with a management harvesting larger trees leaving as many stems as possible in the stand.

1.3.2. The Lübeck model

In this regime the key is to work with a minimum maintenance giving room for natural development. The most important principles are that there are no clearings larger than 0,25 hectare, using only natural generation, at least 10 % retention trees and 10 % of the forest left unmanaged as a reference area. Thinning of damaged trees is allowed together with selective harvesting of trees when they have reached the set diameter goal (Appelqvist, et al., 2021).

1.3.3. Liberich

Liberich is a management regime where the goal is to maximize economic value for each tree or group of trees. If the natural regeneration is unsuccessful planting is allowed and there is no limit to the size of the clearings (Hagner, et al., 2001) (Johansson, 2020).

It is considered as a CCF management method even though the practice to take out trees on a financial basis can give larger clearcuts than 0,25 ha, since many trees in one location can reach the goal at the same time (Appelqvist, et al., 2021).

There is no research on this management regime but harvesting with a similar model has been done in a trial in the north of Sweden. The result shows a lower production than trials with uneven management (Lundqvist, et al., 2014).

1.3.4. Chequered-Gap-Shelterwood-System (CGS-system)

Clear felled gaps are taken up in an even aged stand creating a chessboard like pattern with a two layered forest. This regime keeps the forest feeling and helps hanging lichen to spread into the new stand for the reindeer to graze. It has been performed mainly in the north of Sweden and trials are young, the earliest from 2005, therefore few conclusions can be drawn (Goude, et al., 2022) (Borgstrand, 2014). So far there has been a sufficient regeneration in the clearings (Goude, et al., 2022).

1.4. Fertilizer in forestry

The standard use of fertilizing ten years before final felling with 150 kg N/ha is the most cost-efficient method for increasing tree growth on land with a site index lower than 30. Whereas sites with site index higher than 30 the increase in growth as a result of fertilization will be meagre. Increase in growth is higher in the north of Sweden than in the south but the differences are marginal and therefore fertilization in regions that are not recommended could give satisfactory results (Högberg, et al., 2014).
With nutrient optimization an amount of up to 800 to 1000 kg N/ha and rotation could be applied. Field trials indicate that fertilizing every second year, no thinning and short rotations is the most profitable management, this could reduce the rotation time down to 35-45 years in an area like Dalarna (Högberg, et al., 2014).

Nitrogen leaching poses a risk after fertilization, the risk increases when a stands ability to take up nitrogen is reduced. For example, after thinning, final felling, storm felling or in stands damaged by insects. Fertilization could also lead to a change in the ground vegetation favouring plants that need nitrogen and disfavour the existence of lichens (Högberg, et al., 2014).

1.5. Unmanaged forest

An unmanaged forest often has the highest volume production and the highest mortality (Lagerlöf, 2018).

A property owner certified in the Endorsement of Forest Certification (PEFC), or Forest Stewardship Council (FSC) system has to set-aside a minimum of 5% as either unmanaged (NO) or managed with social and biological values as a goal (NS) in their forestry plan. The certification entitles the property owner a premium upon selling timber. To promote biodiversity Södra Skogsägarna has introduced an extra premium to those who set aside areas larger than the required 5% (Södra, 2022). The highest compensation is for set asides exceeding 14 percent with a premium of 25 SEK/ m^3.

1.6. Economy

There is a high level of uncertainty associated with forestry due to several factors, the long timespan, unknown future prices and the risk of severe biotic and/or abiotic damages (Ekvall & Bostedt, 2009).

When comparing the economy between RFM and uneven-aged stands there are some parameters to be taken in account, the management costs, average tree volume and the total harvested volume. RFM comes with higher costs early in the rotation for scarification, planting, and cleaning than silviculture with single tree selection. On the other hand, harvesting has a higher cost per tree using selection felling than for RFM. The average volume of a harvested tree is 0,5-1 m^3sk in uneven-management and 0,2-0,4 m^3sk/ tree in RMF (Lundqvist, et al., 2014). Appelqvist. et al. (2021) found that production is lower with CCF compared to RFM, this, together with the higher costs for logging and transportation, results a higher financial result for RFM.

In general, studies show that the net present value (NPV) is lower for CCF methods than RFM. The variation in NPV depends on variables like imputed rate of interest, standing volume and time for first harvest. Comparing different studies, they conclude that the NPV is between 8 and 38% lower for CCF than RFM. The NPV in CCF was 90% of the NPV of RFM (Hannerz, et al., 2017; Wikström, 2000; Wikström, 2008). There are also studies showing a positive output for CCF in comparison to RFM. One of them is Hagner (2001) who calculated a 77% higher NPV for the Liberich forest management system. Also, Pukkala, Laiho, & Lähde (2011) finds that continuous cover forestry has a higher NPV than clearcutting. The reason could be the cost for regeneration in RFM, another difference is the thinning from below will generate a lower financial result than the thinning from above used in CCF in their models. Udd & Rowell (2013) has found a similar result.

When it comes to production and growth there are studies indicating lower growth with CCF and others that there is no difference in growth between CCF and RFM. The reasons can be a combination standing volume, soil fertility and standing volume left after a treatment (Wikström, 2008).

For a private forest owner economy is an important driver when managing their property with their own goals. They can use revenue to finance investments in machinery, regeneration, cleaning in stands or for repairing buildings. A profit could also be an income or a possibility to invest in other assets (Skogforsk, 2022). For small property owners a CCF regime could give a better cashflow with incomes every 10 to 15 years (Gyllin, 2015). When some forests are managed with CCF this will have negligible effect on a national economic point of view but using it on a large scale could have a significant impact. He also concludes that the net present value is not as important for a small forest owner compared to one with a larger property and if prise for overgrown trees increased it would benefit CCF as a management model.

1.6.1. Net Present Value

A model for comparing future incomes from different investment alternatives is Net Present Value (NPV). In this model the value of a future cost or income calculated using a discounted interest rate compatible with alternative investments.

In forestry the rate is usually set between 2 and 5 %, which is compatible with what an alternative secure investment would have and the risk a forest owner takes when investing in living trees (Udd & Rowell, 2013).
The inflation goal of 2% is set by the Central bank of Sweden. A net present value would preferably be higher.

1.7. Biodiversity

One way to measure biodiversity is with the amount of dead wood in a stand, about 25% of all forest living species are depending on it (Jonsson, et al., 2005).

These wood living species require different quality of dead wood, it could be the state of decay, dimension of the wood, or the tree species. The amount required vary, some need 50 m³ per hectare or more, others much less. In a report from the Swedish Environmental Protection Agency an estimated 20 m³ of deadwood per hectare spread out covering about 10-30 % of the forest landscape is needed to create habitats of high quality. These habitats should be located to areas where rare species have been found rather than increasing the mean average of dead wood in the landscape. To reach these goals voluntary means will not be enough, new means like economical compensation could be necessary (de Jong & Almstedt, 2005). The importance of dead wood in our forests is stressed by many studies and is one of the 15 environmental quality objects stated by the Swedish parliament (de Jong & Almstedt, 2005; Jonsson, et al., 2005).

Rotation forest management has resulted in changes in the landscape and effects on biodiversity. Clearcutting can change hydrology and can cause increased transportation of organic material from the site into lakes and rivers, and the scarification after the clear-cut has a negative effect on lichen and moss (Appelqvist, et al., 2021).

Figure 3. Marking for set-aside land in Dalarna.

Having a permanent canopy cover results in a more stable environment when it comes to temperature and moisture, benefitting moss and shade tolerant species. Species that have difficulties to spread and are depending on shade and moisture could benefit from the CCF management if it is spread out in the landscape (Karlsson & Weslien, 2006). Working without clearcuts gives mycorrhiza fungi a possibility to prevail and grow into the roots of the regenerating trees and hair lichens has a possibility to spread from larger, older trees. At the same time there are species that are light dependent and need large scale disturbances like the one of a fire. Another example is deciduous trees that are disfavoured with a CCF management without larger clearings (Appelqvist, et al., 2021; Pukkala, 2016).

Studies are showing that biodiversity does benefit from CCF, at the same time ground vegetation and pioneer tree species might not, it is all depending on how the forest is managed. CCF is not without higher risk for certain damages. These include root rot in a pine dominated uneven aged stands, and damages on the remaining trees and the regeneration when harvesting. With a changing climate risks and damages might change over time (Hannerz, et al., 2017).

2. The aim and questions

This is a quantitative study where different management regimes were compared with net present value and deadwood as factors. The aim is to sew if there is a possibility to get the same, or better, financial result using other methods than clearcutting areas exceeding twenty hectares.
The question asked are:

- Which scenario will result in the highest net present value (NPV)?
- Is there an alternative that will yield the same or a higher NPV than RFM?
- Can the amount of deadwood and economy both increase using an alternative management to RFM?

3. Material and method

3.1. Observed field data

To examine the possibilities of using alternative silviculture for a large clearcut area this study is based on field data from actual sites. Two of them in southern and six in northern Sweden with size ranging from 20,5 ha to 51,6 ha. Tree composition was calculated from inventory of sample plots. Site index was calculated by Heureka from the collected data, ranging from 18 to 24 for Scots pine, and Norway spruce had 30 and 24 respectively. Result can be found in table 1, maps showing the location of the clearcuts in figure 4 and 5.
Two of the sites had a bottom layer dominated by thinleaved grass, the others consisted of blueberry or lingonberry. When it came to bottom layer two were lichen-rich and the rest fresh moss type. All sites, except for two that were dry, was mesic or mesic-moist. With deep soils ranging from medium sand to coars silt.

Table 1. Data from inventory of the stands with location, tree composition, size in hectare, location, and calculated site index.

Stand Id	Calculated Site Index	Location	Spruce %	Pine %	Birch %	Other broad leaves %	Area (ha)
Dalarna1	G24	Rättvik	69	28	3		51,6
Dalarna 2	T20	Rättvik	38	60	2		38,2
Dalarna 3	T18	Rättvik	19	78	3		29,4
Dalarna 4	T20	Rättvik	12	86	1	1	25,8
Dalarna 5	T22	Furudal	6	93	1		46,4
Dalarna 6	T18	Älvdalen	8	88	3	1	33,8
Kalmar	T24	Eriksmåla	11	89			25,3
Osby	G30	Immeln	94	3	2	1	20,5

Figure 4. Map of Sweden showing the location of the sites in southern Sweden and Dalarna.

Kartdata ©2023 Google

Figure 5. Overview map of sites in Dalarna.

3.2. Data collection

Eight clear-cuts taken up after January 2019 were selected using data from the SFA (2021). The data was filtered by size exceeding 20 ha (Fridman & Kempe, 2012), sites with natural regeneration were dismissed just like sites that did not appear as large open clearcuts when examined with orthophoto maps (Skogsstyrelsen, u.d.). One clearcut was selected in Kalmar, one in Skåne and six in Dalarna. The sites in Dalarna were chosen by distances in between to make inventory work more time efficient.

A field inventory was conducted in September–October 2021. The inventory included determining the site index variables of the stands, soil texture, vegetation type, bottom layer, soil depth, soil moisture and lateral water, tree composition and number of trees within the sample plot.

Raster data for the clearcuts was downloaded from the SFA(2021) together with shape file maps from SLU (2021).

The number of sample plots were set to nine per ten hectare and randomly distributed over the clearcut area using the research tool “Random points inside polygon” in QGIS (Persson, 2021) (figure 6). Minimum distance between two sample plots was 20 meters. The plots had a radius of 7,98 meters, which responds to an area of 200 m² (Monrad Jensen & Malmqvist, 2019). Coordinates in SWEREF99TM and a Garmin Astro 320 (Persson, 2021)was used to navigate with a calibration time of 10 minutes upon reaching the plot centre.

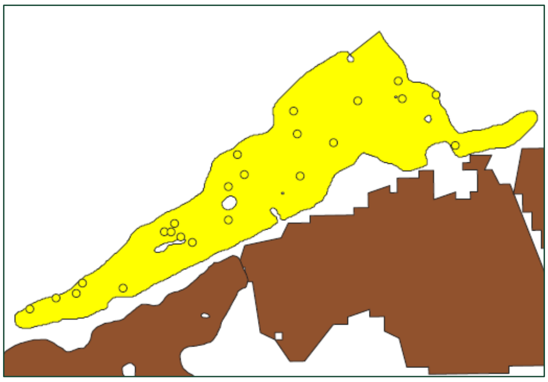

Figure 6. The sample plots marked as circles in the yellow area showing clearcut Dalarna 3.

Tree stumps were counted, and tree species classified. If a stump was on the outer line of the inventory circle, it was recorded if the germination point was within the sample plot circle. When a part of the sample plot was on the outer edge of the clearcut area half of the circular area was included in the inventory and the result doubled.

The site index parameters were defined by the recordings of the majority of the sample plots. Tree species composition of the stand was calculated from sample plot data and can be found in table 1.

3.3. Simulations

Heureka PlanWise version 2.20.0.0 (SLU, 2021) was used to simulate one rotation for the different scenarios. The model with the highest net present value per hectare was selected with the optimization tool from the twenty different options each simulation created. With the optimization tool linear and mixed-integer problems can be solved and the optimal management alternative is selected among all the results from a simulation (Wikström, et al., 2011).

The interest rate was set to 2,5%. Pricelists from Södra was used for the southern sites of Osby and Kalmar, for Dalarna the pricelist came from Mellanskog. For mixed treatments the NPV was calculated separately for each treatment and the NPV added up according to the proportion of each treatment and result can be found in figure 7.

The volume of standing and downed deadwood per hectare was added up for each management alternative and presented for the full rotation as can be seen in figure 8.

In PlanWise management scenarios are created with different Control Categories and link Control Tables to them. The treatment program generator has three different options to choose from: even-aged, uneven-aged, and unmanaged, this were used for the different scenarios. In the Treatment Model both cleaning and thinning was set to the values of the tree composition found in inventory for each site, this together with management specific settings can be found in table 3 and the performed treatments in table 2, all other settings were default.

Uneven-aged management in Heureka is performed as a thinning from above and the ingrowth is simulated as natural regeneration. These thinnings are by default set to a minimum of 20% and maximum 40% harvested volume and selection felling with at least twenty years in between. When calculating NPV for treatments the last treatment is calculated to be repeated in the future with the same interval as the two last treatments (Eggers & Öhman, 2020).

The thinning option Hugin, similar to SFA´s template, and has only one version for all of Sweden. It is calculating basal area as a function of site index and the tallest trees. There are several different fertilization options depending on the scenario and a choice between ammonium nitrate or urea (Eggers & Öhman, 2020).

When selecting fertilize treatment scenario the one with the highest NPV was selected: treatment with ammonium nitrate every ten years.

To set the parameters for harvesting with ten-year intervals the final felling period was set in the treatment program generator. The second felling was at the optimal time, which corresponds with the RMF alternative. To get a final felling ten years before the second felling, the felling period is set to min 0 and max between 2 and 4 depending on the site. To have a final felling ten years after the optimal time the maximum of the final felling period was set to minimum and maximum values that was tried out for each site.

Huereka models were initially developed for even aged conifer stands and has a higher accuracy for spruce and pine. Optimized fertilization is only calculated for pure spruce stands and was therefore not used. Due to the lack of data for CCF silviculture systems the simulations are less reliable and based on data for spruce in the uneven-aged alternative (SLU, 2021; Nordström, et al., 2013).

The scenarios that were compared in this thesis was RFM, CCF, unmanaged in combination with RFM, fertilizing every ten years, a combination CCF and RFM and fertilizing and CCF respectively, and finally dividing the site in three parts clearcutting with 10-year intervals (table 3).

Table 2. Description of .stands, management scenarios and the settings in Heureka PlanWise.

Stand id	RFM	CCF	Fertilized	10-year interval clearcut
Dalarna1	Three thinnings Final felling at 75	Three selection fellings	two thinnings Four fertilizations	Two thinnings for the earlier clearcut area otherwise Same as RFM
Dalarna 2	Two thinnings final felling at 85	Five selection fellings	Two thinnings five fertilizations	Same as RFM
Dalarna 3	One thinning final felling at 90	Two selection fellings	One thinning Four fertilizations	Last clearcut has two thinnings Same as RFM
Dalarna 4	Two thinnings final felling at 80	Cleaning three selection fellings	Two thinnings four fertilizations	Same as RFM
Dalarna 5	Two thinnings final felling at 85	Five selection fellings	Two thinnings four fertilizations and final felling at 80	Same as RFM
Dalarna 6	Two thinnings final felling at 90	Six selection fellings	Three thinnings five fertilizations	Same as RFM
Kalmar	Two thinnings final felling at 75	Three selection fellings	Two thinnings three fertilizations	Same as RFM
Osby	Two thinnings final felling at 70	Three selection fellings	Two thinnings three fertilizations	Same as RFM

Table 3. Management scenarios with settings in Heureka PlanWise.

Simulated management scenario	Abbreviation	Settings in Heureka
Rotation forest management	RFM	Even aged Leaving retention trees and high stumps
Continuous cover forestry	CCF	Uneven-aged Retention trees and high stumps disabled
Fertilizing	Fertilized	Fertilized with ammonium nitrate every 10years Extracting biofuel Retention trees and high stumps disabled
half of the area fertilized; half managed with continuous cover forestry	Fertilized/CCF	Settings as above
Half Continuous cover forestry/ half Rotation Forest management	CCF/RFM	Settings as above
A third Unmanaged/ two thirds Rotation Forest management	UM/RFM	Unmanaged/even aged settings as above for RFM
Clearcutting a third of the site with 10-year intervals		Settings as above for RFM. harvesting 10 years early and later is adjusted with Final felling min and max

4. Result

CCF and Intensive management both had higher NPV than RFM for all sites (Figure 7). The difference varied with sites index, tree composition and location in the country. Pine forest with lower site index in northern Sweden had the highest difference in NPV for CCF management.

Intensive forestry also had a higher net present value than RFM with a higher result for sites in northern Sweden than in southern. There is little difference in the financial result when clearcutting the forest in sections with ten-year intervals compared to the RFM scenario.

Data shows that leaving a larger area unmanaged comes with an excessive cost, resulting in a much lower NPV for all sites.

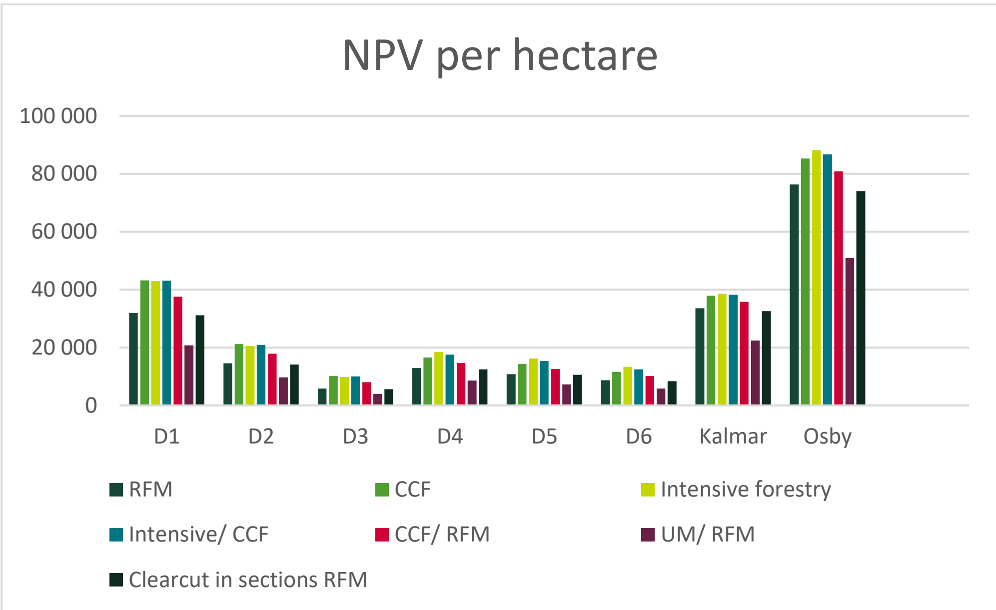

Figure 7. NPV/ha for each of the eight stands and the seven scenarios that were simulated: managing with RFM and CCF, intensive forestry with a fertilization every ten years, intensive management on half of the area and CCF for the remaining part. Managing half of the site with CCF and the other half with RFM, one third of the area unmanage and two thirds with RFM and clearcutting a third of the area with 10-year intervals.

The UM/RFM scenario has the highest amount of deadwood for all scenarios, except for Dalarna 3 where the fertilized option is showing a higher amount for the rotation. CCF has a higher amount in some scenarios than RFM and lower in other. None of the sites have less than 10 m³/ha. All sites, except Dalarna 3 and Dalarna 5, has an amount of deadwood exceeding 50 m³/ha in the unmanaged scenario.

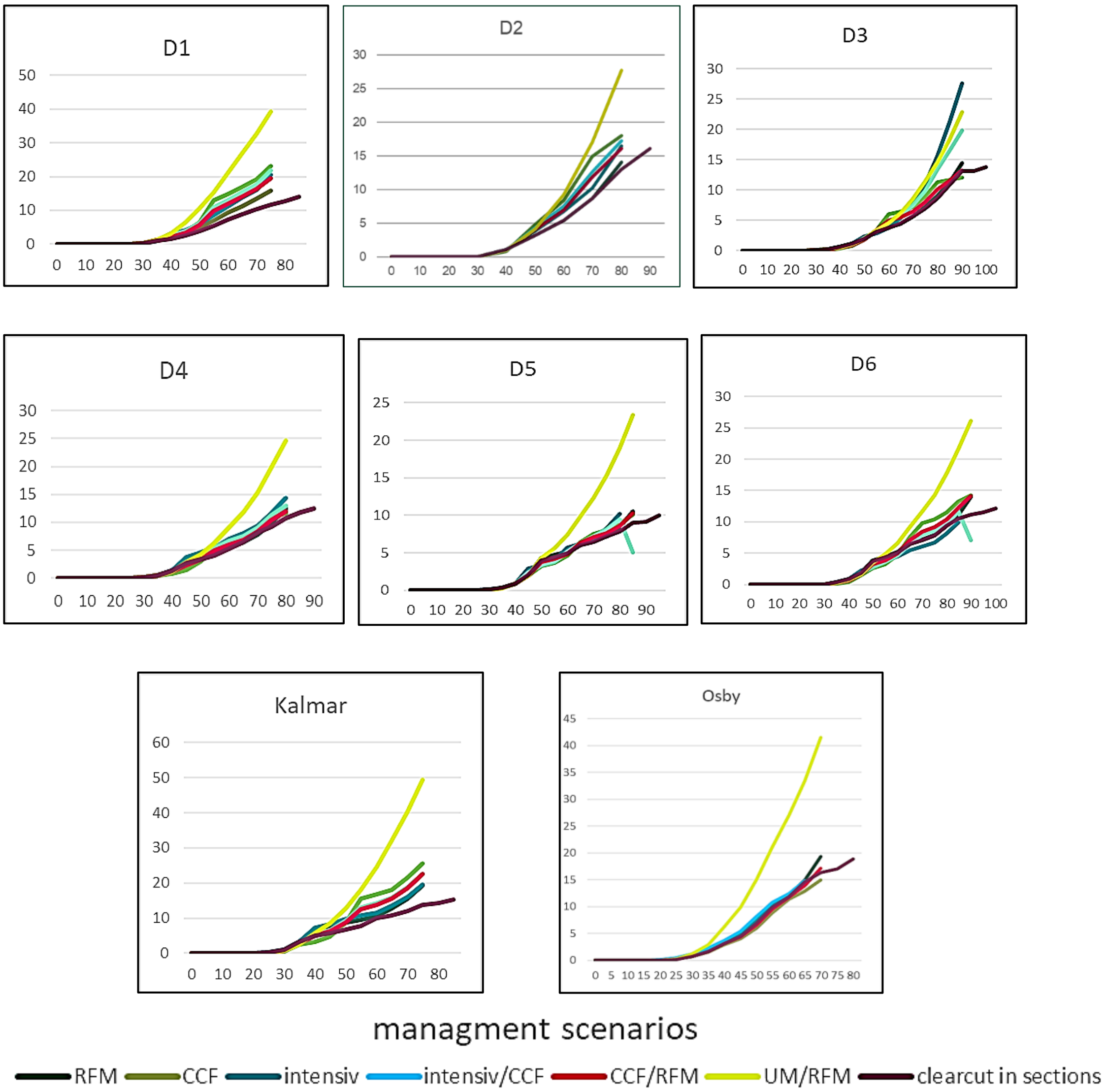

Figure 8. The amount of deadwood m3/ha during one rotation for each of the eight stands and the seven scenarios that were simulated: managing with RFM and CCF, intensive forestry with a fertilization every ten years, intensive management on half of the area and CCF for the remaining part. Managing half of the site with CCF and the other half with RFM, one third of the area unmanage and two thirds with RFM and clearcutting a third of the area with 10-year intervals.

5. Discussion

The selected sites all gave the visual impression of being exceptionally large clearcuts. At the same time the average clearing does not look like this, less than one fifth are larger than 20 ha and the average size is 4,3 ha.

Different CCF regimes are regarded by many as the only alternative to traditional forestry and is often set against RFM and was therefore compared. The result from this study shows a higher net present value for CCF than for RFM with a better financial result for sites in northern Sweden with lower site index than for fertile land in the southern part of the country. This is a conclusion contrary to what have been found in many studies (Wikström, 2008; Appelqvist, et al., 2021; Hannerz, et al., 2017). The result is probably due to the thinning from above in Heureka, with early harvests resulting in higher volumes and early revenue, which has a positive impact on NPV for CCF (Pukkala, et al., 2011; Udd & Rowell, 2013). That low costs early in the rotation and higher, earlier incomes has a positive effect when calculating NPV is recognized by Pukkala et al. and Udd & Rowell (2011; 2013) who found this to be a reason for CCF having a higher NPV than RFM in their studies.

To fertilize is a way to increase production and revenue. The selected fertilization treatment has the highest impact on NPV for sites in Dalarna with lower site index, lesser for sites in southern Sweden. This is in line with conclusion drawn by Högberg, et al. (2014) where a lower site index and sites in northern Sweden benefits the most.

An alternative to CCF could be to leave a part of the stand unmanaged. Certified landowners practice this with their set aside, usually with some form of treatment of the forest to preserve different values. Heureka only gives the option to leave the area unmanaged. This was, in combination with RFM, chosen to create areas in the landscape that are adding to biodiversity and variation. To combine UM and RFM results in a higher amount of deadwood at a high cost with the lowest NPV for all sites. Landowners' do set-aside more than the required five percent, but it might not be such a larger area of productive forestland as in this study. If the forest company Södra's compensation for set-asides is sufficient could depend on site index and forest composition of the set-aside (2022). An alternative could be to choose intensive forestry instead of RFM together with the unmanaged area to compensate for loss in production and net present value. Again, buffer zones are required and must be considered when calculating NPV.

Another way to create a more varied landscape is to divide the area in question into smaller parts that are clearcut with ten-year intervals. This scenario has little difference in NPV compared to RFM but could come with biotic and abiotic risks that might have been taken in account when clearcutting in the first place. The timespan of ten years might be too long in southern Sweden where rotations are shorter and not enough for a site with a slow growth in northern Sweden.

Measuring the amount of deadwood is one way to assess biodiversity. Dead wood in this study is analysed and measured in downed and standing dead wood, not specifying tree species, dimension, or state of decomposition. For all scenarios, except Dalarna 2, a combination of UM and RFM has the highest amount of deadwood per hectare and together with nine other scenarios has a higher amount than the requested 20 m^3/ha to sustain biodiversity in our forests (de Jong & Almstedt, 2005).

The amounts of deadwood differ in the scenarios, there are sites with higher amounts of deadwood in RFM than CCF, and some with the opposite result. Leaving retention trees and high stumps have been practiced in the RFM and not in CCF scenarios and could be a reason. Another reason could be site index, tree species and length of rotation for the stand.

Scenarios including RFM for a third or half the site still leaves a clearing larger than 10 hectares, unless the treatment is spread out. For Dalarna 1, 2 and 5 there are one or more scenarios that could generate clearcuts larger than 20 hectares depending on the layout of the treatment. To spread out the treatments might not be possible when combining fertilization with other silvicultural systems, due to the required buffer zones.

Forestry is a slow process and there are difficulties in changing from even aged forestry to continuous cover forestry (Lundqvist, et al., 2014). There are also those who give examples of the contrary, that a birch or pine forest with an understory of spruce or a two-layered forest that has been undisturbed for a long time could be qualified as CCF (Hannerz, et al., 2017; O´Hara, 2001; Laiho, et al., 2011).

A small property owner might prefer more regular incomes, and this can be supplied with CCF, a larger owner would probably calculate net present value (Gyllin, 2015). All forestry comes with risk, and so does CCF regimes, but with a variation in the landscape with different silviculture, tree species the risks might be lessened and our forest becoming more resilient in a changing climate.

5.2 Analysis of the method

All simulations are a general scenario for the full site, not taking in account the microclimate and local differences in the stand that could affect growth or the tree composition. The choice to include sites in south Sweden gives a spread in site index and tree composition. The result might have been clearer to compare if all sites were similar and in the same part of the country with the same tree composition.

Heureka is building models based on available research, which has mainly focused on even-aged stands of conifers. The simulations are in the form of uneven-aged management that is more suitable for shade tolerant species like spruce. With the majority of the sites having a pine dominance this gives an uncertainty in the result. The regeneration in CCF is calculated as ingrowth by Heureka but might not be as successful for all sites when tried out in field and the future possible harvestable volumes might not be supplied.

The simulation is linear which means that the predictions are assuming that the parameters will be the same over time. Changes in timber price or what products the market will request in the future are not taken in account. Neither are abiotic factors like droughts, storms and climate change, damage by biotic factors like insects or root rot.

With a forest management plan the simulations could have been more site specific and simulations could have more accurate for the site in question. This could have influenced the result.

The inventory method has its limitations when it comes to determining tree composition, this was apparent in the Dalarna 6 site where aspen was found in between the sample plots but not in any of them. They might have been included with a larger amount of sample plots. There is always a balance between the time spent collecting data and the result, even with more plots the aspens might not have picked up at all. It could also be that the broadleaf gets a greater share than it has by the way the sample plots are randomly laid out.

A forests potential cannot always be seen after it has been logged, therefore a further study could be to simulate data from a planned clearcutting. Simulations based on a forest management plan could have an even better prediction with more precise data and possibility to divide the site based on optimal local conditions.

5.3 Conclusion

The discussion on how to manage our forests is ongoing and the dislike for large clearcut areas will probably prevail. At the same time, our industries and our economy require the raw material.

The financial result for CCF in this study shows a higher NPV for all sites than the RFM scenarios, with a better outcome for sites with a lower site index in the north of Sweden. When it comes to biodiversity the highest values are for sites whit a larger unmanaged set-aside, which will come with a substantial cost.

All forestry models have their advantages and disadvantages that must been weight against each other. Depending on the size of the property, cultural values, site index, location, and the owner's own goals one or several different management regimes could be used. If there is a variation in management regimes this will in turn create a variation in the landscape and add to biodiversity and resilience in a changing climate.

Current knowledge in alternative regimes is low and there is a need for more reliable data from research and long-term field trials when it comes to alternative management regimes. With more research in other silviculture systems more reliable data could be supplied for regimes like CCF.

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Acknowledgements

To my mother who told me that they can take everything away from you, but your education and your skills.

I would also like to thank my supervisor Narayanan Subramanian for support, good advice, and patience in my process of writing this thesis. Working on a master thesis has its ups and downs and I am so grateful for all my friends that have given moral support and believing in my ability.

7. Appendix

Appendix 1. Net present value per hectare and scenario.

Stand Id	RFM	CCF	Intensive forestry	Intensive/ CCF	CCF/ RFM	UM/ RFM	Clearcut in sections
D1	31 908	43 158	42 968	43 063	37 533	20 772	15 295
D2	14 502	21 156	20566	20 861	17 829	9 668	14 075
D3	5835	10 157	9 789	9 973	7996	3890	5612
D4	12 874	16 490	18 462	17 476	14 682	8 583	12 419
D5	10 825	14 339	16 215	15 277	12 582	7 217	10 515
D6	8 633	11 597	13 292	12 444	10 115	5755	8337
Kalmar	33 579	37 886	38 483	38 184	35 732	22 386	32 530
Osby	76 374	85 266	88 190	86 728	80 820	50 916	74 028

Appendix 2. Deadwood m³ per hectare and treatment scenario.

Stand Id	RFM	CCF	Intensive forestry	Intensive/ CCF	CCF/ RFM	UM/ RFM	Clearcut in sections
D1	15,95	23,21	20,43	21,82	19,58	39,26	16,95
D2	18,75	20,67	22,18	21,42	19,71	34,52	19,35
D3	14,48	12,07	27,61	16,14	13,28	18,24	13,94
D4	12,38	11,67	14,35	13,01	12,02	24,68	13,27
D5	10,56	10,11	16,43	13,27	10,34	20,42	10,95
D6	14	14,26	9,97	12,12	14,13	26,14	14,52
Kalmar	14,2	22	15,92	18,96	18,1	31,18	12,56
Osby	19,33	14,95	14,74	14,77	17,84	36,39	21,61

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