Bilberry cover and its relationship to silvicultural strategies

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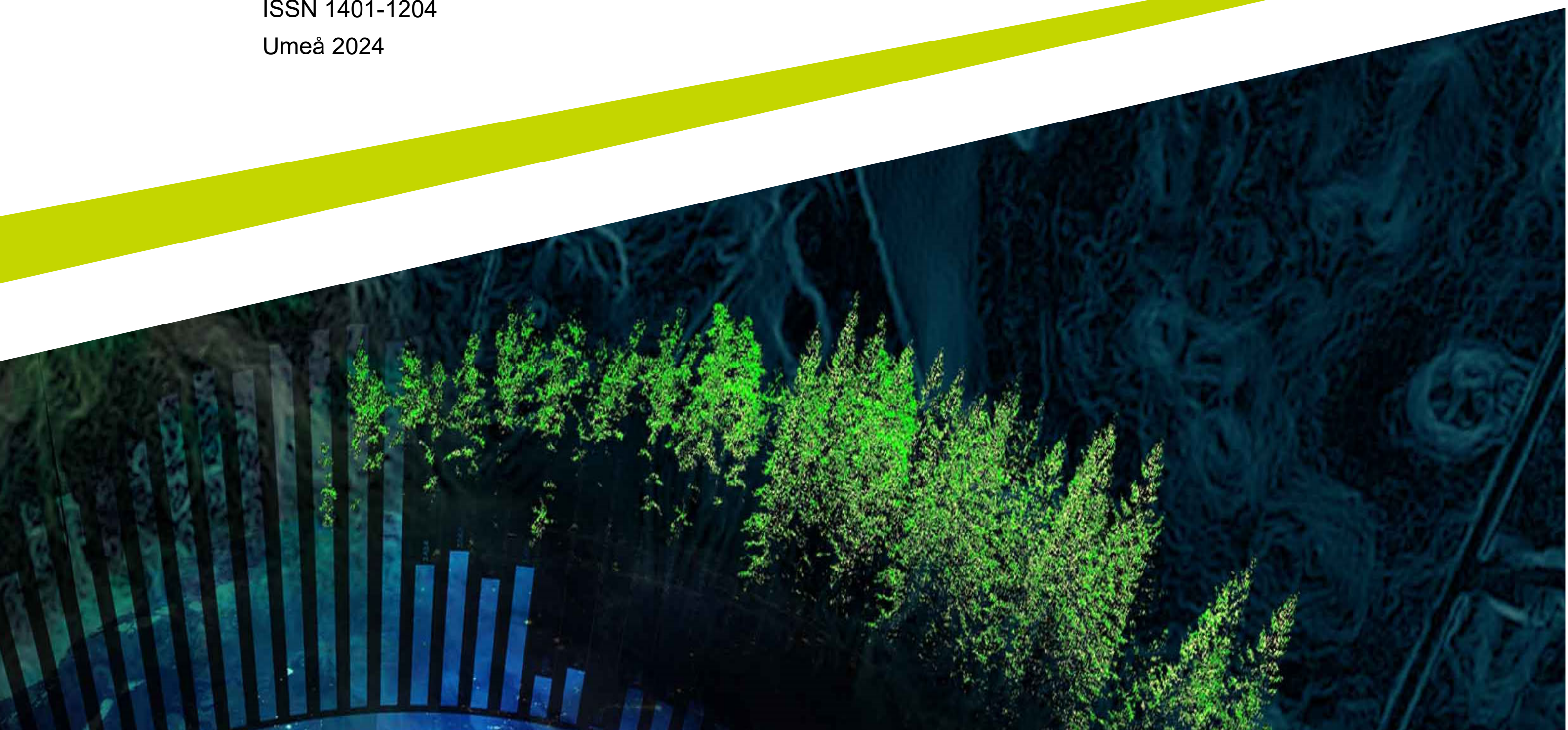

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Abstract

This thesis explores the interplay between silvicultural strategies and bilberry (*Vaccinium myrtillus*) cover in Sweden's boreal forests. Bilberries hold significant ecological, cultural, and economic value, serving as a habitat, a traditional food source, and contributing to rural economies. Forestry practices impact bilberry cover, which this study examines through simulation and optimization in the Heureka Forestry Decision Support System. Data from the Swedish National Forest Inventory and targeted forest characteristics from Västerbotten and Kronoberg counties provide the empirical basis for this analysis. The study investigates various management strategies, including clear-cutting, continuous cover forestry, extended rotation, and their effects on bilberry cover and forest economic outputs. The results reveal a trade-off between maximizing net present value (NPV) and bilberry cover, with strategies integrating diverse practices offering a compromise. This study highlights the need for multi-objective forest management that accommodates the ecological significance of bilberries while considering economic returns from timber production. The findings advocate for forestry guidelines that include bilberry cover optimization, emphasizing the role of decision support systems in sustainable forest management.

Keywords: Bilberry Cover, Ecosystem Services, Boreal Forests, Management Optimization, Heureka Forestry Decision Support System

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Abbreviations

BR	Broadleaf Retention
CCF	Continuous Cover Forestry
CC	Clear-Cuts
ERP	Extended Rotation Period
FD	Free Development
KRO	Kronoberg
MAXBIL	Maximizing Bilberry Cover
MAXNPV	Maximizing Net Present Value
NFI	National Forest Inventory
NPV	Net Present Value
UT	Unthinned Treatments
VB	Västerbotten

1. Introduction

1.1 Bilberry in boreal forests

Bilberry (*Vaccinium myrtillus*), a native species to northern Europe, is of considerable ecological, social, cultural, and economic importance. Ecologically, bilberry shrubs provide critical habitat and food resources for a range of species. The dense foliage offers shelter and nesting sites, while the berries nourish various birds and mammals. Bilberry serves as an indicator species for forest health, reflecting the biodiversity of an ecosystem. It supports pollinators, contributes to nutrient cycling, and is integral to the food web, impacting forest regeneration and dynamics (Kurttila et al., 2017).

Figure 1: Pine forest with bilberry shrubs (Rönnbro 2023)

In a social context, bilberry picking is a recreational activity that promotes well-being and community engagement. It is a tradition that connects generations and fosters a deep appreciation for nature (Saastamoinen et al., 2013). Culturally, bilberries have a storied place in the traditional medicine of Scandinavia. Their use dates back centuries, with bilberry leaf teas and extracts historically utilized as folk remedies for diabetes and other ailments. Helmstädter and Schuster (2010) delve into the medicinal history of *Vaccinium myrtillus*, particularly its antidiabetic properties. Furthermore, recent reviews, such as the one by Vaneková and Rollinger (2022), provide an overview of bilberry's bioactive constituents and their clinical applications, reaffirming the berry's role in traditional and contemporary health practices.

Economically, bilberries have significant value in countries like Sweden and Finland. They contribute to export earnings and rural economies through trade. In Finland, the wild berry yield has considerable economic importance, reflected in the national economy through commercial activities and small-scale food processing (Turtiainen & Nuutinen, 2011; Saastamoinen et al., 2000; Mäkelä & Rautavirta, 2018). The economic impact of bilberries is also seen in the integration of bilberry yields into forest management, highlighting the benefits of multi-objective forest management (Kilpeläinen et al., 2018). These aspects collectively illustrate the multifaceted value of bilberries, demonstrating their significance not just as a species within forest ecosystems, but also as a contributor to human culture, economy, and social traditions.

1.2 Impact of forestry on bilberry cover

The intricate relationship between forestry practices and bilberry (*Vaccinium myrtillus*) cover is a subject of extensive research, with studies highlighting the nuanced effects of various environmental and silvicultural factors. This comprehensive literature review synthesizes findings from eight pivotal studies to elucidate the multifaceted influences on bilberry populations within forest ecosystems, and also incorporates historical data on bilberry cover trends.

Clear-cutting's impact on bilberry is complex and time-sensitive. Nybakken et al. (2013) found that clear-cutting can initially boost bilberry growth due to increased light availability, potentially enhancing phenolic content, which is crucial for the plant's defense mechanisms and nutritional value (Nybakken, L., et al., 2013). However, Atlegrim and Sjöberg (1996) observed that clear-cutting adversely affects bilberry's vegetative growth and ground cover in the long term, especially when compared to selective felling (Atlegrim, O., & Sjöberg, K., 1996). This suggests that the benefits of clear-cutting may be short-lived, and the practice could be detrimental to bilberry populations if not managed with subsequent recovery strategies.

The density and composition of forest stands are critical determinants of bilberry habitat quality. Eldegard et al. (2019) demonstrated that bilberry cover is influenced by stand density, which interacts with stand age, solar irradiation, and tree species composition to create a complex habitat mosaic (Eldegard, K., et al., 2019). Ihalainen et al. (2005) underscored the importance of these stand characteristics in their regional expert models, which predict bilberry yields and highlight the need for tailored forest management to withhold and increase bilberry populations.

However, the relationship between stand age and bilberry cover is not linear, as Eldegard et al. (2019) noted that both very young and older stands can provide favorable conditions for bilberry, depending on the interplay with other factors such as light availability and species composition (Eldegard, K., et al., 2019).

The type of site is a significant predictor of bilberry cover. Miina et al. (2009) found that mesic heath sites typically support higher bilberry cover, with soil type and moisture levels being critical for bilberry growth. This indicates that site-specific conditions must be considered in forest management to optimize bilberry habitats (Miina, J., et al., 2009).

Temperature and altitude have been shown to influence bilberry distribution. While Miina et al. (2009) reported that temperature sum was not a significant predictor of bilberry cover, altitude had a positive effect, suggesting that cooler conditions at higher elevations may be beneficial for bilberry growth (Miina, J., et al., 2009).

Selective harvesting and less intensive logging practices are more conducive to bilberry conservation than clear-cutting. Hedwall and Brunet (2013) highlighted the importance of maintaining a diverse forest structure to support the abundance of keystone species like bilberry, which are integral to forest floor biodiversity (Hedwall, P.-O., & Brunet, J., 2013).

The yield and cover of bilberry are closely related, and studies such as those by Miina et al. (2021) have utilized national forest inventories to assess these parameters, providing valuable data for forest management and conservation strategies (Miina, J., et al., 2021).

Nielsen, Totland & Ohlson (2007) explored the effects of various forest management operations on the conditions for bilberry and lingonberry, contributing to the understanding of how different practices can impact understory vegetation. Their findings suggest that management practices need to be carefully planned to mitigate negative impacts on bilberry populations (Nielsen, A., et al., 2007).

Historical data indicates that bilberry cover has experienced a significant downward trend (figure 2), with notable regional differences (Nilsson et al., 2023). Recent trends suggest a break in this decline, with cover now fluctuating. Notably, cover in Norrland has consistently been higher, almost double the value of that in Götaland. This disparity could be attributed to the difference in tree species composition, with Scots pine (*Pinus sylvestris*) having a higher proportion in Norrland, a species that has been indicated as being more favorable for bilberry cover (Miina et al., 2009). However, another study (Jonsson et al., 2021) partially disagrees with this optimistic view, reporting a continuous decrease in bilberry cover in Swedish boreal forests, influenced by factors such as increased stand basal area and usage of Norway spruce. These findings underscore the complexity of bilberry dynamics, suggesting that while some areas may see fluctuations or even increases in cover, the general trend in certain regions points to a decline, emphasizing the need for region-specific management strategies to address these divergent trends.

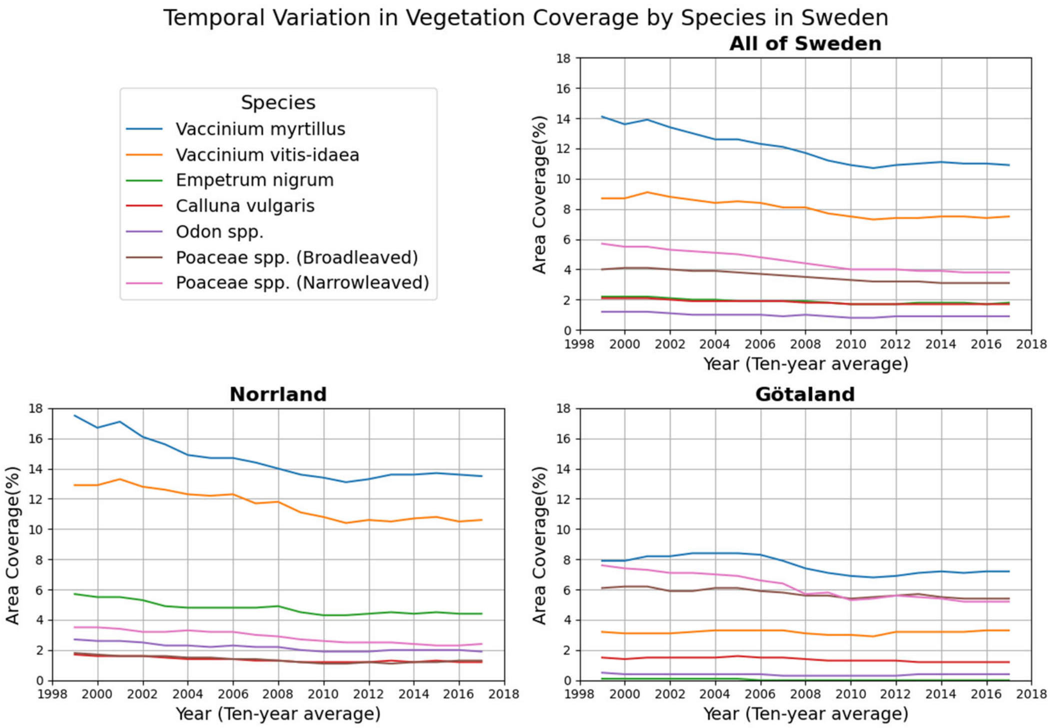

Figure 2 Field layer vegetation cover *of various species (NFI, 2023)*

In conclusion, the literature presents a complex and sometimes contradictory picture of the factors influencing bilberry (*Vaccinium myrtillus*) cover in forest ecosystems. While bilberries serve as a cornerstone of forest biodiversity and represent an important non-timber forest product, the optimal conditions for their cover involve a delicate balance of light availability, stand density, species composition, site type, and forestry practices. These factors must be carefully managed through sustainable forestry practices, tailored to local conditions, and informed by comprehensive research, to promote robust bilberry populations and enhance their cover within forest ecosystems. However, despite the extensive research, key questions remain unanswered, prompting this study to investigate:

How do management strategies affect bilberry cover in Sweden?

What are the effects of maximizing forest management activities on net present value (NPV) and bilberry cover?

What are the implications of these strategies for forestry elements such as harvested volume, basal area, age, final felling age?

Investigating and analyzing these questions will help us better understand the delicate balance required to sustainably manage Sweden's forests.

1.3 Ecosystem services and forestry decision support systems

Forestry decision support systems (DSS) in Sweden and Finland are integral tools designed to facilitate sustainable forest management by providing data-driven insights and predictive analytics for a range of forest management scenarios (Lämås et al 2023, Miina et al 2021). These systems incorporate complex simulation models that utilize data from national forest inventories, targeted inventories and field trials from research parks, to forecast forest growth and development, taking into account a multitude of factors including tree and stand characteristics, climatic conditions, and potential pest and disease impacts.

In Sweden, the Heureka system exemplifies the application of empirical growth models grounded in extensive data from the Swedish National Forest Inventory (NFI). These models, leveraging tree and stand characteristics such as age, species, diameter, and height, are foundational to the system's predictive capabilities (Elfving & Nyström, 2010). Calibrated against long-term thinning experiments, the models assure accuracy and reliability in projecting forest growth.

The Heureka system's simulation models are used by various stakeholders e.g. small-scale owner, forestry companies, researchers and the national forestry agency (Lämås et al 2023). An example of application, is to simulate forest growth over time, integrating factors such as climate, pests, and diseases, thus enabling predictions of the long-term effects of various silvicultural treatments and harvesting strategies. Furthermore, the Heureka system is augmented by various add-ons, notably an economy module which introduces economic considerations into the decision-making process. This module evaluates financial implications, incorporating variables like timber prices, production costs, and discount rates to offer a comprehensive view of the economic sustainability of forest management strategies. One of the major functions of Heureka is located in the Planwise program where one or several variables can be combined and optimized.

Recently, in 2023, the Heureka system was enhanced with the introduction of a first bilberry cover model, adding a new dimension to its biodiversity forecasting tools (Bohlin, 2023). This is based on the general linear mixed model that uses a range of input variables to predict bilberry cover. Predictive variables include field layer vegetation type, soil humidity class, temperature sum, site index, stand age, basal area, and temporal information about thinning (appendix 3). The model offers differentiated predictions for Norway spruce (*Picea abies*) and Scots pine site types (*Pinus sylvestris*), with stand age, basal area, and thinning intervals being the manipulable variables to predict bilberry cover outcomes.

In Finland, bilberry cover models have been a part of forest DSS for some time, supporting multi-objective forest management. The Finnish models for bilberry yields are designed to locate the best berry stands and have been linked into forest simulators that optimize the joint production of timber and berries. These models, while effective, require calibration to ensure precision when applied within the DSS (Kilpeläinen et al., 2016; Peura et al., 2016).

2. Methodology

2.1 Analytical framework

To examine the effects of silvicultural strategies on bilberry (*Vaccinium myrtillus*) cover, in Southern and Northern Sweden, the research undertaken in this study utilizes a robust analytical framework, integrating empirical data derived from extensive forest inventory, simulation and optimization methodologies within the Heureka decision support system. The foundation of the analysis rests upon data obtained from the Swedish National Forest Inventory (NFI), which provides comprehensive insights into the forest stands' current states, including species composition, age distribution, and timber volume. This empirical foundation is then processed through the Heureka system, employing advanced simulation techniques to project the future states of the forests under varying management strategies. These projections enable a nuanced exploration of the long-term impacts of silvicultural decisions on bilberry cover. Optimization algorithms within Heureka further refine the analysis by identifying the combination of management practices that maximize either net present value (NPV) or bilberry cover, thus facilitating an informed assessment of trade-offs and synergies between economic objectives and ecosystem services. By integrating rigorous inventory data with sophisticated simulation and optimization tools, the study provides a comprehensive understanding of how different forest management strategies can influence bilberry cover, thereby offering valuable insights for forestry stakeholders in both Southern and Northern Sweden.

2.2 Geographical regions and forest characteristics

The research was conducted in two distinct areas representative for Sweden, Västerbotten and Kronoberg. These counties, together, span all five vegetation zones (figure 3, Roberge 2018). Data from years 2017 and 2018 National Forest Inventory (NFI) plots was used to represent the forests (Roberge et al 2023). The areas only included productive forest, of which Västerbotten had 3,160,956 hectares and Kronoberg 649,133 hectares (appendix 1-2).

In examining the forest characteristics of Västerbotten and Kronoberg, the data reveals distinct profiles for each region. Västerbotten presents a higher mean age of stands of 69.3 years and a greater total volume of wood at approximately 361 million m^3, indicative of a more mature forest structure. The volume distribution across age classes suggests a prevalence of older trees, with substantial volumes in the 81-100- and 101-120-year age classes (figure 4). Contrastingly, Kronoberg, with a lower mean age of 41.5 years, demonstrates a forest composition skewed towards younger age classes, as evidenced by significant volumes in the 21-40- and 41-60-year age classes, and a total volume of about 94 million m^3. The site index (figure 5), representing forest productivity, is notably higher in Kronoberg (mean 'Bonitet' of 9.27 m^3/ha) compared to Västerbotten (mean forest productivity of 3.36 m^3/ha), suggesting a potential for faster growth rates and shorter rotation times in Kronoberg's forests. These differences are critical to consider when formulating silvicultural strategies and predicting their impacts on understorey vegetation like bilberry.

In Västerbotten, pine is the predominant species across all age classes, with its volume peaking in the 61-80 years category. Spruce follows, with a significant presence in the middle age classes (41-80 years), while birch appears more evenly distributed but less voluminous than the conifers. The category for 'Other broadleaves' is minimal, indicating their limited role in the forest composition of this region. The 'Other conifers' category shows a slight increase in older age classes, suggesting a minor contribution to the forest's overall maturity.

Kronoberg's forests have a different composition; while spruce remains dominant, especially in the 41-60 years age class, pine has a more pronounced volume in the younger age classes (21-40 years) compared to Västerbotten. Birch has a consistent but smaller volume across age classes, and 'Other broadleaves' have a slightly more notable presence here than in Västerbotten, especially in the middle age classes. The 'Other conifers' category is almost negligible.

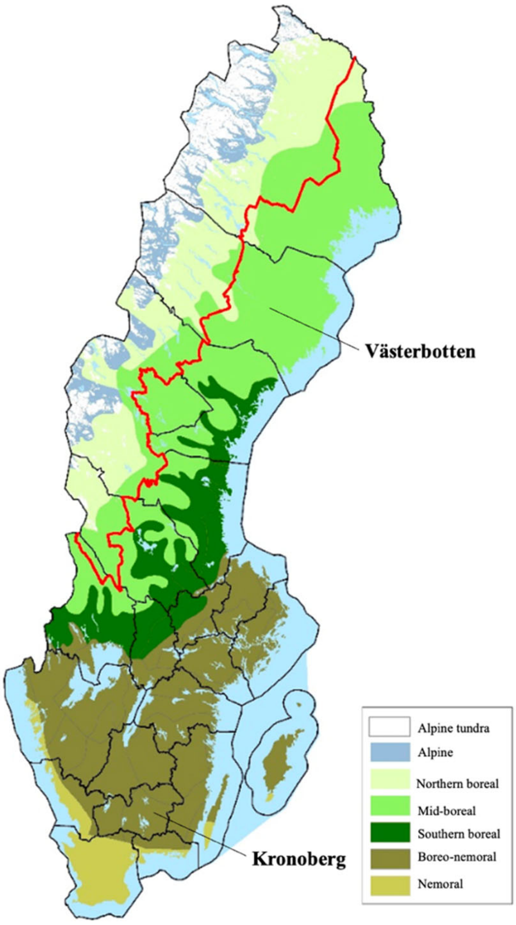

Figure 3: Counties and Types of vegetation regions in Sweden, adapted from Swedish Forest Agency map (Roberge, p.17, 2018).

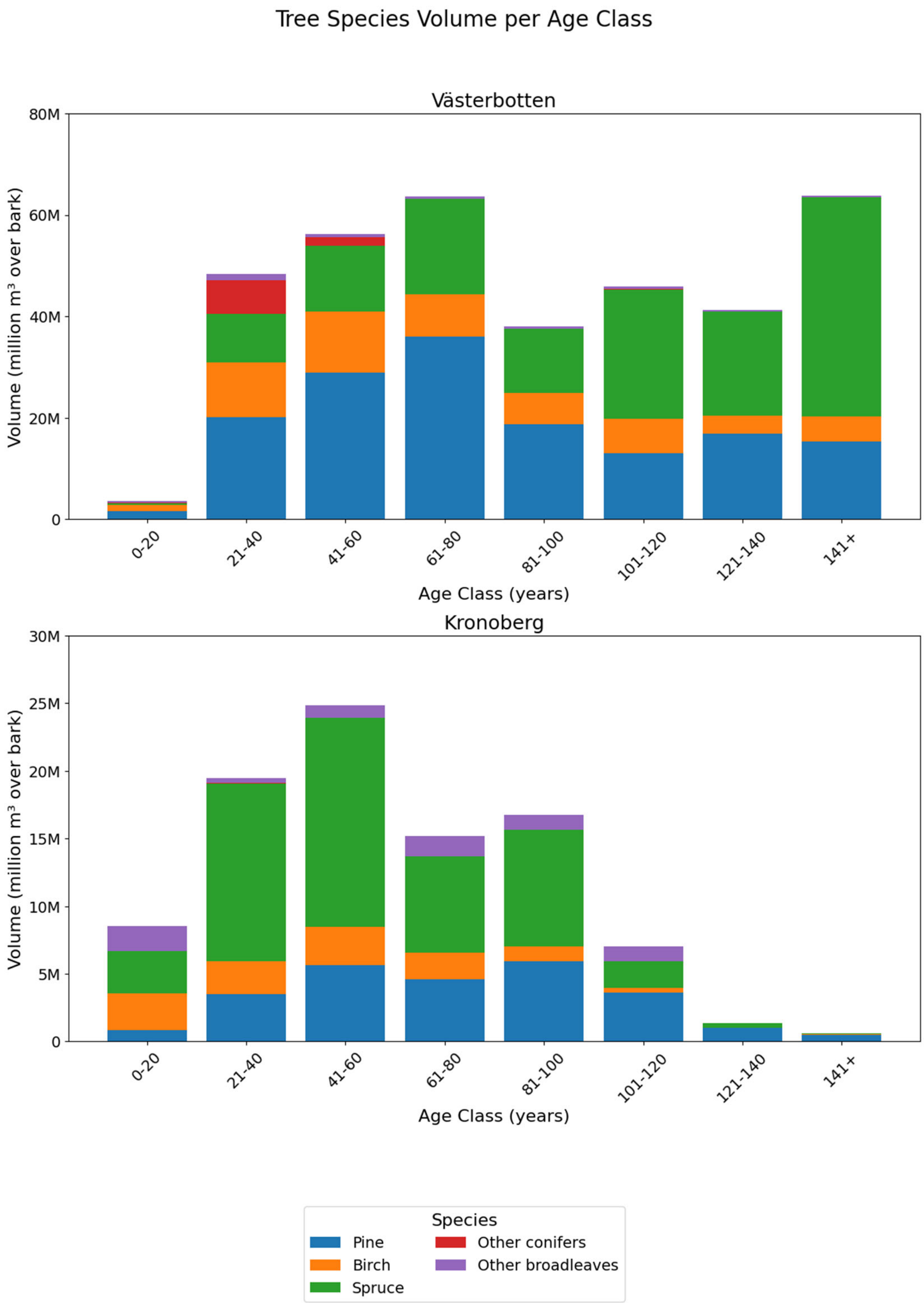

Figure 4: Tree species distribution for different age classes of productive forests in Västerbotten and Kronoberg.

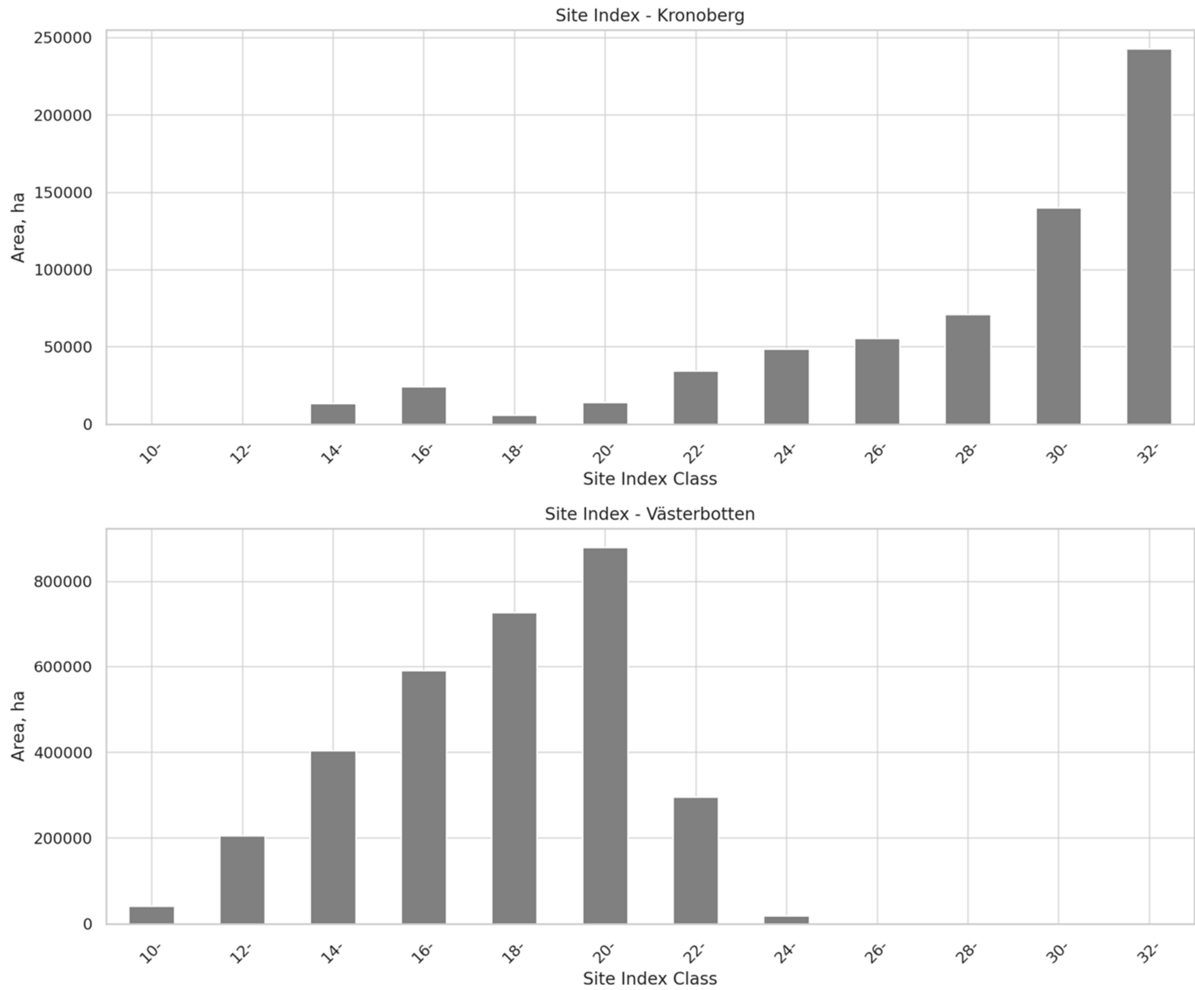

Figure 5: Site index distribution of Västerbotten and Kronoberg counties.

2.3 Indicators

The indicators for this study (table 1) were selected to analyze the relationships between a range of ecosystem services and bilberry cover within forest simulations. NPV, harvested volume, mean age, and final felling age are critical as they reflect economic and ecological aspects of forest management, and their importance is affirmed by previous research, highlighting their role in balancing timber production with non-timber benefits (Kilpeläinen et al., 2018; Gamfeldt et al., 2013; Miina et al., 2020). Additionally, these indicators are vital for the bilberry cover model, an aspect explored in the recent work by Felton et al. (2023), which discusses the trade-offs and synergies in biodiversity and ecosystem services delivery in Northern European production forests. Finally, age and basal area were incorporated due to their direct influence on bilberry habitats (Bohlin 2023) as shown in the bilberry model (figure 8).

Table 1: Indicators and their definitions studied in the simulations.

Indicator	Definition	Unit
NPV per ha	Net Present Value per hectare	SEK/ha
Mean Age	The average age of trees in a stand	years
Average Final Felling Age	The average age at which trees are harvested in final felling	years
Bilberry Cover	The ground area covered by bilberry plants	% cover
Total m3 under bark Volume	Total cubic meters of wood under bark volume harvested	m3 under bark
Basal Area	The sum of all cross-sectional areas of tree trunks at breast height (1.3 m)	m2/ha

2.4 Management strategies, optimization and modelling for bilberry cover

The management strategies mimicking applied forestry-practices in Scandinavia (table 2), were based on a previous optimization study (Eggers et al, 2022). The clear-cut (CC) strategy involved clear cuts as well as planting with soil scarification and maintained a 20% broadleaf composition after cleaning and thinning, with a delayed final felling of up to 30 years. Continuous Cover Forestry (CCF) emphasized natural regeneration, avoiding soil scarification and cleaning, but ensuring at least 50% broadleaf retention during thinning. The Extended Rotation Period (ERP) strategy melded planting and natural regeneration techniques, extending rotation times significantly. Unthinned treatments (UT) focused on planting without subsequent thinning, while the Broadleaf Retention (BR) strategy aimed to boost broadleaf presence significantly after cleaning and thinning procedures. Lastly, the free development strategy allowed the forest to mature without intervention, representing a hands-off management approach (FD). Each strategy was tailored to simulate realistic silvicultural outcomes, ranging from intensive wood production to conservation-oriented practices, thereby enabling a comprehensive analysis of their effects on the forest ecosystem and bilberry habitat.

Table 2: Management strategies

Management practices	CC	CCF	ERP	UT	BR	FD
Regeneration method	Planting	Natural	Spruce; planting Pine; natural, seed trees retained	Planting	Spruce;planting Pine; natural	-
Soil scarification	Yes	-	Yes	Yes	Yes	-
Broadleaf after cleaning	20%	-	20%	20%	40%	-
Broadleaf after thinning	20%	50%	20%	-	40%	-
Delay in final felling after minimal felling age	Max 30 years	-	35-60 years	Max 30 years	25-50 years	-
Number of single retention trees per ha	10	10	20	10	20	-
Number of high stumps per ha	3	-	6	3	6	-

In the assessment of forest management strategies on bilberry cover and forest economics, a two-step optimization process (figure 6) was applied to two distinct regions, Västerbotten and Kronoberg. The first step involved generating treatment schedules for each NFI plot, which were then simulated over a 100-year planning period with intervals of 5 years. The actions of the treatment schedules are defined by the management strategies. A treatment schedule includes a series of silvicultural prescriptions e.g. planting, cleaning, thinning and final felling. The simulations yielded a varying number of treatment schedules depending on the management strategies. There were up to 46 treatment schedules when all strategies were combined and fewer for individual strategies, like one for the FD strategy. Following this, the second step entailed creating optimization problems which were formulated and solved with Heureka's optimisation module. The optimization module utlizies linear programming to maximize or minimize user-defined objectives such as NPV or bilberry cover, within set constraints e.g. harvesting levels. This leads to an optimal combination of treatment schedules for all NFI plots to meet to meet one of two objectives: maximizing either the net present value further referred to as "MAXNPV", or bilberry cover, further referred to as "MAXBIL".

The optimizations were conducted for the collective impact of all management strategies, further referred to as "ALL", as well as separately for each strategy to identify their specific effects on the objectives. A total of 28 optimization exercises were conducted, with each of the seven management strategies in both Västerbotten and Kronoberg counties undergoing two separate optimizations: one aimed at maximizing net present value (MAXNPV) and the other at maximizing bilberry cover (MAXBIL), resulting in 14 optimizations for each county. The results were then organized in Excel (Excel, 2023) and analyzed using Python (Python, 2023). The outcomes, illustrated in diagrams and tables, highlighted the effectiveness of strategies or combinations thereof to achieve MAXBIL or MAXNPV. This two-step process allowed for a detailed comparison of economic and bilberry outcomes across the different geographic and ecological settings of the two counties.

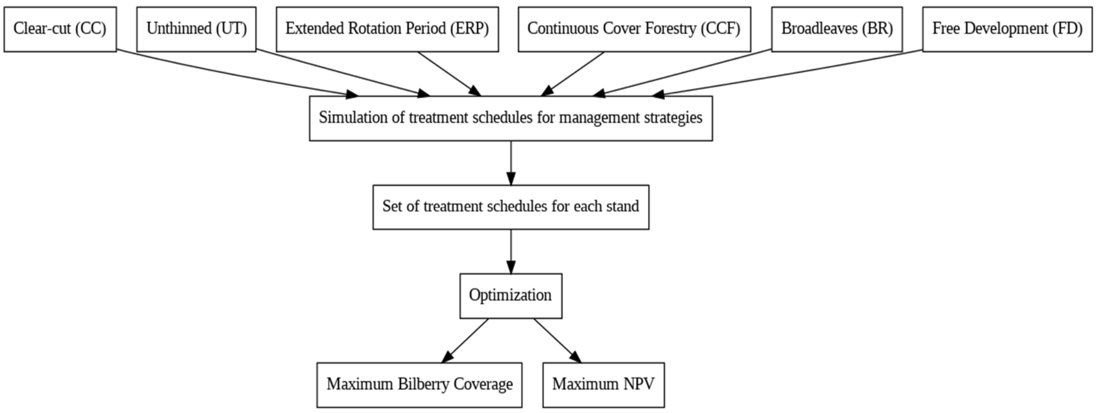

Figure 6: The simulation process, with step 1 generating treatment schedules and step 2 optimizing combination of treatment schedules towards the goal. Illustration inspired by (Eggers et al, 2022).

The process of creating an optimization problem involves sets, parameters, variables and constraints (Holmström, 2021). In the Heureka system, the structure of a forest management optimization model begins with 'sets,' which segment the forest into distinct analytical groups and define the intervals for management activities (figure 7). These include treatment units, the range of management alternatives, specified treatments, and the periods during which these activities occur.

Following the sets, 'parameters' act as the fixed components in the model. These constants, like the area of a forest stand, the volume of timber it can produce, and its associated NPV, shape the model's structure. They are immutable, providing a reliable framework for the model to operate within. Beneath the parameters lie the 'variables,' the malleable aspects of the model that can be adjusted. These variables might include the total bilberry cover across all areas and time periods, or the NPV across all time frames. They represent the elements that the model will optimize to reach the best outcomes. The 'objective function' is positioned under the variables. This is the model's target or goal, such as maximizing the NPV or the total bilberry cover, dictating the direction of the optimization process to achieve the most favorable results. At the bottom, 'constraints' ensure that the model's solutions are practical and achievable. They enforce rules, like limiting the change in harvest volumes to no more than 30% between consecutive periods, ensuring stability and sustainability in the management practices. These constraints uphold the feasibility of the model's outputs, ensuring that the solutions provided are viable within the defined operational parameters (figure 7).

Together, these components—from sets to constraints—establish the foundational architecture of the optimization model, steering the forest management simulations toward optimal outcomes that adhere to set objectives and restrictions. The objective function was clearly defined to maximize either the NPV or total bilberry cover, within the constraints set, such as the requirement that changes in harvest volumes must remain below a 30% increase or decrease between periods to promote sustainable management practices. The interest rate used to calculate NPV was 3%.

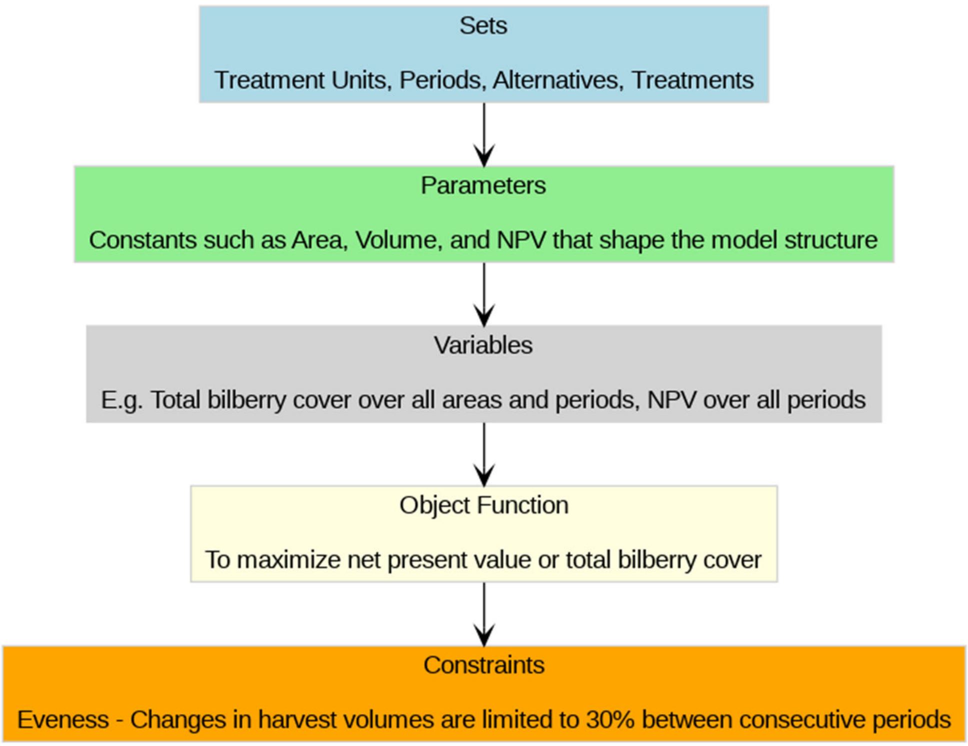

Figure 7: Formulating an optimization problem.

The newly implemented bilberry cover model (Bohlin, 2023), appendix 3, is designed to estimate the potential cover of bilberry shrubs under different forest stand conditions. The model is structured to include various input factors that influence bilberry cover, with a particular focus on species selection, basal area, stand age, and the interval between thinnings—variables that can be directly affected by active treatment prescriptions.

In simplified terms (figure 8), the model considers the temperature sum, which aggregates heat accumulation over a period. Vegetation class of the field layer, which includes the type of vegetation present, as different species compete or facilitate each other. Soil moisture class is another vital input, reflecting the water availability in the soil,. The site index classes provide a measure of the productivity of the site.

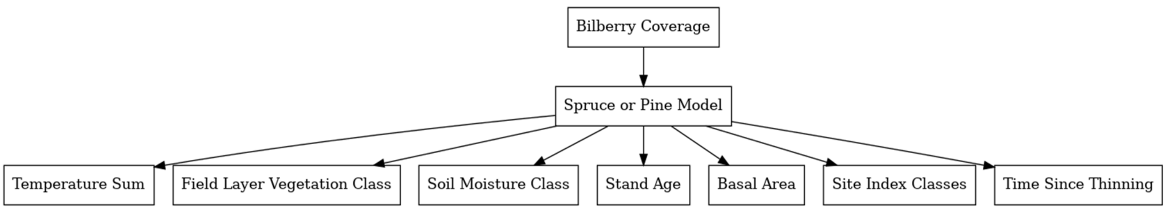

Figure 8 Parameters included in the bilberry cover model.

Stand age and basal area are directly impacted by silvicultural practices regulating available resources and lastly, time since thinning is indicating how many years ago thinning was carried out.

The model operates by integrating these inputs into a general equation that is adapted for specific tree species, such as spruce or pine, reflecting their influence on bilberry cover. The mathematical correlations of the model are outlined in the regression-based formulation (appendix 3) used to derive the bilberry cover predictions under various forest management scenarios.

3. Results

3.1 Optimal strategy

In determining the optimal management strategies to maximize bilberry cover (MAXBIL) and NPV (MAXNPV), the analysis revealed distinct approaches tailored to the objectives and the specificities of the counties Västerbotten and Kronoberg. Figure 9 illustrates the proportional application of each management strategy for the two objectives.

For Västerbotten (VB), the strategy to maximize bilberry cover predominantly utilized continuous cover forestry (CCF, purple), extended rotation periods (ERP, pink) and Broadleaves (BR, light blue). This reflects a conservation-oriented approach. In contrast, strategies to maximize NPV favored clear cut (CC, blue) and continuous cover forestry (CCF, purple), suggesting an economically driven management preference.

In Kronoberg (KRO), the MAXBIL objective was primarily achieved through continuous cover forestry (CCF, purple) and unthinned (UT, beige) strategies, indicating a prioritization of biodiversity and habitat conservation. However, when optimizing for MAXNPV, a significant shift towards clear cut (CC, blue) was observed, denoting a stronger emphasis on timber production.

The observed distribution of management strategies indicates a potential trade-off between economic optimization and the enhancement of ecological conditions favorable to bilberry cover. The strategic preferences displayed for MAXNPV suggest that economic drivers strongly influence forest management decisions, potentially at the expense of understorey biodiversity such as bilberry habitats. As a final conclusion, no single management strategy is optimal for achieving either goal, it is always a combination of strategies. The initial conditions and region characteristics, as described in figures 4 and 5, have large implications for what management strategy is optimal for either goal.

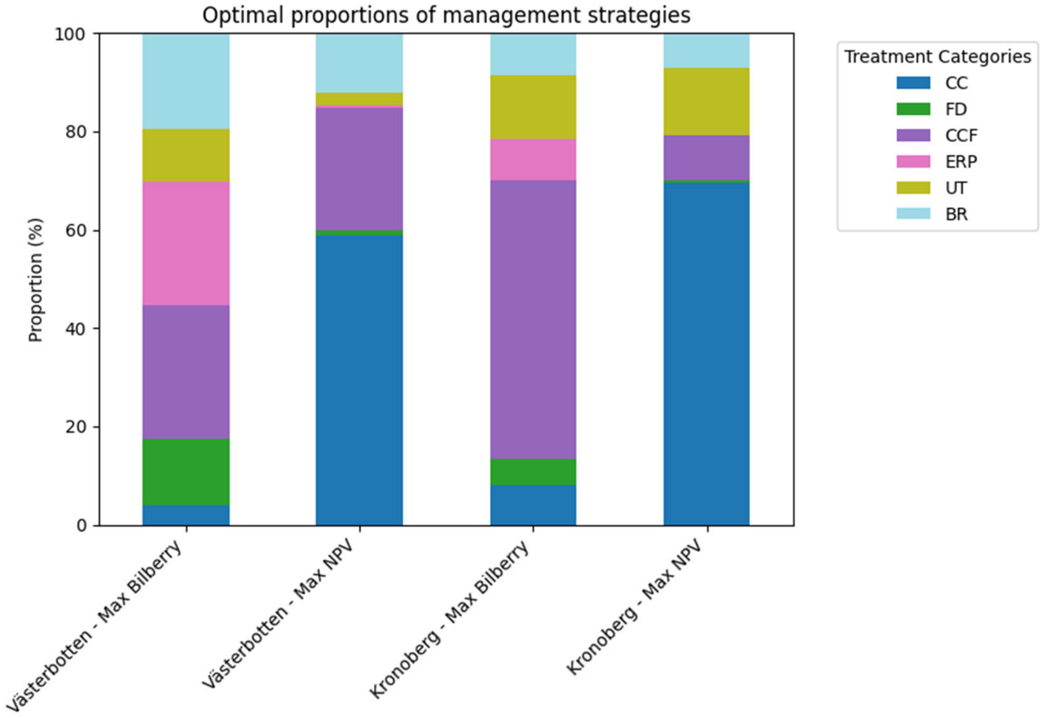

Figure 9: The optimal combination of management strategies to attain MAXBIL or MAXNPV for Västerbotten and Kronoberg.

3.2 Bilberry cover

In the assessment of bilberry cover (figure 10) across various management strategies, the analysis provided insights into how each management approach influenced bilberry habitats within the counties of Västerbotten and Kronoberg.

Västerbotten:

The Continuous Cover Forestry (CCF) strategy, which avoids soil scarification and focuses on natural regeneration with significant broadleaf retention, yielded the highest average bilberry cover at 16.20% (appendix 4), with a standard deviation of 0.78 percentage points. This suggests that the condition promoted by CCF—less disturbance is beneficial for bilberry cover. The Unthinned (UT) treatment, which involves planting without subsequent thinning, showed lower bilberry cover, with the lowest average at 12.28% and a standard deviation of 1.43 percentage points. This might imply that the lack of thinning leads to denser canopy conditions, which can negatively affect bilberry plants that require sufficient light. The Broadleaf Retention (BR) strategy, aimed at increasing broadleaf presence, also supported a relatively high average cover at 15.74%, suggesting that the preservation of broadleaf trees may create a favorable microclimate for bilberry rice.

Kronoberg:
Similarly, CCF in Kronoberg indicated the highest average cover for bilberry at 6.02%, with a standard deviation of 0.50 percentage points, echoing the findings in Västerbotten and underscoring the potential universal benefit of this strategy for bilberry habitats. The Free Development (FD) strategy, which allows forests to develop without active management, was correlated with the lowest average cover at 4.57%, along with a higher standard deviation of 0.75 percentage points, suggesting that a completely hands-off approach may not be conducive to maximizing bilberry cover in this region. The clear-cut (CC) strategy, involving clear cuts and soil scarification while maintaining a broadleaf composition, did not yield as high a bilberry cover as CCF, suggesting that the disturbance from clear cuts and soil scarification might have a more pronounced negative impact on bilberry habitats than the benefit provided by broadleaf retention. The composite 'ALL' strategy, which integrates elements from all the management practices, exhibited the highest average bilberry cover in both counties, at 17.61% in Västerbotten and 6.64% in Kronoberg. This underscores the potential advantage of a multifaceted approach to silviculture for bilberry cover, likely due to the diverse habitat conditions it creates.

The results illustrate that the management strategies promoting natural processes and broadleaf retention, particularly CCF and BR, tend to support higher bilberry cover. In contrast, strategies involving clear cuts, such as CC, or those that omit thinning, like UT, may not be as favorable for bilberry habitats. The temporal trends indicate that these effects are consistent over time, reinforcing the importance of considering long-term ecological dynamics in forest management planning.

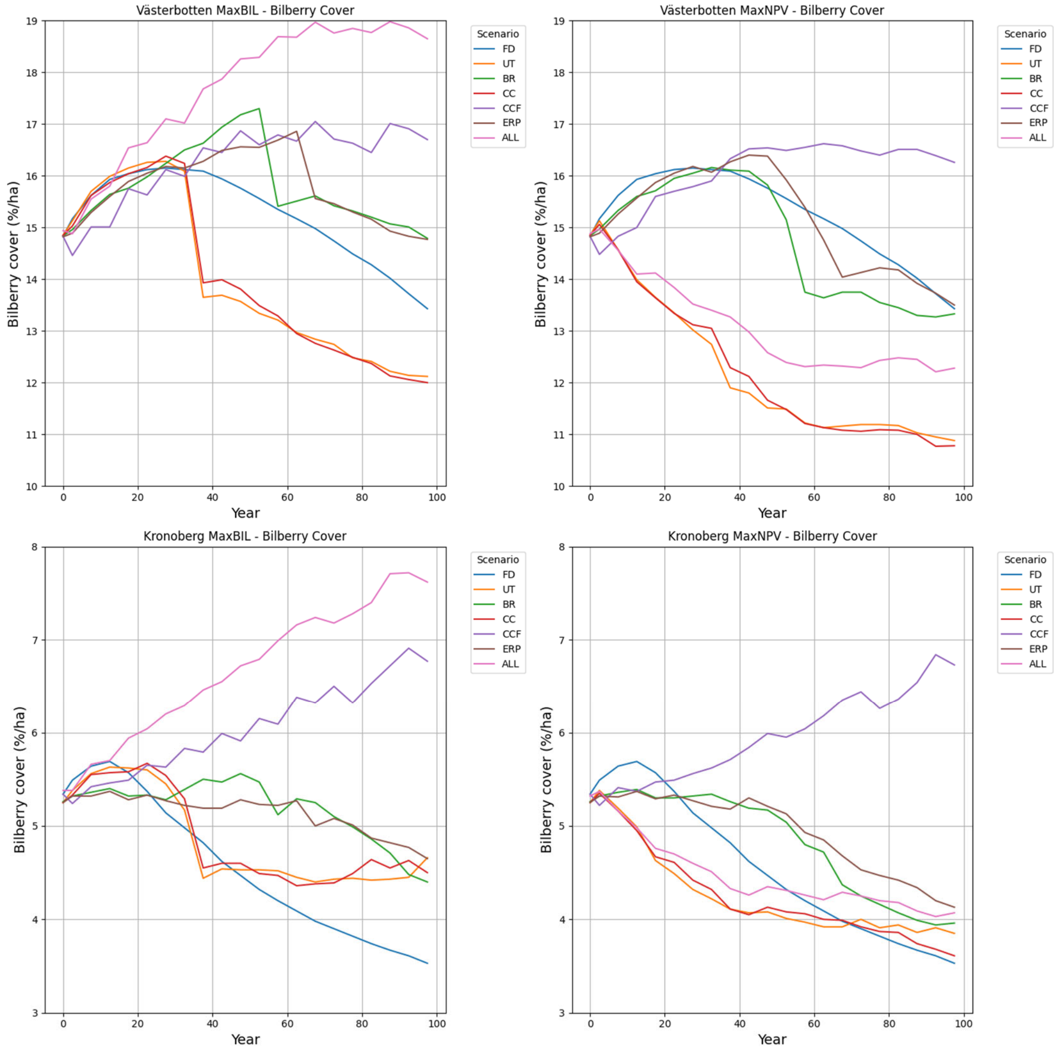

Figure 10: Bilberry cover over a 100-year period for all management strategies.

3.3 Net present value

Västerbotten:

The MAXNPV strategy, represented by VB_CC_NPV (figure 11), commands an NPV of SEK 18,743.28, marking it as the most economically advantageous within the array of strategies analyzed (appendix 4). The strategy yielding the highest bilberry cover, VB_ALL_BIL, presents a notably lower NPV at SEK 11,817.30, with the monetary difference between it and the MAXNPV strategy being SEK 6,925.98. Interestingly, the 'ALL' scenario (VB_ALL_NPV) delivers an NPV of SEK 19,579.65, slightly surpassing the MAXNPV strategy, while still maintaining a higher bilberry cover of 13.13%. The relative increase in bilberry cover in this scenario compared to the VB_CC_NPV strategy is approximately 6.73%, highlighting the ecological advantages of adopting a diversified management approach.

Kronoberg:

KRO_CC_NPV stands as the strategy with the highest NPV, reaching SEK 48,751.60, which emphasizes the economic focus of this strategy. The KRO_ALL_BIL strategy, while prioritizing bilberry cover, achieves an NPV of SEK 36,267.68. The difference in NPV from the MAXNPV strategy is SEK 12,483.92, indicating a significant economic trade-off for ecological gains. In Kronoberg's 'ALL' scenario (KRO_ALL_NPV), the NPV increases SEK 50,681.26, yet it accommodates a bilberry cover increase of approximately 4.90% over the KRO_CC_NPV strategy, again demonstrating the potential ecological benefits of integrated management practices. The analysis reveals that management strategies aimed at maximizing economic output generally do yield higher NPVs. However, strategies that integrate various management practices, such as the 'ALL' scenarios, can achieve both competitive economic returns and enhanced bilberry cover, offering a compromise between the two goals. This multifaceted approach, especially in the 'ALL_NPV' scenarios, underscores the complexity of forest management, where economic and ecological considerations are both critical to the decision-making process. It becomes apparent that while there is no one-size-fits-all solution, the pursuit of balanced outcomes is a viable path.

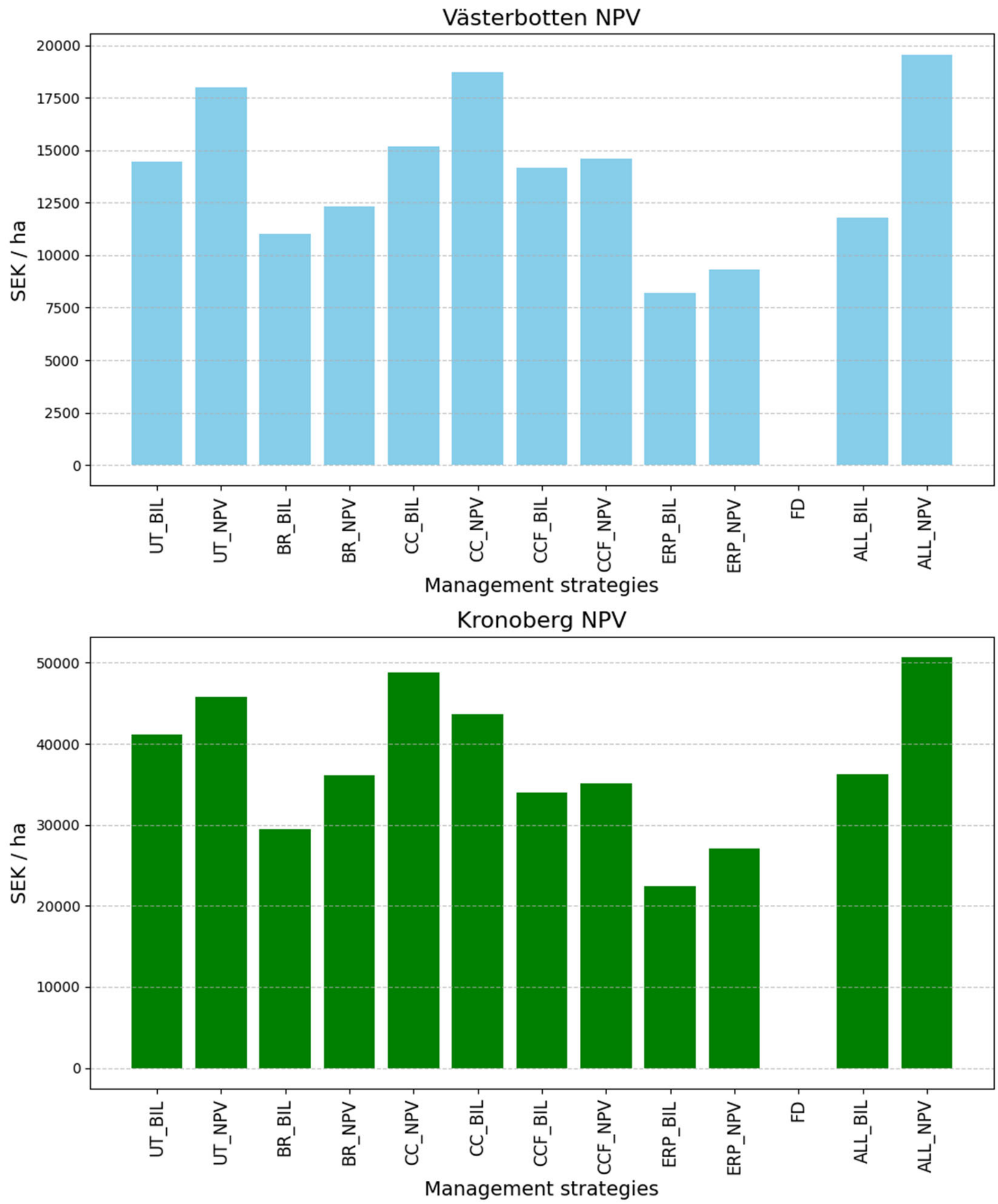

Figure 11: Net present values for management strategies in Västerbotten and Kronoberg

3.4 Harvested volume

Västerbotten:
The VB_ALL_BIL strategy (figure 12), focused on enhancing bilberry cover, achieves a mean harvested volume of 8.42 m^3 (appendix 4). In contrast, the VB_ALL_NPV strategy, optimized for economic returns, presents a higher volume of 9.65 m^3. The trade-off in favoring ecological benefits over maximal economic gains is a reduction of 1.23 m^3 in harvested volume. In general, the harvest volumes are quite uneven, something which indicates the optimization constraints were not strict enough, even though this was the lowest restriction possible. When comparing VB_ALL_BIL to the strategy with the highest harvested volume, not within the "ALL" strategies, the trade-off increases to 4.86 m^3. Additionally, considering the CCF strategy (VB_CCF_BIL), which yields the highest bilberry cover at 16.20%, there's a notable trade-off with the CC strategy (VB_CC_NPV). The latter, focusing on intensive timber production, increases the harvested volume by 3.63 m^3 but results in a 3.90% decrease in bilberry cover.

Kronoberg:
For Kronoberg, the KRO_ALL_BIL strategy shows a mean harvested volume of 20.87 m^3. Shifting to the KRO_ALL_NPV strategy elevates the volume to 27.92 m^3, highlighting a difference of 7.05 m^3 when prioritizing economic outputs. The trade-off becomes even more pronounced at 7.06 m^3 when comparing the KRO_ALL_BIL strategy with the highest volume-producing strategy outside of the "ALL" category. In the context of CCF (KRO_CCF_BIL) versus CC (KRO_CC_NPV), the CC strategy considerably augments the timber yield by 9.81 m^3 compared to CCF, but at the expense of a reduction in bilberry cover by 1.74%. The analysis across both counties illustrates the multifaceted trade-offs in forest management. In Västerbotten, strategies like CCF and ALL_BIL offer a more balanced approach, achieving ecological benefits with a modest decrease in timber production. However, in Kronoberg, the shift towards strategies that maximize economic returns, such as CC and ALL_NPV, results in significantly higher timber yields but with a noticeable compromise on ecological values like bilberry cover.

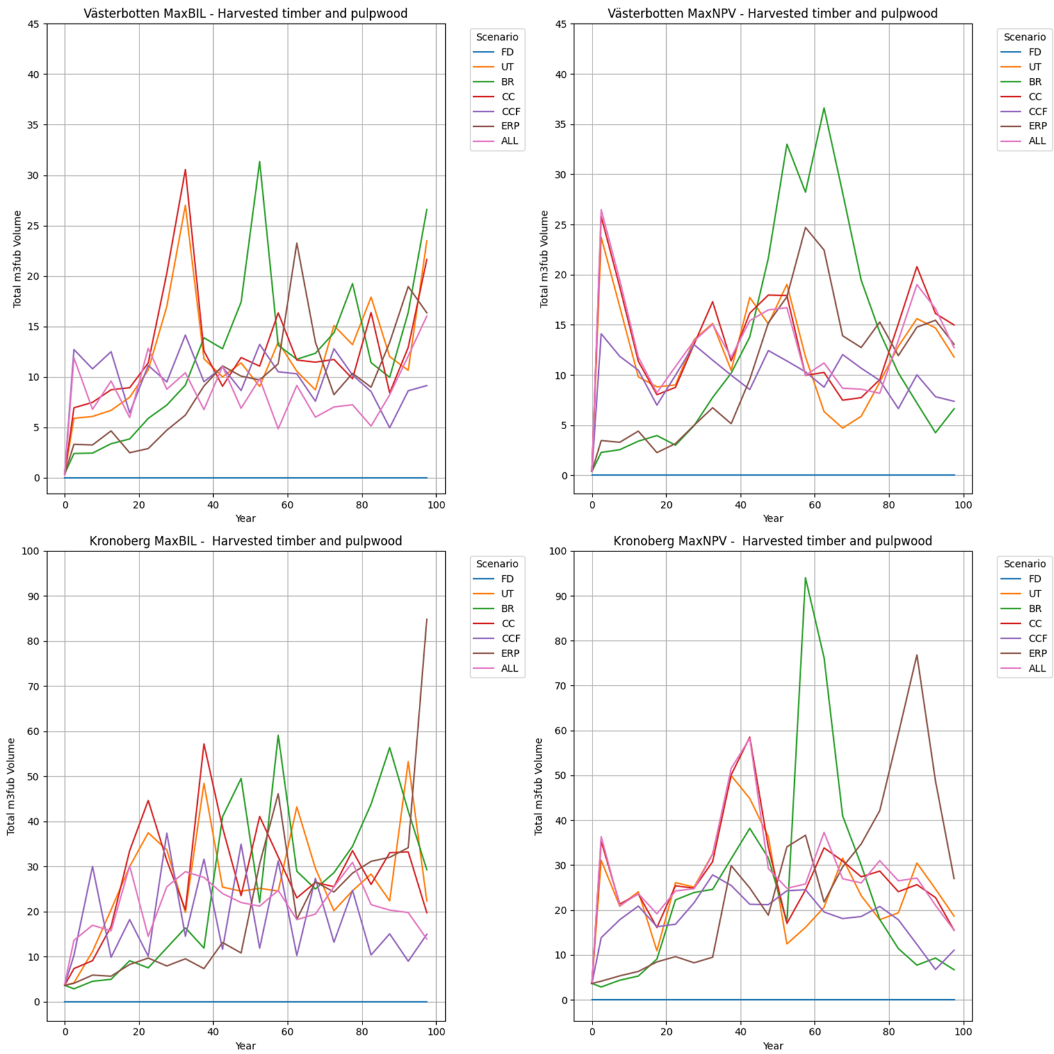

Figure 12: Total m3 harvested, both timber and pulpwood, for all scenarios in both counties.

3.5 Basal area

The basal area (figure 13) for the worst and best bilberry cover scenarios in Västerbotten and Kronoberg reveal a distinct relationship between silvicultural strategy, forest structure, and understory vegetation:

Västerbotten:
Worst Bilberry Cover: The strategy with the lowest bilberry cover in Västerbotten has an average basal area of 15.92 m²/ha with a standard deviation of 1.13, indicating a relatively stable cover over time (appendix 4).
Best Bilberry Cover: The 'ALL' strategy, which resulted in the highest bilberry cover, shows a significantly higher average basal area of 21.12 m²/ha, and more variability with a standard deviation of 2.26. This suggests that a denser forest

structure, up to a certain point, may be conducive to better bilberry habitat, although it introduces more variability into the forest growth dynamics.

Kronoberg:
Worst Bilberry Cover: In Kronoberg, the strategy with the lowest bilberry cover has an average basal area of 21.99 m^2/ha with a standard deviation of 2.17, reflecting slightly more variability than the worst in Västerbotten, which might impact bilberry cover negatively due to factors like reduced light penetration.
Best Bilberry Cover: Conversely, the strategy leading to the best bilberry cover has an even higher average basal area of 26.41 m^2/ha, paired with a standard deviation of 2.79. This higher basal area in Kronoberg correlates with better bilberry cover, again up to a point before possibly becoming detrimental due to excessive shading. The relationship between basal area and bilberry cover aligns with the bilberry cover model, which indicates that basal area has a positive effect on bilberry presence to a certain threshold, beyond which the effects may become negative. This is consistent with ecological understanding that while a certain level of forest canopy can provide beneficial microclimatic conditions for increases in bilberry cover, too much canopy cover can reduce light availability to a level that hinders understory vegetation.

In both counties, the best bilberry cover scenarios are associated with higher basal areas, suggesting that more mature forest stands with a developed canopy structure can be beneficial for bilberry cover. However, this beneficial effect is likely nonlinear and subject to diminishing returns or even negative impacts as the basal area continues to increase, as indicated by the quadratic terms in the bilberry cover model and the results for the high basal areas in the Free development (FD) scenarios.

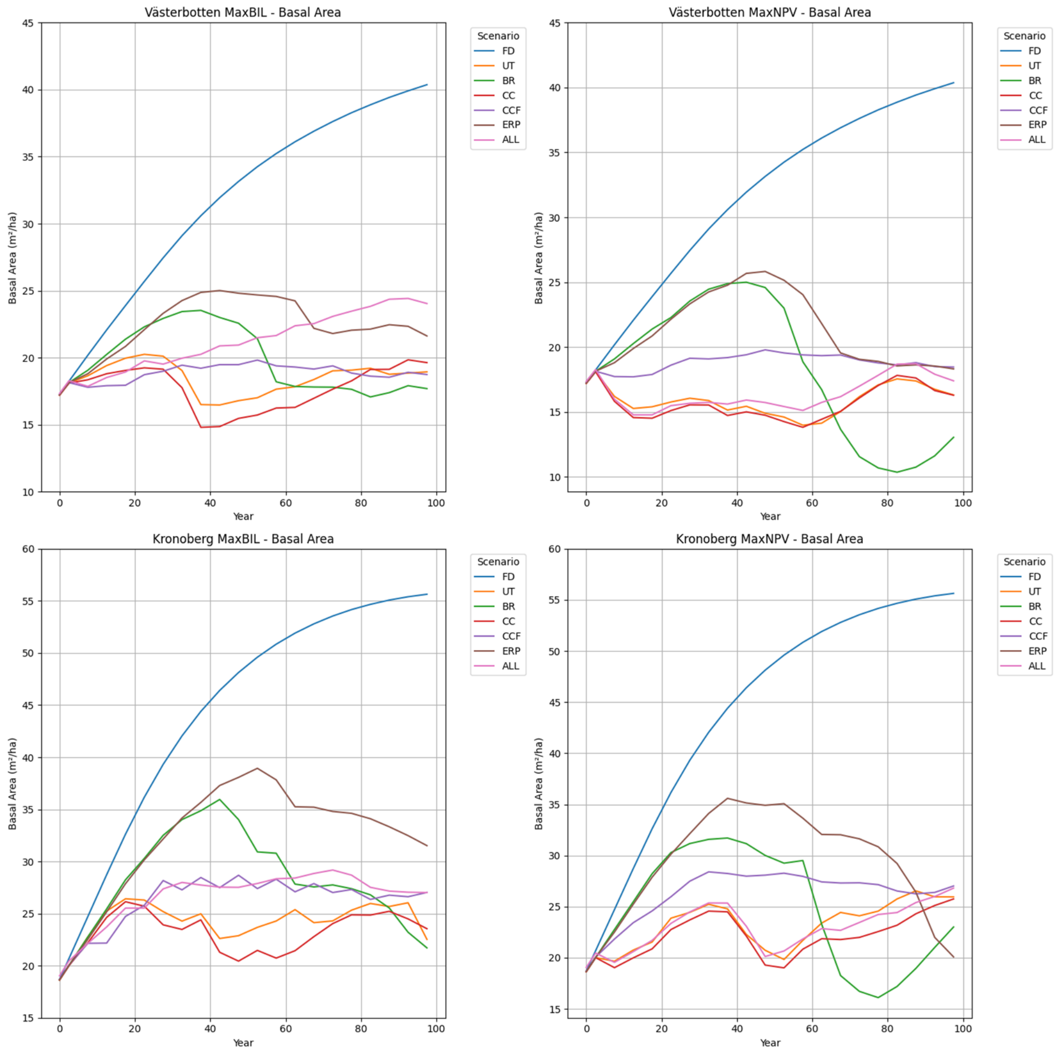

Figure 13 Mean basal area for all scenarios and counties.

3.6 Mean age

Västerbotten:

Worst Bilberry Cover Strategy: The strategy with the lowest bilberry cover (appendix 4) in VB ('VB_UT_NPV') has a total mean age over all periods of approximately 50 years. This suggests that this strategy, optimized for net present value rather than bilberry cover, does not align with the optimal conditions for bilberry habitat as indicated by the model.

Best Bilberry Cover Strategy: The strategy resulting in the highest bilberry cover ('VB_ALL_BIL') has a total mean age over all periods of 94.93 years. This strategy, which includes a composite of silvicultural practices, aligns well with the model's prediction of an optimal mean age for bilberry cover.

Kronoberg:

Worst Bilberry Cover Strategy: The strategy with the lowest bilberry cover ('KRO_CC_NPV') has a total mean age of 36.34 years (appendix 4). This strategy, which is optimized for NPV, may represent a forest too young to support a rich bilberry understorey.

Best Bilberry Cover Strategy: The strategy with the highest bilberry cover ('KRO_ALL_BIL') corresponds to a total mean age over all periods of 72.18 years. This indicates that a diversified approach to silviculture, as represented by the 'ALL' strategy, is likely to provide optimal conditions for bilberry cover.

The analysis of these strategies shows that the mean age of the forest stands plays a significant role in the potential for bilberry cover. Strategies with mean ages that are either too young or too old do not foster the best conditions for bilberry cover, whereas those within a middle-aged range tend to support it better. This is in line with the bilberry model (appendix 3) that suggest there is an optimal mean age range for understory biodiversity, including bilberry cover. There are also large differences between the optimal mean age for Västerbotten and Kronoberg, strengthening the need to account for other parameters in the bilberry model as well.

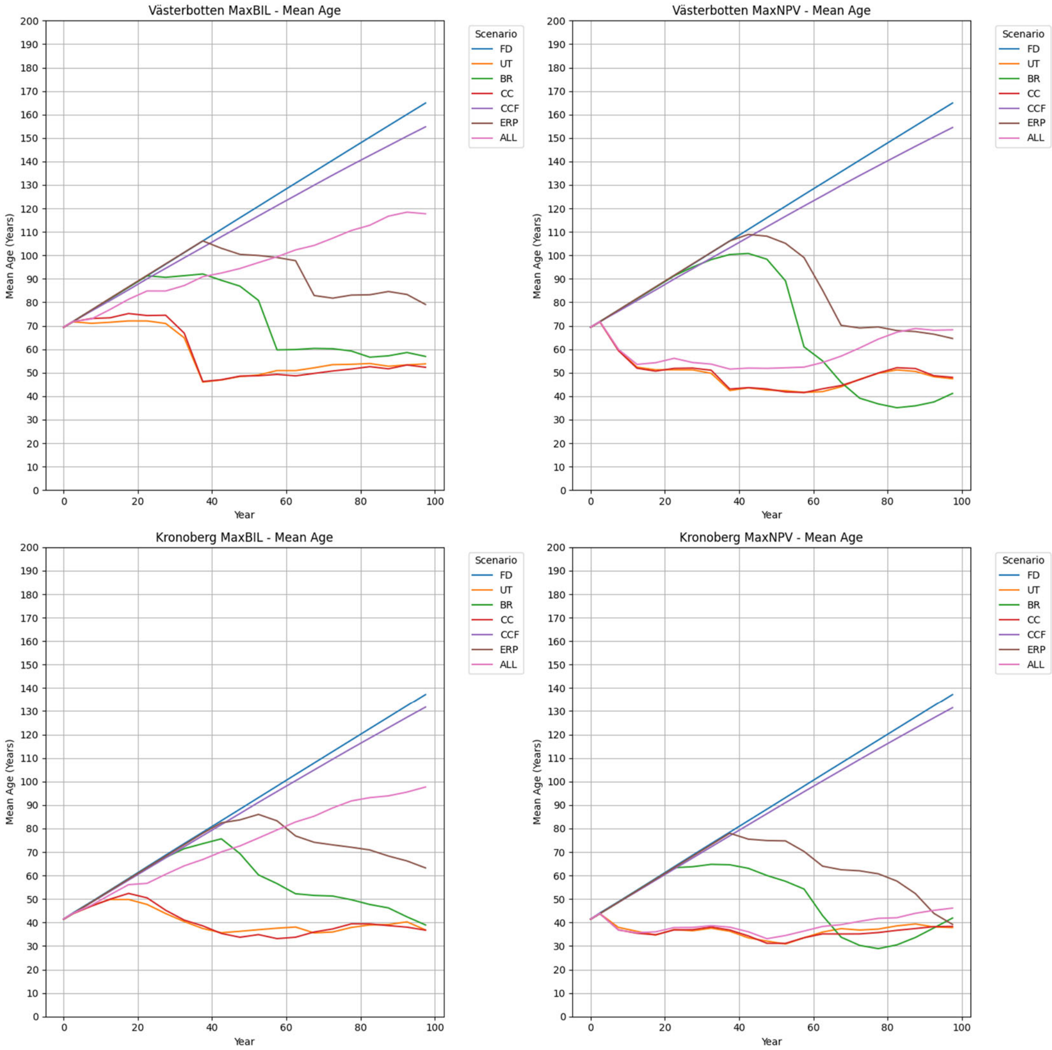

Figure 14; Mean age for all scenarios and counties.

3.7 Mean final felling age

Västerbotten:

The strategy for unthinned with Bilberry focus (VB_UT_BIL) presented a mean final felling age of 109.21 years (appendix 4).

The counterpart strategy focusing on Net Present Value (VB_UT_NPV) showed a mean final felling age of 96.26 years.

The Broadleaf Retention with Bilberry focus (VB_BR_BIL) strategy reported the highest mean final felling age at 136.41 years, while the Net Present Value focus (VB_BR_NPV) had a slightly lower mean age of 133.01 years.

Clearcutting strategies with Bilberry focus (VB_CC_BIL) and Net Present Value focus (VB_CC_NPV) showed mean final felling ages of 108.47 years and 97.22 years, respectively.

For Extended Rotation Period strategies, the Bilberry focus (VB_ERP_BIL) had a mean age of 163.31 years, and the Net Present Value focus (VB_ERP_NPV) had a mean age of 155.49 years.
The ALL strategies, which combine elements from all management practices, showed a mean final felling age of 130.62 years for the Bilberry focus (VB_ALL_BIL) and 98.75 years for the Net Present Value focus (VB_ALL_NPV).

Kronoberg:
The Unthinned strategy with Bilberry focus (KRO_UT_BIL) had a mean final felling age of 73.65 years, while the Net Present Value focus (KRO_UT_NPV) had a mean final felling age of 69.36 years. Broadleaf Retention strategies in Kronoberg followed with mean final felling ages of 105.38 years for Bilberry focus (KRO_BR_BIL) and 94.86 years for Net Present Value focus (KRO_BR_NPV).
The mean final felling ages for Clearcutting strategies were 73.89 years for the Bilberry focus (KRO_CC_BIL) and 68.62 years for the Net Present Value focus (KRO_CC_NPV).

Extended Rotation Period strategies showed a mean final felling age of 126.75 years for the Bilberry focus (KRO_ERP_BIL) and 114.98 years for the Net Present Value focus (KRO_ERP_NPV).

The ALL strategies in Kronoberg had a mean final felling age of 78.35 years for the Bilberry focus (KRO_ALL_BIL) and 68.45 years for the Net Present Value focus (KRO_ALL_NPV).

Across both counties, it is evident that strategies with a focus on bilberry cover generally exhibit higher mean final felling ages compared to those with a focus on net present value. This suggests a strategic inclination towards maintaining older stands when ecological considerations, such as bilberry cover, are prioritized over immediate economic returns. Notably, the Extended Rotation Period strategies (ERP) present the most significant differences in mean final felling ages between the two objectives, highlighting the long-term perspective adopted when the focus is on enhancing bilberry habitats.

4. Discussion

The influence of forestry practices on bilberry (*Vaccinium myrtillus*) cover is multi-dimensional, intertwining ecological, economic, and cultural aspects. This study's findings contribute to a nuanced understanding of these interdependencies, revealing that certain silvicultural strategies can either bolster or diminish bilberry habitats.

The results of this study suggest that continuous cover forestry (CCF), extended rotation periods (ERP), and broadleaf retention (BR) strategies are connected to higher bilberry cover, aligning with ecological benefits linked to minimal disturbance and stable broadleaf components, as supported by Hedwall (2013). This finding supports the idea that timber harvesting is beneficial, as is consistent with the findings of Nybakken et al. (2013), who showed that clear-cutting initially boosts bilberry growth by increasing light availability. However, the findings also affirm the longer-term negative impacts highlighted by Atlegrim and Sjöberg (1996), suggesting the temporary nature of such gains.

The findings underscore the potential of selective harvesting and less intensive logging over clear-cutting for bilberry conservation, a view that resonates with another recent study (Felton et al., 2023). E.g. regeneration of scots pine is a challenge due to browsing pressure from elks, whose diet partially consists of various shrubs such as bilberries (Felton et al., 2022). Other studies (Hedwall & Brunet, 2013) also advocate for maintaining diverse forest structures, which the study confirms as beneficial. Moreover, the 'ALL' strategies that integrate various silvicultural practices present a balanced approach, indicating a synthesis of competitive economic returns and improved bilberry cover, thus offering a viable compromise between economic and ecological objectives. However, there is a big difference in appropriate strategies depending on the geography. Where higher mean ages and a more diverse mosaique was more suitable for Västerbotten. It could be a combination of the initial conditions but also general differences in site conditions for the counties. The size of the counties is also large, with Västerbotten having a size in multiples bigger.

The economic role of bilberries, particularly within rural economies, is well-documented (Turtiainen et al., 2015). With an adequate pricing for bilberry harvests, the optimal strategy severly changes and shifts towards longer rotational periods (Miina et al, 2016). The study delineates a clear trade-off between maximizing NPV and maintaining bilberry cover, thus highlighting the need for a multi-objective forest management framework that includes considerations for non-timber forest products.

The study advocates for the adaptation of forest management guidelines to include strategies that balance economic gains with ecological outcomes. For instance, the prioritization of older stands in bilberry-focused strategies versus those targeting NPV suggests a strategic inclination towards ecological considerations, which should be reflected in policy formulations.

Forestry decision support systems (DSS) play a pivotal role in integrating such multi-objective strategies into practical management (Lämås et al., 2023). By leveraging predictive models and data analytics, these systems can help in planning and implementing forestry practices that align with the findings of this study, particularly in optimizing bilberry cover alongside timber production.

The limitations of this study, including its scope and the range of management strategies evaluated, suggest the need for broader research to explore these dynamics over smaller areas and extended periods. Future studies could leverage DSS to model the long-term impacts of different silvicultural practices on a larger scale.

4.1 Conclusion

In conclusion, this study highlights the complex interplay between silvicultural practices and bilberry cover, emphasizing the necessity for balanced forestry management that values both timber production and the preservation of ecological and cultural assets like bilberries. The integration of bilberry cover considerations into forestry DSS represents a forward-thinking approach to sustainable forest ecosystem management.

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Navigating Sweden's Forests: A Mosaic of Strategies for Timber and Bilberries

"Balancing Trees and Berries" – that's the heart of my thesis, exploring how we manage Sweden’s diverse forests. I found out that there’s no one perfect way to do this. Whether we're looking to make money from timber or keep our forests full of bilberries for nature's sake, mixing different forestry methods is key.

Often, people think about forestry in two ways – either cutting down lots of trees for wood or not touching the forest at all to keep it natural. My research, however, shows that neither of these ways is the best on its own. In Västerbotten and Kronoberg, two very different forested regions, I learned that a mix of methods works best. This means using different approaches in different parts of the forest, based on what each area needs.

It’s not about picking just one way, like cutting down all the trees or leaving them completely preserved. My study highlights the importance of a variety of strategies. For example, in some places, certain ways of cutting trees can help bilberries grow and support lots of different plants and animals. In other places, different methods might be better for getting wood without harming the forest too much. The important thing is to really understand each part of the forest to decide the best mix of methods.

The big idea from my study is to think of forest management as something flexible and ready to change, not stuck doing things just one way. This means we need a wide range of ways to manage our forests. Understanding this is really important for keeping our forests healthy and full of life, and also making sure they can still provide us with wood.

By embracing this varied approach and really focusing on smart forest planning, we can make sure Sweden’s forests stay lively and full of resources, both for us and the environment. This is about moving away from a one-way-fits-all mindset to a smarter, more local way of looking after our forests.

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I am also indebted to Inka Bohlin, whose explanations clarified the complexities of the bilberry cover model, deepening my understanding of this critical aspect of forest ecology.

Special thanks are also due to Hampus Holmström, whose knowledge was instrumental in the formulation and resolution of the optimization problems that underpin the core of this thesis.

Finally, a heartfelt thank you to my mother, Lis Boje—a warm, witty, and intelligent woman. Her sacrifices and steadfast belief in me have laid the foundation for everything in my academic life of which I take certain pride.

Appendix 1

Kronoberg

Data	Value
No. of treatment units	492
Total area (ha)	649¬†133,56
Productive forests (ha)	649¬†133,56
Low productive forests (ha)	0
Impediment area (ha)	0
Other area (ha)	0
Total volume (m¬≥sk/ha)	93¬†736¬†147,2
Mean volume (prod. area, m¬≥sk/ha)	144,4
Mean volume (total area, m¬≥sk/ha)	144,4
Mean Age (yrs)	41,5
Area <= 20 years (ha)	212¬†708,7
Area >= Min Final Felling Age (ha)	178¬†245,3
Volume >= Min Final Felling Age (m¬≥sk)	47¬†569¬†274,8
Mean 'Bonitet' (m¬≥sk/ha)	9,27

Appendix 2

Västerbotten

Title	Value
No. of treatment units	1¬†130
Total area (ha)	3¬†160¬†956,23
Productive forests (ha)	3¬†160¬†956,23
Low productive forests (ha)	0
Impediment area (ha)	0
Other area (ha)	0
Total volume (m¬≥sk/ha)	360¬†844¬†479,9
Mean volume (prod. area, m¬≥sk/ha)	114,2
Mean volume (total area, m¬≥sk/ha)	114,2
Mean Age (yrs)	69,3
Area <= 20 years (ha)	426¬†221,0
Area >= Min Final Felling Age (ha)	1¬†068¬†202,2
Volume >= Min Final Felling Age (m¬≥sk)	189¬†454¬†957,5
Mean 'Bonitet' (m¬≥sk/ha)	3,36

Appendix 3

$$\text{General Model (Equation 1)} = -3.903858 - 0.000825\left(\frac{T^2}{1000}\right) + \sum_{i=1}^{16} a_i F_i + \sum_{j=1}^{3} b_j M_j + 0.013928A - 0.090987\left(\frac{A^2}{100}\right) + 0.023883B - 0.090987\left(\frac{B^2}{100}\right) + \sum_{k=1}^{7} c_k S_k + \sum_{l=1}^{2} d_l T_l \quad (1)$$

$$\text{Norway Spruce Model} = 100 \times \left(1 + \exp\left(-1 \times \left(\text{Model (Equation 1)} + 0.5 \times (0.1382452^2 + 0.5141306^2)\right)\right)\right)^{-} \quad (2)$$

$$\text{Scots Pine Model} = 100 \times \left(1 + \exp\left(-1 \times \left(\text{Model (Equation 1)} + 0.5 \times (0.06597713^2 + 0.4079041^2)\right)\right)\right)^{-1} \quad (3)$$

Where:

Variable	Explanation
T	Temperature sum ($^\circ C$)
F1 - F16	Field Layer Vegetation
M1, M2, M3	Soil Moisture (Class 1-3)
A	Stand Age (Years)
B	Basal Area (m^2/ha)
S1 - S7	Site Index Classes
T1, T2	Time Since Thinning (Years)

1

Table 1: Coefficients for Spruce and Pine Models

Variable	Spruce Coefficient	Pine Coefficient	Explanation
Intercept	-3.903858	-3.280995	-
$\frac{T^2}{1000}$	-0.000825	-0.000768	Temperature sum squared per 1000 ($^{\circ}C$)
Field Layer Vegetation (F1 - F16)			
F1	0	0	High herbs without shrubs
F2	1.769779	1.774384	High herbs with shrubs/blueberries
F3	1.169872	0.176064	High herbs with shrubs/lingonberries
F4	0.682309	0.149473	Low herbs without shrubs
F5	1.834069	1.290381	Low herbs with shrubs/blueberries
F6	0.916496	0.898266	Low herbs with shrubs/lingonberries
F7	-0.581593	-1.419408	Without field layer
F8	1.027658	0.764586	Broad grass
F9	1.11003	0.723186	Narrow grass
F10	1.108045	0.758342	High sedges
F11	0.847527	0.392126	Low sedges
F12	1.293939	-1.285909	Horsetail
F13	2.156197	1.644119	Blueberries
F14	1.48958	0.804939	Lingonberries
F15	1.265554	0.222912	Crowberries/heather
F16	0.899272	0.961085	Poor shrubs
Soil Moisture (M1 - M3)			
M1 - M2	0	-	Classes 1-2
M3	-0.194992	-	Class 3
M4 - M5	-0.721635	-	Classes 4-5
A	0.013928	0.009922	Stand Age (Years)
B	0.023883	0.027498	Basal Area (m^2/ha)
Site Index Classes (S1 - S7)			
S1	0	0	SISF15 or smaller
S2	0.419434	0.277178	SIS_16_18
S3	0.582249	0.469907	SIS_19_21
S4	0.639741	0.596769	SIS_22_24
S5	0.710107	0.535652	SIS_25_27
S6	0.785021	0.459747	SIS_28_30
S7	0.376799	-	SIS_30 or bigger
Time Since Last Thinning (T1, T2)			
T1	0	0	Longer than 10 years
T2	-0.347907	-0.126514	0 to 10 years

Appendix 4

Västerbotten

	Basal area (m2/ha)	Bilberry cover (%/ha)	Mean Age (years/ha)	Final Felling Age (years/ha)	NPV (SEK/ha)	Number of stems (stems/ha)	Harvested Volume (m3fub/ha)
UT_BIL	18.4	14.0	58.5	109.2	14459.6	2511.8	11.9
UT_NPV	15.9	12.3	50.0	96.3	18012.5	2666.9	12.0
BR_BIL	19.7	15.7	73.2	136.4	11014.6	2127.4	11.7
BR_NPV	18.2	14.7	68.9	133.0	12326.7	2274.6	12.5
BAU_BIL	17.7	14.0	58.5	108.5	15205.3	2384.0	12.4
BAU_NPV	15.7	12.3	50.3	97.2	18743.3	2549.6	13.3
CCF_BIL	18.8	16.2	112.0	nan	14172.3	1371.7	9.7
CCF_NPV	18.8	16.0	111.8	nan	14596.5	1375.9	9.7
ERP_BIL	22.3	15.7	88.6	163.3	8225.4	1803.7	9.2
ERP_NPV	21.1	15.1	84.0	155.5	9313.7	1923.8	10.5
FD	31.3	15.2	116.1	nan	-4.8	2017.3	0.0
ALL_BIL	21.1	17.6	94.9	130.6	11817.3	1741.1	8.4
ALL_NPV	16.4	13.1	59.1	98.7	19579.6	2375.7	13.1

Kronoberg

	Basal area (m2/ha)	Bilberry cover (%/ha)	Mean Age (years/ha)	Final Felling Age (years/ha)	NPV (SEK/ha)	Number of stems (stems/ha)	Harvested Volume (m3fub/ha)
UT_BIL	24.1	4.9	40.5	73.7	41152.6	2828.3	26.3
UT_NPV	23.1	4.3	36.8	69.4	45750.8	2922.7	24.8
BR_BIL	27.9	5.2	55.4	105.4	29420.9	2034.1	25.4
BR_NPV	24.5	4.8	48.4	94.9	36156.2	2172.0	24.2
BAU_BIL	23.1	4.9	40.3	73.9	43596.6	2574.7	27.6
BAU_NPV	22.0	4.3	36.3	68.6	48751.6	2680.7	27.3
CCF_BIL	26.0	6.0	86.2	nan	33944.1	1191.5	18.1
CCF_NPV	26.0	5.9	86.1	nan	35145.9	1203.9	18.1
ERP_BIL	31.9	5.1	68.0	126.8	22470.6	1718.2	21.1
ERP_NPV	29.0	4.9	60.3	115.0	27061.1	1914.6	25.7
FD	43.6	4.6	88.3	nan	-14.3	2021.3	0.0
ALL_BIL	26.4	6.6	72.2	78.4	36267.7	1686.1	20.9
ALL_NPV	22.9	4.5	39.2	68.4	50681.3	2577.6	27.9

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