Alternative methods for continuous cover forestry in boreal forests: consequences for timber production, carbon sequestration and biodiversity

Project Description

Scientific justification and objectives of the project

Boreal forests are a key resource for Sweden's bio-based economy while also providing other important ecosystem services related to climate change mitigation and biodiversity. Sustaining these various goals whilst future climatic changes are projected to progress most rapidly in the boreal region, will require adaptive management strategies. For this purpose, a transformation from traditional Rotation Forestry (RF), i.e. even-aged stands based on forest clear-cutting, towards Continuous Cover Forestry (CCF) methods is currently debated in Scandinavia as a way forward to increase environmental benefits and climate resilience. Common CCF methods for boreal forests include various approaches, for example, i) 'selective harvesting/thinning', ii) 'checkerboard regeneration systems' and iii) partial cuttings such as 'gap or strip systems'. Since these methods differ in spatial stand structure and vegetation composition, their effects on tree growth, soil biogeochemistry and biodiversity likely differ. At present, however, comprehensive empirical data to evaluate these associated consequences for ecosystem services is lacking, particularly for carbon sequestration and biodiversity. Thus, filling this knowledge gap is a critical prerequisite for developing CCF methods that can form a part of a sustainable future silviculture strategy for boreal forests.

In this project, we will assemble a unique empirical database on timber production, carbon (C) balance and biodiversity values across key CCF methods in the boreal region of Sweden with the aim to: **Evaluate the consequences of alternative CCF methods for key forest ecosystem services including timber production, carbon sequestration, and biodiversity.**

Utilizing established series of alternative CCF trials within the SLU Experimental Forests across boreal Sweden, the main objectives are to:

1) Assess differences in forest biomass and timber production for various CCF methods,
2) Determine the C sequestration and its resilience to weather extremes for a range of CCF methods,
3) Evaluate ecological functions provided by various CCF methods,
4) Compare trade-offs among these key ecosystem services (timber production, C sequestration, and biodiversity) among CCF methods and RF.

These objectives will be addressed within four integrated work packages (WPs) which evaluate these key ecosystem services for diverse CCF methods including selective thinnings (WP1), checkerboard systems (WP2) and gap-felling (WP3), including a synthesis and comparison with RF (WP4).

Since these different CCF treatments differ in spatial stand structure and intensity of tree removals, we hypothesize that differences in tree growth and vegetation composition/structure as well as altered soil C dynamics in response to CCF treatments will result in contrasting potentials for timber production, C sequestration and biodiversity across the different CCF methods and compared to RF stands.

Outcome: Our project will deliver an evidence-based knowledge framework for developing a well-constrained decision-making matrix for multiple benefits of alternative forest management strategies, which will provide valuable decision support to forest stakeholders and policy makers.

Background

The pressure on Swedish forests to fulfil economic and environmental goals has increased, with contrasting views on priorities emerging and additional constraints from a changing climate arising. At present, however, the development of forest management strategies that reconcile the trade-offs and synergies among economic and environmental goals and pressures is fundamentally limited by the lack of an integrative empirical knowledge base. Our most detailed empirical understanding results from over one century of forest silviculture which has delivered detailed insights on biomass and timber production under RF[1,2]. Meanwhile, it is less clear which biomass production levels can be achieved in alternative CCF stands in boreal forests, particularly in the long-term[2–4]. Furthermore, despite the well-known coupling of forest tree growth and C uptake, the C balance of CCF is highly uncertain given the large variability and gradients in stand structure among various CCF methods[5]. It also remains unclear how resilient CCF stands are to extreme weather events which are predicted to increase in the changing global climate[6]. This project will assemble comprehensive data to evaluate timber production and C sequestration in various CCF approaches and with reference to RF stands[7].

Although sustained biomass yield and environmental services are equal goals in the Forestry Act, recent studies show that Sweden does not meet national and international environmental targets[8]. For instance, concern has been raised that RF has several negative effects on biodiversity, mainly by reducing the variability in important structures (e.g. deadwood) and processes (e.g. wildfire and water regimes)[9,10]. In comparison, recent studies show that CCF has less negative effects than clear-cutting for some organism groups. Specifically, assemblage composition of mosses, lichens and beetles associated with mature forests appear unaffected by selective felling, at least in the short term[11–13]. Furthermore, CCF may provide more habitat for demanding species commonly associated with old-growth forests[12]. However, CCF may experience similar problems as RF in terms of lacking deadwood and old trees[14], which requires careful management adaptation to really provide biodiversity benefits. Currently, however, research on CCF is still scarce in the boreal forest[11] and studies comparing ecological functions between RF and CCF are missing. This project will explore how these environmental goals related to biodiversity functions can be maximized through appropriate CCF strategies in boreal Sweden.

At present, knowledge building often occurs within the research boundaries of a specific ecosystem service or relies on merging data from various studies carried out across large and confounding gradients in forest stand and environmental properties. The absence of all-inclusive empirical datasets further limits our ability to develop well-constrained management strategies that are adapted to enhance overall benefits under specific local conditions. In this project, we will compile and analyse comprehensive data for key ecosystem services from different alternative CCF methods and RF reference stands within a forest landscape typical of boreal Sweden. By developing such novel database that illustrates potential trade-offs and synergies among key ecosystem services as a function of CCF method and management regime, this project will advance our empirical understanding and thereby create an urgently needed decision support for developing optimized strategies for boreal forest management.

Methodology

The project will span 4 years, including 3 years of data collection and 1 year of synthesis and thesis writing. To achieve the project objectives, we will assess forest ecosystem services including biomass production, C sequestration, and biodiversity in various CCF trials maintained in the SLU experimental forest database 'Silvaboreal' (www.silvaboreal.com). This includes i) thinning trials (WP1), ii) checkerboard trials (WP2) and iii) gap-felling trials (WP3). For comparison, similar data are available from 50 RF stands in the Krycklan catchment[15]. Together, this provides an excellent suite of monitoring sites for evaluating key ecosystem services provided by alternative CCF concepts against conventional RF. In WP4, we will synthesise the data on ecosystem services in relation to management regime and CCF method (from WP1-3), which will result novel support for developing optimized strategies for boreal forest management. The applicant and collaborators combine expertise in silviculture, terrestrial C cycle and biodiversity, and thus represent an ideal team to address this pending research question.

Selective thinning trial (WP1)

In WP1, we will explore selective thinning as means to transform old even-aged Norway spruce forests into CCF stands. For this purpose, we will use replicates from the SLU Experimental trial series 'Gallrings- och gödslingsförsök i skiktad granskog" which was established in 2013. Specifically, measurements will be made in plots '1571 Kulbäcksliden', '1570 Sidensjö', '1565 Korpmarken', and '1569 Enviken', which cover a climatic north-south gradient across the boreal region (Fig. 1). Since establishment, tree and understory vegetation growth as well as biodiversity indicators have been

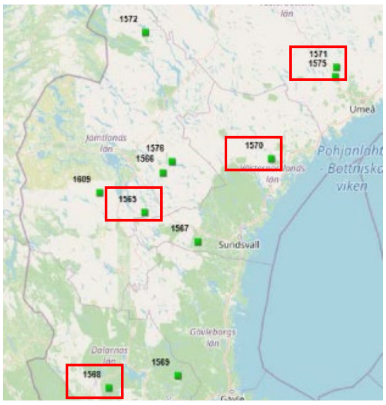

Fig 1. Selected sites of the thinning trials in WP1

quantified repeatedly in each plot. Replicates 1565, 1569, and 1570 also include an additional treatment of combined thinning and nitrogen fertilization. Each trial replicate consists of treatment and control blocks (each 40 × 25 m). The thinning has resulted in a relatively equal spacing of remaining trees and higher stem volume compared to those in WP2 and WP3.

Checkerboard trials (WP2)
In WP2, we use the established trials Åheden (trial 25343) and Kulbäcksliden (trial 7201) which are located close to Vindeln (Fig. 2). Here, harvest and regeneration cuttings have been carried out in checkerboard patterns, resulting in blocks of treed and harvested areas (each 50 × 50m at Åheden; 30 × 45m at Kulbäcksliden). This design creates strong spatial gradients in vegetation structure and environmental conditions. Both sites are dominated by Scots pine with regeneration of mixed Scots pine-Norway spruce in the gaps. Tree growth has been repeatedly recorded. Here, the soil C fluxes and biodiversity indicators will be quantified along transects to cover the strong spatial differences between forest plots and gap areas.

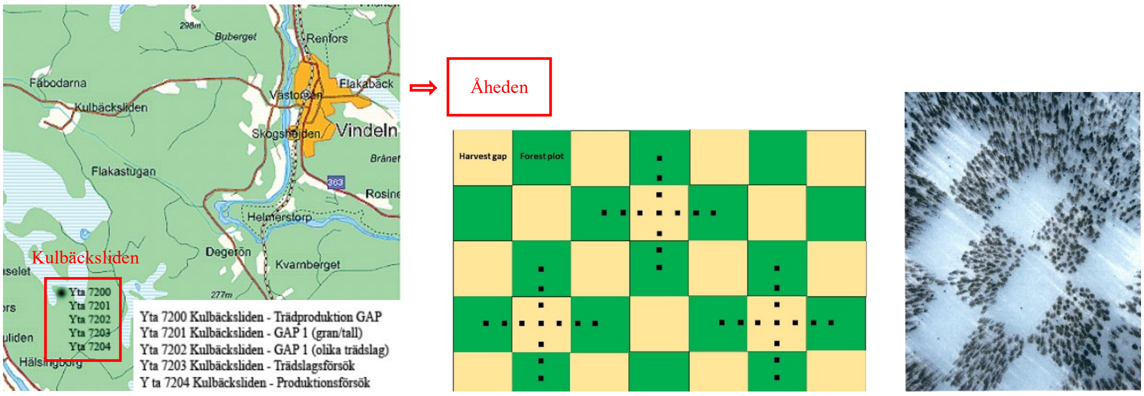

Fig 2. Checkerboard trials Aheden and Kulbäcksliden explored in WP2, left: site location, middle: experimental design for soil C flux measurements, right: areal photograph

Gap-felling trial (WP3)
In WP3, we will assess key ecosystem services in a gap-felling trial near Botsmark. The site has circular gaps that are 10 m in radius. In total, the gaps cover ca 20% of the area. In every second gap, deadwood is left for biodiversity while in the other gapz all trees are harvested and removed. Hence this CCF method represents an intermediate intensity of tree removal and stand structural changes compared to the thinning (WP1) and checkerboard (WP2) methods. Here, both tree growth and biodiversity functions have already been previously assessed by a team of collaborator TL.

Synthesis (WP4)
In WP4, we will synthesise the knowledge gathered from WP1-3 to evaluate the overarching questions 1) what is the variability in timber production, C sequestration and biodiversity functions among diverse CCF methods, and 2) how do the potentials for benefits and trade-offs in these ecosystem services compare between CCF and RF? Based on this assessment, management recommendations will be made. Furthermore, as the final step, we will seek collaborations with the modelling community to utilize the empirical data collected in this project to develop and validate CCF model simulations.

Estimates of forest biomass and timber production
Annual tree biomass and timber production is estimated by tree inventory and tree coring measurements in each CCF trial series. Historic data of tree biomass stocks and production have been collected by collaborator FS and his team in each of the investigated CCF trials, thus providing a valuable baseline. In this project, we will extend these time-series by conducting an additional tree survey and determine annual growth from tree increment cores. Based on long-term data from the tree cores and climate records from the SLU Svartberget climate station, we will also be able to evaluate the sensitivity of biomass production of forests managed according to CCF to weather extremes.

Estimates of carbon sequestration
Although extensive data on tree biomass production have been collected at each of the investigated CCF trials, assessments of the forest ecosystem-scale C balance, i.e. the net ecosystem production (NEP), are lacking at present. In this project, we will determine the NEP in the CCF trial stands as the difference between the C uptake via net primary production (NPP) of trees and understory versus the soil C loss via heterotrophic respiration (RH), i.e. NEP = NPP - RH[7]. Specifically, tree NPP will be estimated as the sum of annual changes in living and dead tree biomass as well as litterfall production. Changes in living tree biomass will be derived from the tree survey measurements and tree coring data combined with existing allometric functions[16]. Understory vegetation NPP will be quantified through destructive sampling during the peak of the growing season. We will use the chamber technique to measure soil RH fluxes from experimental subplots (1 m) where all living ground vegetation will be removed and lateral roots trenched (i.e. applying the 'trenching technique' following ref[7]) in bi-weekly intervals during the growing season. RH from deadwood decomposition will be estimated by applying a decay constant to the deadwood pool determined as part of the tree inventory measurements and combined with the soil RH flux to obtain an estimate of total RH. To assess the difference in soil C storage of different types of spatial tree species mingling, we will take three soil cores to a depth of 50 cm in each plot. The soil bulk density and C concentration (for each 10 cm depth interval) will then be determined in the lab. Data from the CCF stands will be referenced against an existing, exceptional biometric dataset on the C balance of 50 forest stands spanning from clear-cut to old-growth stands under RF in the nearby Krycklan catchment (previously collected by the applicant)[7].

Estimates of biodiversity functions
Population densities and assemblage composition for key arthropod species (beetles, ants and spiders[17]) will be determined in each CCF trial series. We will also establish ground vegetation species composition and biomass, woody debris and standing deadwood using the established National Forest Inventory protocol. In the old Norway spruce thinning trial (WP1) and gap-felling trial (WP3), both insect and ground vegetation data have already been collected by collaborator TL. In the checkerboard trials (WP2), we will deploy flight intercept traps (Polish IBL traps) and pitfall traps to obtain similar data during this project. Similar insect species and ground vegetation data will be available from the 50 RF stands across the Krycklan catchment from previous and other ongoing projects by the main applicant and collaborator TL. Differences in assemblage structure, species composition and functional diversity within CCF approaches and between CCF and RF will be determined using Hierarchical Modelling of Species Communities (HMSC)[18]. Data about species traits and habitat requirements will be obtained from a database developed by collaborator TL.

Scientific competence and organization of the project team
Matthias Peichl, applicant, Professor, SLU, Dept. of Forest Ecology and Management (130 peer-reviewed papers, >7500 citations, H-index = 45), he has a background in forestry and >15 years of experience in exploring terrestrial carbon cycle-climate feedbacks. He will lead the project and act as the main supervisor of the PhD student.

Therese Löfroth, Associate Professor, SLU, Dept. of Wildlife, Fish, and Environmental Studies (46 peer-reviewed papers, >2000 citations, H-index = 27), she is an expert in biodiversity and will be responsible for evaluating biodiversity aspects. She will also act as PhD student co-supervisor.

Arne Pommerening, Professor, SLU, Dept. of Forest Ecology and Management (80 peer-reviewed papers, 3 textbooks, >4400 citations, H-index = 31), he is an expert in forest biometrics, quantitative ecology and silviculture. He will support the project with his extensive knowledge on statistics, modelling and continuous cover forestry. He will also act as PhD student co-supervisor.

Fredrik Sjödin, MSc, Project Leader at the SLU Unit for Field-based Forest Research, he has a background in forestry and is main responsible for maintaining the CCF trials stands (WP1-3) on behalf of the SLU Experimental Forests, he will provide background data on forest growth. He will also act as PhD student co-supervisor.

PhD student, responsible for collection and analysis of data on timber production, carbon sequestration, and biodiversity, and for disseminating results from all 4 WPs.

Technical Assistance, a team of engineers, technicians and seasonal workers employed at the SLU Unit for Field-based Forest Research will help with field logistics and data collection.

Scientific Deliverables and Dissemination
Project findings will be disseminated through 4 publications in peer-reviewed journals with open-access. Additional publications are expected from future work related to this project.

Preliminary and previous results relevant to the doctoral project
At present, estimates of C balance estimates for CCF stands rely primarily on model simulations[19,20], where most models are still based on data from conventional RF stands for calibration of tree growth. This project will deliver the urgently needed empirical information required to establish data-driven estimates of the C balance of boreal CCF stands, and to help improving CCF models.

Preliminary and previous results at the proposed study sites include baseline measurements of tree and understory vegetation carried out in all the trials studied in WP1-3 by the team of collaborator SJ. Similarly, data on key arthropod species have been previously collected at the selective-thinning (WP1) and gap-felling (WP3) trials by collaborator TL. However, while these data exist, they have not yet disseminated them in a scientific publication and are available for use in this project.

Detailed biometric and chamber-based data for the C balance of conventional RF exist for 50 stands (spanning from 5 to 211 years of age) in the Krycklan catchment from a previous project[7]. These data will serve as valuable reference for comparison with the C balance estimates from the CCF stands.

Justification of the suitability of the project for doctoral studies
This project will be structured in 4 WPs, which each will serve as the basis for a publication. Hence, this proposed WP structure will facilitate compiling a PhD thesis including 4 thesis chapters.

The project work be highly suitable for a doctoral study since it includes both sufficient low-risk components to ensure the feasibility of successfully completing the thesis work, as well as some high-risk elements which offer the opportunity for the student to obtain exciting novel results. Specifically, all CCF trials studied in WP1-3 are well-established and baseline data on biomass production and biodiversity (except for WP2), as well as reference data from RF stands will be readily available. Given the ambitious goal to integrate comprehensive data on various ecosystem services in this project, this will alleviate potential pressure on the student regarding data collection and analysis. The available data will also allow the student to develop a first manuscript already in the first year and thus create an ideal start into the doctoral studies. At the same time, this project will provide ample opportunities for the student to develop own ideas and directions of this research, and to shape the final outcome in the synthesis chapter (WP4).

The ideal time frame for the proposed project is 4 years. This will allow for multiple years of field data collection to obtain a robust dataset. Specifically, tree growth, C fluxes and insects are sensitive to weather patterns and therefore display inter-annual variability. Hence, compared to a 2-year postdoc project, this proposed research work is much more suitable to be conducted by a doctoral study.

The proposed project will also relate to several other ongoing and planned projects by the main applicant and collaborators and therefore provide opportunities for the student to interact and collaborate with other students and postdocs on related research topics.

The applicant and collaborators combine expertise on conventional rotation and continuous cover forestry, quantitative forest ecology, statistics, silviculture, terrestrial C cycling and biodiversity, and provide extensive experience in student supervision. Thus, they represent an ideal supervision team to guide the student and to ensure a successful outcome of this doctoral thesis project.

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