METHODOLOGY FOR IMPROVED FOREST MANAGEMENT IN BOREAL PRODUCTION FORESTS

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Prepared By	Övertorneå kommun
Contact	Övertorneå kommun Tillväxtenheten 957 85 Övertorneå Sweden ++46 927 79658 anna.andersson@overtornea.se www.overtornea.se

Relationship to Approved or Pending Methodologies

Approved and pending methodologies under the VCS and approved GHG programs, which fall under the same sectoral scope and AFOLU project category, were reviewed to determine whether an existing methodology could be reasonably revised to meet the objective of this proposed methodology. Two methodologies were identified, and are set out in Table 1 below.

Table 1: Similar Methodologies

Methodology	Title	GHG Program	Comments
VM0005	Methodology for improved forest management: Conversion of low productive to high productive forest	VCS	This is also an IFM LtHP methodology, but it uses a project method for determining additionality and it is limited to evergreen tropical rainforest.
Pending	Protocol for the Creation of Forest Carbon Offsets in British Columbia	VCS	This is a very broad methodology which includes ARR, REDD and IFM activities in the Province of British Columbia, Canada.

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1. SOURCES

The following have also informed the development of the methodology:

- VCS Methodology VM 0012
- CDM Tool for the demonstration and assessment of additionality
- Good Practice Guidance for Land Use, Land-Use Change and Forestry
- AFOLU Guidance regarding Calculating of the Long-Term Average Carbon Stock for IFM Projects with Harvesting
- Sourcebook for Land Use, Land-Use Change and Forestry Projects (Pearson, Walker & Brown, 2005)

This methodology uses the latest versions of the following tools:

- VT0001, VCS tool for the demonstration and assessment of additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities, or the
- CDM Tool for the demonstration and assessment of additionality
- AFOUL Non-Performance Risk Tool

2. SUMMARY DESCRIPTION OF THE METHODOLOGY

Additionality and Crediting Method	
Additionality	Activity Method
Crediting Baseline	Project Method

This methodology facilitates the quantification of the net GHG benefits of Improved Forest Management projects that achieve carbon benefits in a combination of tree growth increasing forest management activities. This methodology is limited to boreal production forests.

Project activities include the following:
- Pre-commercial thinning
- Early fertilization

The baseline scenario is forest management according to common practice in the project area. The methodology uses an activity method (Option B, Financial viability, in the *VCS Standard*) for the demonstration of additionality. Neither of the project activities are regarded as common practice nor are they financially viable in Sweden. The conclusion is thus that these activities are additional. For project areas outside Sweden, project proponents have to demonstrate additionality using either the *VCS tool for the demonstration and assessment of additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities,* or the *CDM Tool for the demonstration and assessment of additionality.*

All management activities will be carried out according to the framework of the national Forestry Act in production forests with low nature conservation values. This is ensured through certification via FSC or PEFC and/or assessments of nature conservation values before a project activity is performed.

The project will contain forest stands of different ages merged together to a cluster of forest stands, thus making the carbon sink permanent for the cluster even when some of the individual stands are cut. Clustering of forest stands into one project allows smaller forest owners to participate in the project.

The project boundary includes above-ground tree biomass and below-ground biomass carbon pools. The biomass is measured on a number of sampling plots. The first measurement is carried out at the same time as the project activity is performed. From those data, the reference level is calculated for both the baseline scenario and the project scenario. Total tree carbon stock is estimated through modelling using the HEUREKA Forestry Decision Support system, which is maintained by the Swedish University of Agricultural Sciences. Sample plots are re-measured ≤ 5 years. The total GHG benefit is calculated by subtracting the baseline tree growth, project emissions and leakage from the project activity tree growth.

As set out in the VCS standard, the crediting period must include final harvesting and GHG credits will not be issued above the long term average GHG benefit maintained by the project. Project proponents must prepare a non-performance risk report in accordance with VCS document AFOLU Non-Performance Risk Tool at both validation and verification.

3. DEFINITIONS

List of acronyms

FCS	Forest Stewardship Council
PEFC	Programme for the Endorsement of Forest Certification
PU	Prediction unit
SLU	Swedish University of Agricultural Sciences
TPG	Treatment program generator

4. APPLICABILITY CONDITIONS

This methodology applies to project activities that increase the growth and carbon sequestration through tree growth increasing forest management in conifer dominated (>50%) production forests. Project activities include the following:

- *Pre-commercial thinning*. Pre-commercial thinning performed when trees are 1.8-2.2 m in average height, corresponding to an age of 10-20 years, and by leaving more stems per hectare than the prevailing praxis in the project area.

- *Early fertilization.* Fertilization performed in young forest stands of 30-60 years of age.

A project can include both or only one of the activities. The project activities are described in more detail in Appendix C.

This methodology is applicable under the following conditions:

- Commercial forest operations in conifer dominated (>50%) boreal production forest.
- Forest management, in both baseline and project scenarios, involves clear cutting forest management according to the framework of the national Forestry Act.
- Forests must either be certified by FSC or PEFC or an assessment of nature conservation values must be performed in the individual forest stands by the start of the project crediting period. FCS/ PEFC certification or assessment of nature conservation values must be demonstrated no later than at the time of the first verification.
- The project must contain forest stands of different ages aggregated together to a cluster of forest stands, thus making the carbon sink permanent for the cluster even when some of the individual stands are cut.

5. PROJECT BOUNDARY

5.1 Project area

The project geographical area is to be defined by the project proponent with maps and legal land description. The project activity will contain more than one discrete area of land aggregated into a cluster of forest stands. Aggregation of forests with multiple landowners is treated as a single project area. The following must be defined in the project description:

- Project location must be specified using geodetic polygons to delineate the geographical area of each project activity and provided in a KLM file.

- Each discrete area of land must have a unique geographical identification

- Maps of the project area

- Details of ownership of land

- Landowner agreement

- Forest management activity for each discrete area of land

5.2 Temporal project boundaries

The project start date must be the date on which activities that lead to the generation of GHG emission removals are implemented, i.e. the date when the IFM activities are performed. As per

VCS requirements for AFOLU projects, validation must be completed within five years of the project start date.

Project proponents must specify a project crediting period as set out in the most recent version of the VCS Standard. For IFM projects the crediting period must include a complete harvest/cutting cycle and must be a minimum of 20 years up to a maximum of 100 years.

This methodology allows for grouped projects.

5.3 Selected carbon pools and emission sources

The carbon pools included in or excluded from the project boundary are shown in Table 1 below.

Table 1: Selected carbon pools

Source	Included?	Justification/Explanation
Above-ground tree biomass*	Yes	Required by VCS. Major carbon pool subject to increase from baseline to project scenario.
Above-ground non-tree biomass	No	Excluded by VCS. Minor carbon pool subject changes from baseline to project scenario.
Below-ground tree biomass*	Yes	Optional by VCS. Minor carbon pool subject to increase from baseline to project scenario.
Litter	No	Excluded by VCS. Minor carbon pool subject changes from baseline to project scenario.
Dead wood	No	Optional by VCS. Minor carbon pool subject changes from baseline to project scenario.
Soil	No	Optional by VCS. Minor carbon pool subject changes from baseline to project scenario.
Wood products	No	Optional by VCS. Major carbon pool subject to increase from baseline to project scenario, but verifiable information for this carbon pool is difficult to obtain. The methodology does not provide an approach for accounting for this carbon pool.

** The stump of the tree is included in below-ground biomass and excluded from above-ground tree biomass.*

The greenhouse gases included in or excluded from the project boundary are shown in Table 2 below.

Table 2: GHG sources included in the project boundary

Source	Gas	Included?	Justification/Explanation
Use of fertilizers	CO_2	No	Carbon emissions from nitrogen fertilizers are deemed *de minimis* and not accounted for in the project scenario (Appendix A).
	CH_4	No	
	N_2O	No	
Combustion of fossil fuel in vehicles / machinery	CO_2	No	Carbon emissions from forest management and harvesting equipment and log transport are deemed *de minimis* and not accounted for in the project (Appendix B).
	CH_4	No	CH_4 and N_2O emissions are assumed to be *de minimis*. Exclusion of these combustion gases does not increase the emission reductions in the project activity.
	N_2O	No	

6. BASELINE SCENARIO

The baseline scenario must reflect what most likely would have occurred in the absence of the project. The baseline scenario consists of common practice in forest management in the area and cannot be below the national Forestry Act minimal guidelines. Common practice is demonstrated with the management plans of the dominating forest owners in the area. As set out in the VCS standard, project proponents must, for the duration of the project, reassess the baseline every 10 years.

7. ADDITIONALITY

For project areas within Sweden, this methodology uses an activity method for the demonstration of additionality. Additionality was established using the financial viability option (Option B in the *VCS Standard*). Demonstration of financial viability is set out in Appendix C. None of the project activities are regarded as common practice in Sweden. Furthermore they are all financially non-viable.

Project activities that meet the applicability conditions of this methodology (see section 4) and demonstrate regulatory surplus are deemed as additional in Sweden.

Step 1: Regulatory Surplus

Project proponents must demonstrate regulatory surplus in accordance with the rules and requirements regarding regulatory surplus set out in the latest version of the *VCS Standard*.

Step 2: Positive List

The applicability conditions of this methodology represent the positive list. The project must demonstrate that it meets all of the applicability conditions, and in so doing, it is deemed as complying with the positive list.

For project areas outside Sweden, project proponents have to demonstrate additionality using either the *VCS tool for the demonstration and assessment of additionality in VCS Agriculture, Forestry and Other Land Use (AFOLU) Project Activities,* or the *CDM Tool for the demonstration and assessment of additionality*

8. QUANTIFICATION OF GHG EMISSION REDUCTIONS AND REMOVALS

8.1 Estimation of Baseline Onsite Carbon Stock

8.1.1 Stratification

Since IFM activities are carried out in stands of different site conditions (moisture conditions, fertility) and different tree species composition, age, stem number and basal area, the measurements and calculation of GHG emission reductions and removals should be made separately for each Project activity stand, to achieve highest possible accuracy. The Project activity stand area boundary should be adjusted as to achieve as homogenous site and stand characteristics as possible, in order to minimize the variation in tree carbon stock and maximize the precision of estimated tree carbon stock changes.

8.1.2 Stand and Tree Variable Data Collection

Stand and tree variable data are collected from stand data bases and field sample plot tree measurements before the Project activity is carried out, according to the methods described in paragraph 9.3.2 and 9.3.3.

8.1.3 Tree Carbon Stock Estimation

Total tree carbon stock is estimated, using the following built-in functions in the HEUREKA system (see 8.1.5) and for the following tree fractions:

- stem above stump
- bark
- branches, leaves/needles
- stump including roots (stump height is defined as 1% of the tree height).

The biomass content of trees (dry matter ton/ha) in established stands (see 8.1.5.2) is estimated according to Petersson (1999) and Repola (2008) (for leave biomass of broadleaved trees), and stump, including below-ground root biomass with diameter > 2 mm, according to Petersson & Ståhl (2006). Since Petersson (1999) is not a peer-reviewed publication, the functions are presented in Appendix E.

For young stands (see 8.1.5.2), the biomass functions by Claesson et al. (2001) are used for the stem and crown biomass and the functions by Petersson & Ståhl (2006) for stumps and roots with diameter > 2 mm).

The same biomass functions as for birch are also used for other broadleaved trees. In these cases, the calculated biomass weight is adjusted for the wood density of each species, in relation to the wood density for birch. The carbon content of the tree biomass dry matter is set to 50% (West 2009) and the corresponding sequestered (CO_2 removal) CO_2 weight is 3,64.

The allometric functions are of the following type:

$\mathrm{Ln}(Y_{fraction}) = \beta_0 + \beta_{1*}x_1 + \beta_{2*}x_2 + \beta_{3*}x_3 + \ldots\ldots\ldots\beta_{n*}x_n + \ln(\varepsilon)$, where fraction is biomass fraction of the tree, $\beta_0 - \beta_n$ are function parameters, x_1-x_n are variables and $\ln(\varepsilon)$ a random variable with expected value 0.

8.1.4 Tree Biomass Growth and Carbon Stock Changes

Expected tree biomass growth and tree carbon stock changes during a 100 year rotation after that the IFM activities *Pre-commercial thinning* or *Early fertilization* are carried out, are estimated every 5 years for the Baseline scenario, using tree growth models coupled with a management program (The HEUREKA system), with several thinnings and a final clear cut. The management program, growth models and biomass determination functions may differ between *Pre-commercial thinning* and *Early fertilization*. Harvested wood carbon is subtracted from the living tree carbon stock at each simulated harvest in the model. Site and tree measurement data after *Pre-commercial thinning* and before *Early fertilization* year 0, respectively, are input data to the models. The HEUREKA system is described in the following section.

8.1.5 HEUREKA Forestry Decision Support System

HEUREKA Forestry Decision Support system (www.slu.se/heureka) which is developed and maintained by the Swedish University of Agricultural Sciences (SLU). For an overview of the system, see Wikström et. al (2011). HEUREKA is a software system for forestry planning and analysis and is applicable from a single stand level to whole landscapes, forest ownerships and country regions. The system is widely used by Swedish forest owners and forest companies, as well as for forest research and graduate education at the Forestry Faculty at SLU in Sweden. HEUREKA has since the first release in 2009 become the de facto standard tool for long-term forestry analysis in Sweden. For a list of publications where the system is used, see Anon. (2015). The system is the result of a ten year research program and all included models and functions are first subjected to a scientific evaluation through the peer-review or similar systems. The tree growth model has been validated and published in a peer-reviewed journal (Fahlvik, Elfving et al., 2014).The growth model in Heureka projects growth in five-year discrete time intervals. The default planning horizon when using Heureka is twenty five-year periods corresponding to 100 years, i.e., approximately one forest rotation.

8.1.5.1 Input data required

The minimum input data (variables) required to apply the tree carbon stock prognosis model for a forest stand may be divided into the following three groups:

Group	*Input variables*
Geografic location	GPS coordinates
Site characteristics	Site index (H100) Altitude, m Vegetation type class Soil moisture class
Tree layer	Mean tree age Number of trees /ha Basal tree area/ha Mean tree height Mean tree diameter Tree species distribution

The system may also import sample plot data and tree lists. The model can handle any naturally occurring tree species in Sweden. The HEUREKA system supports prognosis on either stratified sampling data, or on one or many stands that belong to a forest holding.

8.1.5.2 Growth and Yield Models

Tree Development Models

The HEUREKA growth model system consists of several subcomponents. Each component is responsible for a certain phase of a forest stand's succession from bare land to final felling, or, for uneven-aged management, to an extended series of selection felling. The system uses single-tree objects as the primary description unit. The input data is either actual sample plots with measured trees, or stand-level aggregate values as described above from which the system can generate simulated sample plots and trees. The model acts on a so called prediction unit (PU), which correspond to a sample plot in a stand. A stand may consist of one or more PU:s. For each five-year period, growth is calculated for each PU separately. The results are presented as sums or averages over the included PU:s, taking the inclusion probability for each PU into account. Before calculating the growth, possible treatments are simulated. The treatments are coordinated over the PU:s units. For example, a thinning is distributed over the PU:s so that the thinning grade for an individual PU is adjusted as a function of the basal area. Dense PU:s will obtain a larger thinning grade percentage than less dense PU:s. The system distinguishes between the two development phases, young stand phase and established stand phase.

The Young Stand Phase

The young stand phase applies until the mean height of a stand is 6.5 m, after which the established phase follows. The IFM Project activity ***Pre-commercial thinning*** is carried out during this stand phase. During this phase, the growth development of trees is driven by the calculated height development. The height development is based on the mean height development of crop trees for each species, after which the height growth for each individual tree is calculated as a function of the tree's relative size, species and site characteristic on the plot (Elfving 1982). The diameters of young trees in young stands are calculated with a function using tree height, relative tree size, and site variables as explanatory variables (Nyström and Söderberg, 1987). Regeneration of new stands on bare land or after final felling is simulated with height distribution functions, from which tree lists are generated (see Elfving 2009, p. 14). The regeneration model generates a tree list at a mean height of about 2 m called the activation height. The forest states in periods between the regeneration treatment and the time at which the activation height is reached are interpolated. The model consists of five steps:

Step 1: The total number of stems is calculated.

Step 2. The number of stems for each species is calculated.

Step 3. The mean height of each species is calculated.

Step 4. The height distribution is calculated for each species with a Weibull distribution functions.

Step 5. Trees are generated from the tree list using either a deterministic or stochastic approach. The deterministic approach is used as default, and in this case each tree object is given a tree expansion factor weight for the number of trees that the tree object represents (in the prediction unit). The regeneration result depends on the selection regeneration method (planting, sowing or natural regeneration), regeneration species, and site type.

Mortality and damages in young stands are calculated according to Näslund (1986). As for the regeneration model, it is applied in a deterministic way by default, so that mortality probability is applied by reducing the tree expansion factor weight.

The Established Stand Phase

In the established phase, growth is driven by basal area growth functions and height development functions (see Fahlvik, et al. 2014 for details). The basal area growth model consists of two components, a basal area growth for all trees in stand or plot (called a “stand-level” model), and a single-tree model to allocate the predicted growth to individual trees (Fahlvik, Elfving et al. 2014). This setup, with a stand-level growth model to determine the total growth before proceeding to the single tree growth functions, has shown to give the best growth predictions on a large number of validation plots (Fahlvik, et al. 2014).

Tree mortality in established stands are calculated with a model develop by Eflving (2014, se appendix), an adapted version of the peer-reviewed model by Elfving (2010).The calculated probability for a tree to die is applied by reducing its tree expansion factor weight proportionally to the mortality probability.

8.1.5.3 Generation of Treatment Schedules

For generating treatment schedules for each stand included in an analysis, Heureka has a so called treatment program generator (TPG). Based on user settings, legislative restrictions (minimum cutting age and mandatory regeneration), and thinning prescription guides, the TPG model uses enumeration to create a number of alternative treatment programs for each stand within the feasible region of allowed actions. Two different treatment schedules for a stand differs in one or several choices of what activities to apply, and when and how to apply them. A user can for example set the bounds for what management system to apply (even-aged, uneven-aged or no management), what thinning guide to use, what regeneration species to use, the number of plants when planting, the desired stem density and species distribution after pre-commercial thinning, whether to fertilize or not, and how many year the time for final felling should be varied.

The output from the TPG is used in a built-in optimization model. The optimization problem is formulated by the user which is therefore very flexible to what the user wants to analyze. The optimizer can either be used to optimize the net present value or another objective, subject to those constraints that the user defines (for example related to FSC certification rules and timber flow restrictions). The optimizer can also be used for sensitivity analysis and investigation of trade-offs between different utilities.

8.1.5.4. Handling Uncertainty

The Heureka growth model is be default run in a deterministic mode. Of course, tree growth and tree mortality is a highly stochastic process. Likewise, future prices and costs are unknown. Elfving (2009) concludes that the variation coefficient in predicted growth can be expected to be about 20 % (see Appendix 1). In Fahlvik et al. (2014) it was also shown that the prediction errors did not increase with the time horizon length used in the growth projections.

8.2 Estimation of Project Activity Carbon Stock

8.2.1 Stand and Tree Variable Data Collection

- Project activity *Pre-commercial thinning* : The same stand variable data as for baseline are used for carbon stock calculations. Tree variable data are collected from field sample plot tree measurements *after* the Project activity is carried out, according to the methods described in chapters 9.3.2 and 9.3.3.

- Project activity *Early fertilization*: The same stand and tree variable data as for Baseline are used for the carbon stock calculations

8.2.2 Tree Carbon Stock Estimation

Tree carbon stock is estimated in a similar way as for baseline (8.1.3).

8.2.3 Tree Biomass Growth and Carbon Stock Changes

Tree biomass growth and carbon stock changes after pre-commercial thinning are calculated in the same way as for Baseline. For project activity ***Early fertilization,*** a certain fertilization policy model in HEUREKA is used, in which time for fertilization and amount of fertilizer are optional. The fertilization effect is calculated according to Petterson (1994) (also recited in Elfving, 2009, p. 78). The fertilization effect in this model is given as volume growth increase, and is allocated to the trees by assuming that the height growth to diameter growth ratio is not affected by the fertilization effect.

8.3 Measurements and Verification of Estimated Project Activity Carbon Stock

The model estimated living tree carbon stock size in a Project activity stand, will always deviate from the ”true” total carbon stock, as determined from field tree measurements. Therefore, this deviation has to be calculated at each measurement/verification occasion as an “uncertainty factor”. This factor will then be used for correction of the model estimated GHG removals for both Baseline and Project activity as well as for the number of credits, available for issue during the years until next verification. The uncertainty factor should be calculated according to the method described in “Approved VCS Methodology VM 0012”.

8.4 Assessment of Leakage

According to the AFOLU requirements, there are three types of leakage:

1) Market leakage occurs when projects significantly reduce the production of a commodity causing a change in the supply and market demand equilibrium that results in a shift of production elsewhere to make up for the lost supply.
2) Activity-shifting leakage occurs when the actual agent of deforestation and/or forest or wetland degradation moves to an area outside of the project boundary and continues its deforestation or degradation activities elsewhere.
3) Ecological leakage occurs in WRC projects where a project activity causes changes in GHG emissions or fluxes of GHG emissions from ecosystems that are hydrologically connected to the project area.

Leakage in IFM projects is predominately attributable to market leakage. However, under the applicable conditions of this methodology, the Project activities do not result in decreased harvest amounts, resulting in market leakage. The Project activities increase the production of raw materials and hence there is no loss in supply and no shift of production elsewhere. According to the AFOLU requirements the market leakage discount factor can therefore be set to 0%.

This methodology is not applicable to project activities stopping deforestation and/or forest or wetland degradation.

8.5 Calculation of Net CO_2 Removals as Sink for Baseline and Project activity

8.5.1 Net Greenhouse Gas Benefit in Each Stand

The HEUREKA model calculates the expected amount of C in the living tree carbon pool for each 5-year period during a 100 year rotation. The amount of C is converted to sequestered CO_2 by multiplication by 3.67.

From this, the expected net (**N**) greenhouse gas removals (**R**) for the Baseline (**BSL**) scenario for 5-year period number **p** may be calculated as:

$\Delta C_{N,BSL,p} = \Delta C_{R,BSLp} - \Delta C_{E,BSLp}$ **as** t CO_2-e

where

p= 5-year period number (1-20).

$\Delta C_{N,BSL,p}$ = Baseline net greenhouse gas removals as sinks; t CO_2-e

$\Delta C_{R,BSL,p}$ = Baseline carbon stock changes (removal) in living tree biomass; t CO_2-e

$\Delta C_{E,BSL,p}$ = GHG emissions from FM activities within the Baseline area; t CO_2-e

Similarly to this, the expected net removals for the Project (**PRJ**) scenario, may be calculated as:

$\Delta C_{\mathbf{N,PRJ,p}} = \Delta_{\mathbf{R,PRJ,p}} - \Delta C_{\mathbf{E,PRJ,p}} - \Delta C_{\mathbf{Leakage}}$ **as** t CO_2-e

where

p= 5-year period number (1-20).

$\Delta C_{\mathbf{N,PRJ.p}}$ = Project activity net greenhouse gas removals as sinks; t CO_2-e

$\Delta C_{\mathbf{R,PRJ,p}}$ = Project activity carbon stock changes (removal) in living tree biomass; CO_2-e

$\Delta C_{\mathbf{E,PRJ,p}}$ = GHG emissions from IFM activities within the Project activity area; CO_2-e

$\Delta C_{\mathbf{Leakage}}$ = Project activity leakage as described in Section 8.4. According to the conclusion from the Assessment of Leakage, $\Delta C_{Leakage}$ is set to 0.

The greenhouse gas benefit (**B**) of the Project activity may be calculated for 5-year period number p as

$\Delta C_{\mathbf{B,PRJ,p}} = \Delta C_{\mathbf{N,PRJ,p}} - \Delta C_{\mathbf{N,BSL,p}}$ **as** t CO_2-e

and for a whole rotation (100 years) as $\sum \Delta C_{\mathbf{B,PRJ,p}}$ for p = 1-20, and as annual average as

$\sum \Delta C_{\mathbf{B,PRJ,p}} / 100$.

The AFOLU Requirements for IFM-Projects that include wood harvesting, are that the annual GHG benefit for each IFM-activity has to be accounted, on which the available number of credits, that may be issued, and the first year when credits are available, is based. Therefore, a linear interpolation of $\Delta C_{\mathbf{B,PRJ,p}}$ has to be made for the years between the calculated 5-year period values, according to the proposal in chapter 5.6 “Time series consistency and recalculations” of “Good Practice Guidance for Land Use, Land-Use Change and Forestry”.

The interpolated annual stand GHG benefit is calculated as:

$\Delta C_{\mathbf{B,PRJ,p,t}} = (\Delta C_{\mathbf{B,PRJ,p}} - \Delta C_{\mathbf{B,PRJ,p-1}})/5$ for each 5-year period, where

t= year number (1-5) for 5-year period number p.

Based on this, the total GHG benefit to date and the total available credits each year are calculated, according to the “AFOLU Guidance regarding Calculating of the Long-Term Average Carbon Stock for IFM Projects with Harvesting”.

8.5.2 Expected Net Annual Greenhouse Gas Benefit and Available Amount of Credits for the Whole Project

During a period of years after the Project start, new stands in the Project area and within the framework of the Project may be subjected to IFM activities and thus added to the pool of IFM-stands. The total expected Project GHG benefit of all Project activity stands for calendar year y is calculated as:

$\Delta C_{\mathbf{B,PRJ,\,y}} = \sum \Delta C_{\mathbf{B,PRJ,p,t,\,y}}$ for stand number 1-n.

9. MONITORING

The purpose of the monitoring program is to reliably monitor changes in carbon stocks in a cost-effective way for the Project scenario and to compare the measured carbon stocks against modelled carbon stocks for the Baseline and for the Project scenario. Based on this, an uncertainty factor is calculated, and used for correction of the modelled tree carbon values related to the calculation of VCU's, prior to each verification. A Project monitoring report on the results of implementation of the monitoring plan have also to be produced for each monitoring period prior to verification.

9.1 Data and Parameters Available at Validation

Data / Parameter	GPS coordinates
Data unit	-
Description	GPS coordinates according to national standard systems
Equations	Input variable to the Heureka model
Source of data	Stand characteristics data bases or field registration
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The growth prediction models include a geographical location variable for each forest stand.
Purpose of Data	Input variable for tree growth prediction functions for Baseline and Project activity scenarios.

Data / Parameter	Site index H100
Data unit	m
Description	Average height of the 100 tallest trees at the age of 100 years for Scots pine and Norway spruce. A measure of site fertility.
Equations	Input site characteristics variable to the Heureka model
Source of data	Stand characteristics data bases
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	The H100 site fertility index system is applied as standard in Swedish forestry. The site fertility index is specific for Scots pine, Norway spruce. Almost all production forest sites are fertility classified according to this standard.
Purpose of Data	Input variable for tree growth prediction functions for Baseline and Project activity scenarios.

Data / Parameter:	Vegetation type class
Data unit	N/A
Description	Input site characteristics variable to the Heureka model
Equations	
Source of data	Stand characteristics data bases
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	Input variable for tree growth prediction functions for Baseline and Project activity scenarios.
Comments	Vegetation type classes are described in Appendix F

Data / Parameter:	Soil moisture class

Data unit	
Description	
Equations	Input site characteristics variable to the Heureka model
Source of data	Stand characteristics data bases
Value applied	N/A
Justification of choice of data or description of measurement methods and procedures applied	
Purpose of Data	Input variable for tree growth prediction functions for Baseline and Project activity scenarios.
Comments	Soil moisture classes are described in Appendix F

9.2 Data and Parameters Monitored

Data / Parameter:	Area
Data unit:	hectare
Description:	Area of Project activity forest stands
Equations	
Source of data:	Digitalized Project activity area boundary
Description of measurement methods and procedures to be applied:	Area is calculated using digital map data
Frequency of monitoring/recording:	At Project start after Project activity is carried out
QA/QC procedures to be applied:	Check list controlled at Project start. Remeasured for 10% of the Project activity stands
Calculation method:	Calculation of Baseline and Project removal

Data / Parameter:	Db
Data unit:	mm
Description:	Tree diameter on bark at 1,3 m height above ground
Equations	Used in Biomass estimation functions, growth functions
Source of data:	Sample plot monitoring
Description of measurement methods and procedures to be applied:	Measured with an electronic caliper, with computer recording
Frequency of monitoring/recording:	Measured at Project start and then at 10 year interval
QA/QC procedures to be	Check list controlled at Project start. Remeasured for 10% of the

applied:	Project activity stands
Purpose of data:	Calculation of Project emission/removal

Data / Parameter:	Tree height
Data unit:	dm
Description:	Tree height above ground
Equations	Used in biomass estimation functions, growth functions
Source of data:	Sample plot monitoring
Description of measurement methods and procedures to be applied:	Measured with an electronic height measurement device in established stands and/or a ruler bar in young stands
Frequency of monitoring/recording:	Measured at Project start and at 10 year interval
QA/QC procedures to be applied:	Daily calibration of device. Check list controlled data at Project start. Remeasured for 10% of the Project activity stands.
Purpose of data:	Calculation of Project emission/removal

Data / Parameter:	Tree species
Data unit:	Pine, Spruce, Birch, Other broadleaved species
Description:	Species is recorded for each diameter and height measured tree
Equations	Used in biomass estimation functions, growth functions
Source of data:	Sample plot monitoring
Description of measurement methods and procedures to be applied:	-

Frequency of monitoring/recording:	Recorded at Project start and at 10 year interval
QA/QC procedures to be applied:	Check list controlled data at Project start. Remeasured for 10% of the Project activity stands.
Purpose of data:	Calculation of Project emission/removal

9.3 Description of monitoring plan

The monitoring plan includes procedures for:

- Spatial inventory change monitoring
- Field plot measurements of tree carbon stock
- Monitoring standard operation
- Quality control and data storage

9.3.1 Spatial Inventory Change Monitoring

Project proponents have to update and document spatial changes in the forest inventory data or Project activity area annually. Such changes might be caused by harvests, fires, wind- and snow-break.

9.3.2 Field Plot Measurements of Tree Carbon Stock

The objective of the field plot measurements is to determine the statistical accuracy of the modelled carbon stock in each stand. The input to the tree carbon stock models are tree measurements at the Project start (year 0), when the Project activity is carried out, on either permanent or temporary sample plots (or a combination) for both the Baseline and the Project scenario. Similar tree measurements and carbon stock calculations are then repeated at 5 year interval for the Project scenario and compared against the associated modelled values to determine the error (deviation) in the modelled value for each stand. This error value is then used for calculation of the uncertainty factor, described in the Chapter 9. Further useful information about appropriate carbon stock estimation methods may be found in “Sourcebook for Land Use, Land-Use Change and Forestry Projects" (Pearson, Walker & Brown, 2005) and in (Pearson, Brown & Birdsey, 2007).

Sample Plot Type, Size, Number and Distribution

Permanent circular sample plots with radius between 3 (young stands) and 7 m (established stands), marked on a map and with geo-reference and all measured trees marked, are recommended for this Methodology.

Young stands (Pre-commercial thinning activity)

Permanent circular sample plots are systematically distributed in advance on a map over the whole Project activity area in each stand, with randomly chosen start point, and with recorded GPS coordinates for plot centres.

Established stands (Early fertilization activity)

In established stands, not previously thinned, sample plots are distributed in a similar way as for young stands. In stands, where a first thinning already is carried out, the forest is traversed by mainly parallel running clear-cut thinning vehicle roads of about 4 m width at a distance of 20-25 m. In order to minimize the variation in expected tree carbon stock between sample plots, the centre of the plots is placed centred between the thinning roads. The map plot distribution is made in advance in the same way as for young stands, but the plot centre in field is moved from the preliminary GPS determined centre point to the closest centred point between the thinning roads.

The sample plot number per stand required, to achieve an estimated tree carbon stock plot mean, deviating less than 10% from the true mean value at a 90% confidence interval, is calculated. For this purpose, an introductory survey of the variation in plot basal area within the Project activity stand area has to be carried out, for determination of the coefficient of variation between plots in percentage of the mean. A reasonable sample plot number under these conditions in well managed boreal conifer forests should be 10-15 plots/stand.

9.3.3 Sample Plot Tree Measurements

Stem diameter at breast height (1.3 m above ground) is measured using a computerized caliper for efficient data transfer directly into the HEUREKA system. All reasonable healthy trees with diameter > 4 cm in established stands and diameter > 2 cm in young stands, are measured. Dying or severely damaged trees (wind or snow break, moose browsing) are not measured. In addition, tree height is measured on one randomly chosen tree/plot and species in established stands and 1-3 trees/plot in young stands (more trees if the height variation is greater). Tree heights are linked with the stem diameter, when recorded. All measured trees are colour marked at the diameter measuring point of the stem, with water resistant colour.

9.3.4 Quality Assurance and Quality Control Methods (QA/QC)

The monitoring plan has to include QA/QC procedures for:

- reliable field measurements
- verifying data entry
- data archiving

9.3.5 Field Measurements

All field activities regarding tree and stand data collection, have to be accompanied by written check lists and step by step procedure descriptions, to ensure that measurement data quality and accuracy are fully repeatable and are independent of measurement time and field crews. Field crews must be subjected to sufficient training in all aspects of field data measurements and collection. All such training activities have to be documented by the Project proponent.

All Project activity stands have to be subjected to a measurement audit, at which at least 10 % of the sample plots are completely re-measured. This audit should be carried out within one month after the measurements. At this occasion, also other field observations of relevance are made, according to an elaborated check list. The deviation between audit measurements and original measurements (the measurement error) is calculated and compared against a maximum error threshold value of 10% of the true (audit) value at 90% confidence interval. If the error exceeds this threshold value, the reason for that has to be evaluated, according to an elaborated step-by step check list. The evaluation result determines which measures have to be taken. Possible alternatives may be re-measurements of all plots or establishment of new plots.

9.3.6 Data Entry

Measurements should to highest possible extent be carried out with measurement device with in-built data memory for immediate digital recording of measurement values. Written data and information should be transferred into digital form after each work day. A measurement data screening procedure should be elaborated, for check of that the data are complete before leaving the Project activity area. Missing or erroneous data may be completed by re-measurements. If such correction is not possible, the actual sample plot must be excluded from calculations.

9.3.7 Data Archiving

All the Project procedure descriptions, Project activity descriptions, maps, measurement data, data analyses and calculations and reports will be securely stored until 2 years after the Project period.

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APPENDIX A: EFFECTS OF NITROGEN FERTILIZATION ON GHG EMISSIONS

Nitrogen nutrient addition to the forest ground results in reduced autotrophic root respiration and heterotrophic respiration through decomposition of organic matter, resulting in a reduced CO_2 emission by 15-50% (Olsson *et al* 2005). The autotrophic respiration is regulated by the root biomass amount and activity. Increased nitrogen availability results in reduced root biomass and activity, caused by reduced allocation of carbon to the root system (Bloom 1985). The reduction of heterotrophic respiration after nitrogen fertilization is explained by production of less decomposable litter, less litter production from mycorrhiza and fine roots and lowered soil temperature due to more dense tree crowns. From several nitrogen fertilization experiments in Scandinavia, it was calculated that soil carbon increased by 13 kg per kg applied nitrogen in spruce stands and by 7 kg in pine stands (Hyvönen *et al.*, 2008). It was estimated that 60 % of the increased carbon sequestration was a result of slower litter decomposition rate, and the rest of increased litter production.

N_2O emissions may occur after fertilization of boreal forests from denitrification under anaerobic (wet) conditions or nitrification of supplied nitrogen. There is a strong positive correlation between soil nitrogen availability and N_2O emissions, with a threshold value of 20 for the C/N ratio in the soil, under which the N_2O emissions increase more rapidly (Klemedtsson *et al.*, 2005). Nitrogen fertilization on medium to low fertile mineral soils in boreal forests in Scandinavia is estimated to result in emission rates, corresponding to only 0.5-1% of applied nitrogen (Maljanen *et al.*, 2006). These emissions constitute less than 5% of the increase in forest CO_2 sequestration after fertilization (Nordin *et al* 2009)

Methane may both be consumed in the forest ecosystem through oxidation to CO_2 and formed and emitted under oxygen free, mostly wet, conditions in the soil. Such moist conditions will not be common in forests, subjected to nitrogen fertilization, whereas the risk for increased methane emissions after nitrogen fertilization is consider as negligible (Nordin *et al* 2009).

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APPENDIX B: CARBON DIOXIDE EMISSIONS FROM PRODUCTION, TRANSPORT AND DISPERSAL OF FERTILIZER

Nitrogen fertilization has a very positive effect on the carbon balance in Swedish forest (Swedish Forestry Agency Report 1/2014). On average, carbon sequestration in the tree trunk is 700 kg CO_2/m^3. Fertilization of forests in Sweden results in an increment increase of 10-20 m^3 per hectare (Pettersson, 1994), which is equal to an extra carbon sequestration of 15 x 700 = 10500 kg CO_2 per hectare. On top of this, there is an increase in carbon sequestration in branches, tops and roots.

The main fertilizer used in Swedish forestry is Skog-CAN, which is produced outside Sweden and brought to the market by Yara (yara.com). Skog-CAN is used at 150 kg nitrogen per hectare. According to Yara, the production, transport and dispersal of Skog-CAN result in emission of 3.14 kg CO_2 per kg nitrogen (Table 1).

Table 1: Emissions of carbon dioxide for Skog-CAN (built on data from Yara)

Emissions	**CO_2-eq/kgN**	**CO_2-eq/ha (150kgN/hectare)**
Production	3	450
Transport	0.053	8
Dispersal	0.087	13
Total	**3.14**	**472**

The extra carbon sequestration per extra m^3 of biomass that is produced by fertilization is in total about 1.3 tons for the whole tree, including trunk, branches and roots. Table 2 and Figure 1 illustrate the effect of nitrogen fertilization on the production of biomass and carbon sequestration. The “Carbon dioxide ratio” explains the ratio between the amounts of CO_2 taken up by increased increment (CO_2-incr) divided with the amounts of CO_2 that is emitted for production, transport and dispersal (CO_2-emi). For example, if the increment increases with 15 m^3 then the photosynthesis uses 10.5 ton of carbon dioxide for the production of the biomass that is stored in trunks. This gives a CO_2-ratio of 10500/472 = 22. For transport and dispersal (excl. production) of Skog-CAN the CO_2-ratio is 500.

Table 2. Carbon sequestration in different parts of the tree, effects per hectare and carbon dioxide ratio.

	Increased increment:	10 m^3	15 m^3	20 m^3	10 m^3	15 m^3	20 m^3
Tree parts	**CO_2-eq/m^3**	**Uptake tons of CO_2/hectare**			**Carbon dioxide ratio**		
Trunk	0.7 tons	7	10.5	14	15	22	30
Trunk+branches	1.0 tons	10	15	20	21	32	42
Trunk+branches+roots	1.3 tons	13	19.5	26	28	41	55

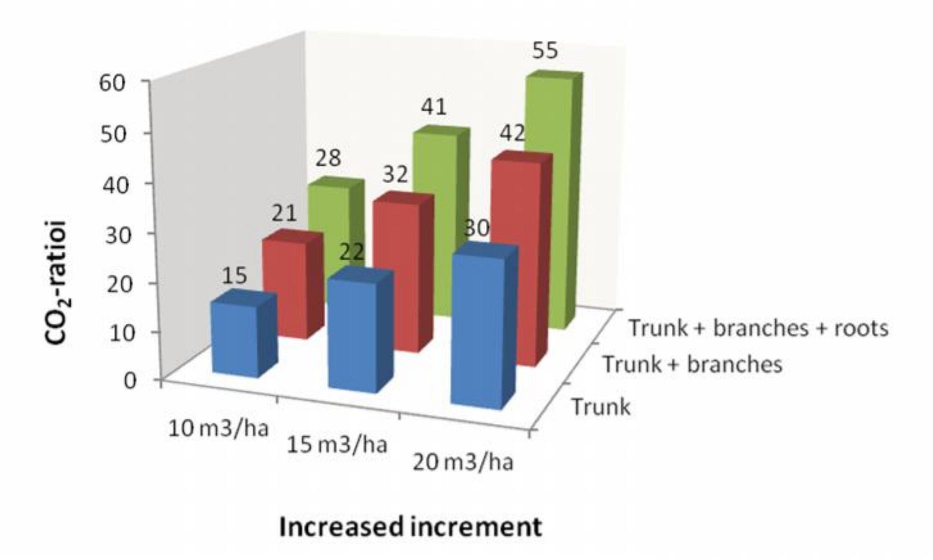

Figure 1. CO_2-ratio for different parts of trees in combination with three increment responses to nitrogen fertilization

In conclusion, less than 5 % of the increase in carbon sequestration is lost due to emissions during production, transport and dispersal of the fertilizer. Carbon emissions from combustion of fossil fuels in vehicles and machinery can therefore be deemed *de minimis* for fertilization of forest land.

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APPENDIX C: ACTIVITY METHOD

This methodology uses the standardized activity method approach for the demonstration of additionality. Project activities that meet the applicability conditions of this methodology (see section 4) and demonstrate regulatory surplus are deemed as additional.

Applicability Conditions

The applicability conditions of this methodology represent the positive list. The project must demonstrate that it meets all of the applicability conditions, and in doing so, it is deemed as complying with the positive list.

Project activities on the positive list are all financially non-viable in commercial forestry in Sweden without the intervention created by the carbon market. This is due to the slow forest growth and long rotation cycles (80-120 years) that prevent forest owners from extended early forest management investments with uncertain long-term future revenues.

Productive forests in Sweden are typically managed in a clear-cut harvest regime with planting or natural regeneration. Differences between sub-areas of Sweden are normally related to the intensity of the forestry, driven by growth rates etc., but the guiding principles of the management regimes are similar. The methodology can for this reason be applied across the total geographic scope, i.e. Sweden.

Baseline Scenario

This methodology is applicable to commercial forest operations utilizing the standard FSC/PEFC certified forest management regime that is common practice in Sweden. Both large-scale industrial forest owners as well as the family forestry can apply project activities on their properties.

The common practice forest management regime typically focuses on a single dominant tree species in each forest stand. Norway spruce and Scots pine are very common tree species. Forest stands, dominated by hardwood are uncommon as well as stands of other softwood species. When regenerating forests, most often only a single species is planted on each site or section of a site. A pre-commercial thinning is normally made after the regeneration phase and is typically not generating any commercial products. Stand management is in most cases driven by an overall objective of producing softwood saw logs that generate the highest values to the forest owner. To improve growth rates and diameter distribution, stands are generally thinned 1-3 times depending on site conditions. During thinning operations, the majority of the harvested volume is pulpwood. In some cases stands are fertilized ~10 years before final harvest to avoid the declining growth rate in 70-110 year old stands. Final harvest is generally made through a clear-cut of a harvest site and generates a large proportion of saw logs. Pulpwood and in some cases tree biomass for energy is also harvested.

Forest certification schemes and the forestry act are driving towards higher biodiversity in forest stands, which has lead to increasing volumes of hardwoods mixed with the dominant softwood species.

The common practice forestry in Sweden is considered to be the baseline scenario of this methodology. Forest operations are similar across the country and consistently distributed through forest owners associations, large industrial/non-industrial landowners and purchasing organizations. Most of them utilize subcontractors for on the ground harvest and forest management operations. Contractors are generally well educated to comply with forest certification standards.

Positive List

Project activities were selected to the positive list by using the financial viability option (VCS Standard 4.6.9, option B) to demonstrate that they are financially or economically less attractive than their alternatives. The CDM *Tool for the demonstration and assessment of additionality* sets out the procedures for the investment analysis. The VCS Standard requires that step 1, 2 and 4 of the tool are followed.

- Step 1: Identification of alternatives to the project activities consistent with current laws and regulations
- Step 2: Investment analysis
- Step 4: Common practice analysis

The following sections describe the analyses conducted in each step.

Step 1: Identification of alternatives to the project activities consistent with current laws and regulations

Step 1 of the additionality tool identifies realistic and credible alternatives to the project activity. The most realistic alternatives to the project activities are found in the standard FSC/PEFC certified forest management regime utilized by most of the forest owners in Sweden. This regime is common practice across both large-scale industrial forest owners as well as the family forestry.

Alternatives to the *early and modified pre-commercial thinning* (PCT) project activity are either the PCT that is utilized in the standard management regime or simply no PCT. There are no legal requirements related to PCT. However, a forest management regime without PCT is normally long-term less beneficial to the forest owner due to the poor commercial value and high thinning cost of lower volume trees that is generally the outcome from omitted PCT. Given this, the realistic alternative to the project activity is the short-term expensive standard common practice pre-commercial thinning regime that is utilized by all major forest owners in Sweden.

Alternatives to the project activity *early fertilization* are either a regime with no fertilization or a regime with several early fertilizations. Fertilization of commercial forests in Sweden is relatively unusual. In 2004-2013 on average ~46,000 ha per year of the productive forest area was fertilized. This is only 0.2% of the total productive forest area in Sweden (Swedish Forest Agency, 2015). If fertilization takes place, it is normally conducted 10 years before final harvest. Early fertilization is very unusual, which makes the common practice of no fertilization the most credible alternative to the project activity. There are no laws or regulations that force forest owners to fertilize.

Step 2: Investment analysis

Sub-step 2a and 2b: Determine appropriate analysis method

The investment comparison analysis using net present value (NPV) as financial indicator was selected as outlined in step 2 of the additionality tool. This is the standard forestry investment analysis utilized by most forestry professionals in Sweden.

Sub-step 2c: Calculation and comparison of financial indicators

The project activities were compared with baseline alternatives in a model where forest management costs and harvest revenues were used to calculate net present values. Below are the factors allowed to vary:

- Discount rate
- Wood prices, saw-log and pulpwood prices
- Management costs, e.g. planting or pre-commercial thinning costs
- Harvest costs, e.g. thinning and final harvest costs
- Total rotation time and timing of management operations and thinning, etc.
- Harvest volumes and distribution of saw-log/pulpwood

Discount rate

The discount rates, tested were 2 and 3% for *Pre-commercial thinning* and 2, 3 and 4% for *Early fertilization*. These are commonly used real interest rate levels, used in comparable forest management analyses[1].

Wood prices

The model uses wood prices for the dominant tree species pine and spruce. Assortments were limited to the main assortments on the market – saw-logs and pulpwood. Data was supplied by Sveaskog, which is the state forest company of Sweden. Sveaskog utilize Pöyry Management Consulting to collect price data on the Swedish wood market for their own long-term forest management planning. Price information is collected from both the selling and purchasing side of the market.

The model allows prices to increase or decrease over time, by means of a real price inflator/deflator. In this comparison, the deflator is set to 0%, as it is very hard to predict price development over a full forest management cycle (80-120 years). Over the last 20 years prices have declined by 0.5-1.5%[2] per year in real terms depending on assortment. However, during the last 5-10 years prices have increased by 0.5-3.0% per year. Current price development is positive, but also less predictable given uncertainty regarding the forest industrial development and potential demand from the biomass energy sector.

Management costs

Forest management costs are considered when e.g. pre-commercial thinning operations take place. Overhead management and planning costs are assumed to be fixed and independent of the choice of a baseline or project activity. This is also the case for e.g. road maintenance that will be similar in each forest regime.

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[1] Lars Karlsson, Kenneth Nyström, Dan Bergström & Urban Bergsten (2015) Development of Scots pine stands after first biomass thinning with implications on management profitability over rotation, Scandinavian Journal of Forest Research, 30:5, 416-428

[2] Statistics Sweden, http://www.scb.se/sv_/Hitta-statistik/Statistik-efter-amne/Priser-och-konsumtion/Konsumentprisindex/Konsumentprisindex-KPI/33772/33779/Konsumentprisindex-KPI/272151/

As with wood prices, the model allows costs to increase or decrease over time, by means of a real price inflator/deflator. In this comparison, the deflator is set to 0%. Management cost development over the last 20 years is fairly flat, with decreasing costs in the 1990's and slightly increasing costs in the early 2000's.

Harvest costs

The model considers varying harvesting costs in different harvest operations. Thinning is more expensive per harvested cubic meter than final felling due to lower tree volume.

Similar to forest management costs, harvest costs are also allowed to vary over time. In this case , the deflator is set to 0%, as it is very hard to predict cost development over a full forest management cycle (80-120 years). Historically (1970's-1990's), real harvest costs have declined due to the mechanization of the forestry. In 1993-2003 harvesting costs fell at a real annual rate of 0.5% per year[3]. However, harvest costs have increased at a real annual rate of 0.6% per year over the last 10 years. Current cost development is less predictable given strengthened demand for low impact logging operations and potential warmer winters due to climate change, which increase logging cost in wet conditions.

Total rotation time and timing of management operations and thinnings

Rotation times and timing of management operations and thinnings are dependent on chosen activities. The model allows timing to be changed to optimize production in different management regimes.

For each activity, the cost/revenue balance was considered until a full management cycle was reached, i.e. until final harvest. Given the long rotation times, it was assumed that the value of following forest cycles was negligible.

Harvest volumes and distribution of saw-log/pulpwood

As with rotation time, the model allows harvest volumes to vary as a result of different management regimes. Similarly the management regimes will affect the distribution of saw-logs vs. pulpwood.

To simplify modelling only the dominant tree species is considered. It is assumed that hardwood volumes as a result of forest certification will be equal in project and baseline activities and thus have limited impact on analysis results.

Model calculations and results

The software Heureka PlanWise version 2.1 of the Heureka Forestry Decision Support System (www.slu.se/heureka), was used for the model calculations. The Heureka system is a series of software developed at SLU, the Swedish University of Agricultural Sciences, that allows the user to perform a large amount of different analyses and management plans for forestry. The system can make short and long term projections of timber, economy, environmental conservation, recreation and carbon sequestration. More than 20 of the major forest management companies/institutions are using the system for decision support and forest management planning, including the Swedish Forest Agency and Sveaskog. It is concluded that the use of the system is common practice in Swedish commercial forestry.

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[3] Swedish Forest Agency, http://www.skogsstyrelsen.se/Myndigheten/Statistik/Amnesomraden/Ekonomi/Tabeller--figurer/

For *Pre-commercial thinning* (PCT), the net present value was calculated for different number of stems after PCT. Analysis showed that the standard recommendations for stem density after PCT applied in Sweden were very close to those giving the largest NPV:s (Figure 1) and therefore the baseline NPV for each stand type was set to the largest NPV obtained. Discount rates were 2 and 3% real rate.

For *early fertilization,* first thinning with thinning grade 35%, was carried out in year 10 for baseline scenario. For project scenario, fertilization was carried out in year 1 and first thinning in year 10. Fertilization ten years before first thinning was repeated in subsequent forest generations. Thinning grade was increased to 40 % in order to harvest the additional volume, resulting from fertilization.
Discount rates were 2, 3 and 4 % real rate.

Input data

A number of stands representing different forest site types were simulated with PlanWise for the analyses. To do this, a stand register was create manually for the three spruce plantations and three pine plantations with varying site indexes. The number of trees was set to 6000 of which 90 % was the main species (spruce or pine) and 10 % was birch. After that the data was imported to Heureka and a prognosis was made long enough to include a PCT. In the first time period in which PCT was suggested by PlanWise, data for the forest state (before the PCT) was again extracted (mean age, mean height and number of stems per species). From this data a new stand register was created and imported to PlanWise, giving an initial state where PCT will be the first and immediate treatment (Table 1).

For the fertilization, a similar approach was used to obtain starting conditions for when a fertilization will be applied at the start of the planning period (ten years before the first thinning). To obtain this, the stands in table 1 were projected with a fixed PCT stem density of 2500 trees/ha, and projected until the first thinning. The forest state ten years before this thinning was extracted, a new stand register created in the same was as described above for the PCT case, and imported to PlanWise as a new dataset. Also, so called “treatment proposals” (a way to enforce predefined treatments in PlanWise and thus override the automatic treatment prescription generator in PlanWise for a given set of time periods) to enforce fertilization in the first year was entered into PlanWise.

Table 1. Initial state for the simulated stand used in the PCT analysis.

Forest site fertility index	Mean age (yrs)	Mean height (m)	Stems (trees/ha)	Species distribution		
				Spruce	Pine	Birch
G18 (Spruce Low fertility)	21	2.6	5987	90%	0%	10%
G24 (Spruce Medium fertility)	16	3.0	5994	90%	0%	10%
G30 (Spruce High fertility)	16	4.4	5977	90%	0%	10%
T14 (Pine Low fertility)	21	2.4	6000	0%	90%	10%
T20 (Pine Medium fertility)	16	2.8	5948	0%	90%	10%
T26 (Pine High fertility)	16	4.9	5766	0%	90%	10%

Table 2. Initial state for the simulated stands used in the fertilization analysis.

Forest site fertility index	Mean age (yrs)	Volume (m3sk/ha)	Basal area (m2/ha)	Dgv (cm)	Hgv (m)	Stems (trees/ha)	Species distribution		
							Spruce	Pine	Birch
G18	59	128.0	21.3	12.4	11.6	2297	89%	0%	11%
G24	36	113.4	19.9	11.8	10.9	2410	89%	0%	11%
G30	26	77.9	15.2	11.6	9.8	1961	91%	0%	9%
T14	61	108.8	20.8	13.7	10.3	1819	0%	91%	9%
T20	41	127.9	23.5	13.8	10.8	2049	0%	91%	9%
T26	21	61.5	14.8	10.6	7.6	2346	0%	93%	7%

Net present value for PCT

The response curve for NPV as a function of stem density after PCT was not strictly concave with a unique optimum. For example, stand fertility index T26 (Table 4) had a maximum NPV at 2000 stems/ha followed by a decreasing NPV up to 2200 /ha, after which the NPV increased again at 2300 /ha up to 2500 /ha. The reason for this irregularity is that the thinning schedule was changed when increasing the stem density from 2200 to 2300 /ha, with an earlier first thinning which was profitable enough to increase the total NPV. The main results showed that the differences in NPV between project and baseline scenarios were negative for both pine and spruce on low to medium to high fertility sites (Tables 3 and 4).

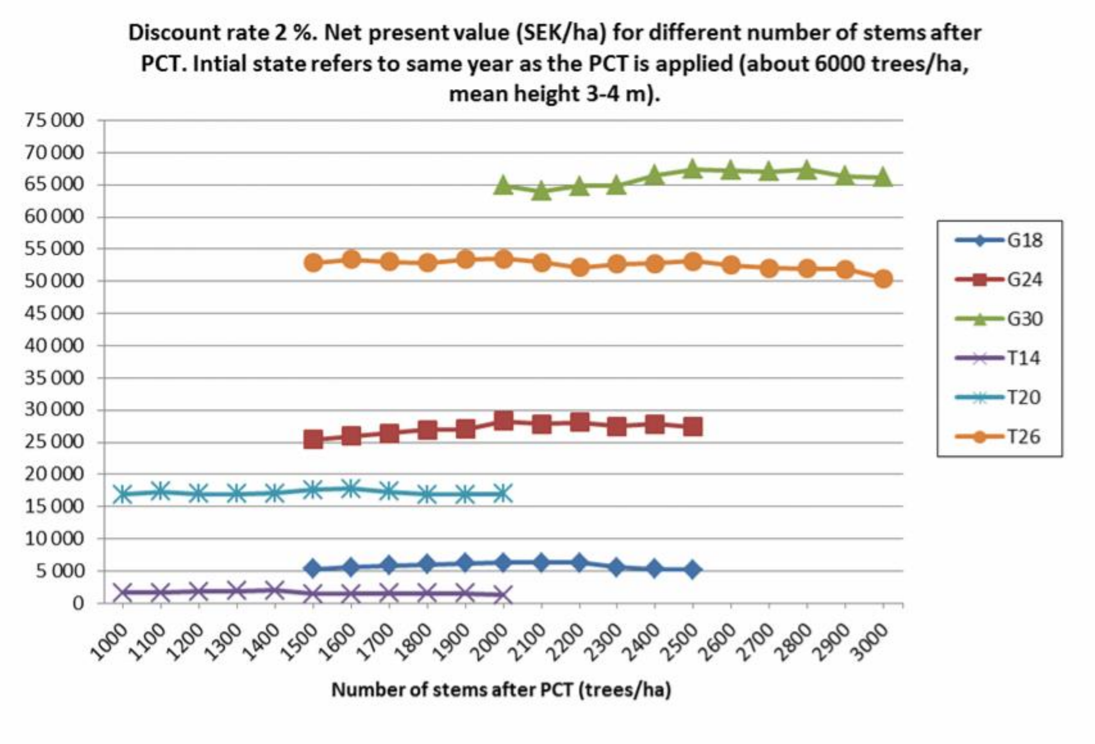

Figure 1. Net present value for different stem densities after PCT, with discount rate 2 %.

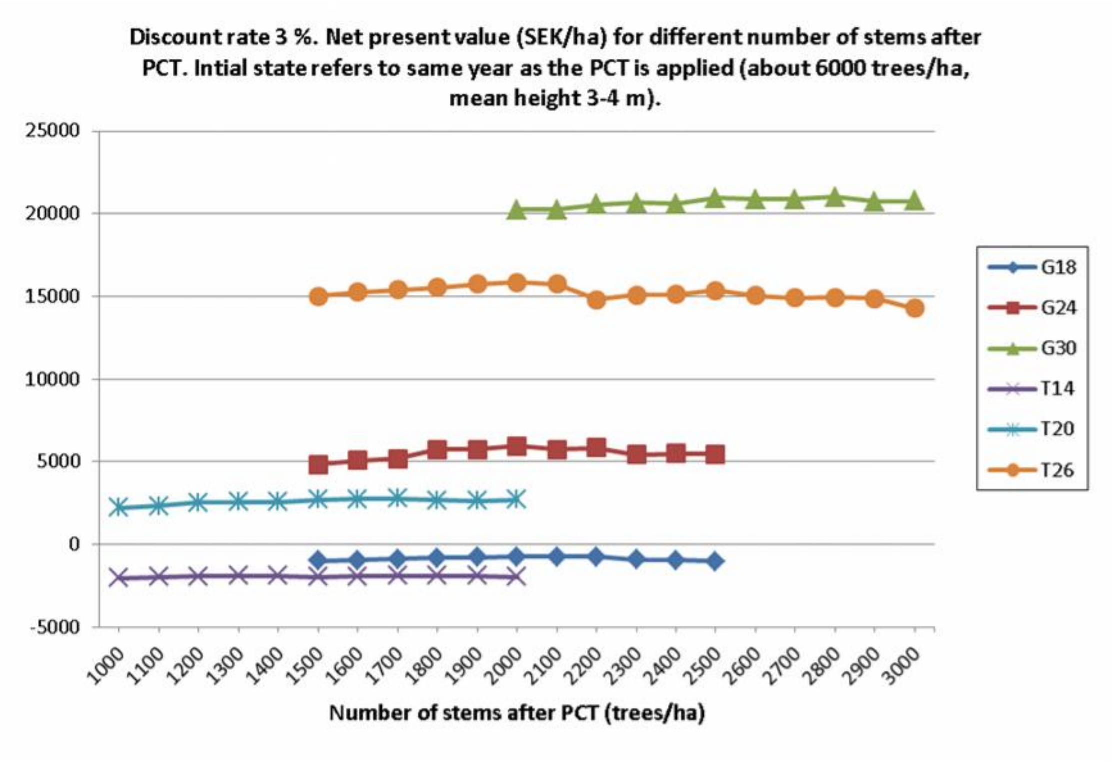

Figure 2. Net present value for different stem densities after PCT, with discount rate 3 %.

Tabell 3. Net present values (SEK/ha) for spruce stands for different stem densities after PCT.

Forest site type	Stems after PCT (trees/ha)	NPV (SEK/ha)			
		Discount rate 2 %		Discount rate 3 %	
		PCT modified	Diff PCT - Baseline	PCT modified	Diff PCT - Baseline
G18	1500	5355 ▼	-978	931 ▼	-465
	1600	5584 ▼	-749	1026 ▼	-370
	1700	5854 ▼	-479	1154 ▼	-241
	1800	6069 ▼	-264	1256 ▼	-140
	1900	6235 ▼	-98	1342 ▼	-54
	2000	6332 ▼	-1	1391 ▼	-5
	2100	**6333** ▬	+0	**1396** ▬	+0
	2200	6316 ▼	-17	1394 ▼	-1
	2300	5622 ▼	-711	1035 ▼	-361
	2400	5360 ▼	-973	952 ▼	-444
	2500	5192 ▼	-1 141	860 ▼	-536
G24	1500	25377 ▼	-2 951	11238 ▼	-1 704
	1600	25955 ▼	-2 373	11595 ▼	-1 347
	1700	26407 ▼	-1 922	11811 ▼	-1 132
	1800	26963 ▼	-1 365	12429 ▼	-513
	1900	27047 ▼	-1 282	12435 ▼	-507
	2000	28328 ▬	+0	**12942** ▬	+0
	2100	27802 ▼	-527	12593 ▼	-349
	2200	28116 ▼	-213	12755 ▼	-187
	2300	27470 ▼	-858	12232 ▼	-710
	2400	27813 ▼	-516	12408 ▼	-534
	2500	27381 ▼	-947	12309 ▼	-634
G30	2000	64871 ▼	-2 509	34867 ▼	-1 501
	2100	64005 ▼	-3 375	34771 ▼	-1 597
	2200	64803 ▼	-2 578	35240 ▼	-1 128
	2300	64916 ▼	-2 464	35369 ▼	-999
	2400	66531 ▼	-850	35812 ▼	-556
	2500	**67380** ▬	+0	36325 ▼	-43
	2600	67192 ▼	-189	36194 ▼	-174
	2700	67068 ▼	-312	36191 ▼	-177
	2800	67339 ▼	-41	**36368** ▬	+0
	2900	66358 ▼	-1 022	35856 ▼	-512
	3000	66142 ▼	-1 239	35815 ▼	-553

Tabell 4. Net present values (SEK/ha) for pine stands for different stem densities after PCT.

		NPV (SEK/ha)			
Forest site type	Stems after PCT (trees/ha)	Discount rate 2 %		Discount rate 3 %	
		PCT modified	Diff PCT - Baseline	PCT modified	Diff PCT - Baseline
T14	1000	1640 ▼	-334	-939 ▼	-200
	1100	1670 ▼	-304	-894 ▼	-155
	1200	1852 ▼	-122	-805 ▼	-66
	1300	1901 ▼	-73	-778 ▼	-39
	1400	**1974** ▬	+0	**-739** ▬	+0
	1500	1451 ▼	-523	-932 ▼	-193
	1600	1481 ▼	-493	-905 ▼	-166
	1700	1544 ▼	-429	-871 ▼	-132
	1800	1579 ▼	-394	-844 ▼	-105
	1900	1576 ▼	-398	-836 ▼	-98
	2000	1291 ▼	-682	-975 ▼	-236
T20	1000	16927 ▼	-826	6780 ▼	-645
	1100	17311 ▼	-442	6972 ▼	-453
	1200	16941 ▼	-812	7032 ▼	-393
	1300	17029 ▼	-724	7083 ▼	-342
	1400	17061 ▼	-692	7100 ▼	-326
	1500	17588 ▼	-165	7360 ▼	-65
	1600	**17753** ▬	+0	**7425** ▬	+0
	1700	17379 ▼	-374	7363 ▼	-62
	1800	16869 ▼	-884	7141 ▼	-284
	1900	16936 ▼	-817	7130 ▼	-295
	2000	16966 ▼	-787	7170 ▼	-255
T26	1500	52889 ▼	-608	27326 ▼	-863
	1600	53442 ▼	-55	27681 ▼	-508
	1700	53043 ▼	-454	27663 ▼	-526
	1800	52900 ▼	-597	27773 ▼	-416
	1900	53375 ▼	-122	28072 ▼	-117
	2000	**53497** ▬	+0	**28189** ▬	+0
	2100	52993 ▼	-504	27971 ▼	-218
	2200	52128 ▼	-1 369	26964 ▼	-1 225
	2300	52705 ▼	-792	27340 ▼	-849
	2400	52803 ▼	-694	27419 ▼	-770
	2500	53148 ▼	-349	27712 ▼	-477
	2600	52562 ▼	-935	27294 ▼	-895
	2700	52043 ▼	-1 454	27032 ▼	-1 157
	2800	51942 ▼	-1 555	27041 ▼	-1 147
	2900	51873 ▼	-1 624	26982 ▼	-1 206
	3000	50482 ▼	-3 015	26092 ▼	-2 097

Net present values for Early fertilization

The NPV differences between project and baseline scenarios were negative for low and medium fertile sites for both species and all discount rates. For the high fertile site, the difference was similar only for 4% discount rate (Table 5).

Table 5. Net present value (SEK/ha) comparisons for fertilization.

Forest site type	Discount rate 2 %			Discount rate 3 %			Discount rate 4 %		
	BASELINE	FERT	Diff. to BASELINE	BASELINE	FERT	Diff. to BASELINE	BASELINE	FERT	Diff. to BASELINE
G18	20085	19498	▼ -586	14215	13207	▼ -1 007	10914	9610	▼ -1 305
G24	49855	49240	▼ -616	31287	30183	▼ -1 104	21382	19959	▼ -1 423
G30	84714	86453	▲ +1 738	52282	52706	▲ +425	35295	34954	▼ -341
T14	9718	8621	▼ -1 097	6778	5367	▼ -1 410	5143	3487	▼ -1 655
T20	32251	31894	▼ -357	21188	20259	▼ -929	15285	13969	▼ -1 316
T26	60697	62185	▲ +1 489	34767	34973	▲ +206	21789	21169	▼ -620
		Average diff:	▲ +95		Average diff:	▼ -637		Average diff:	▼ -1 110

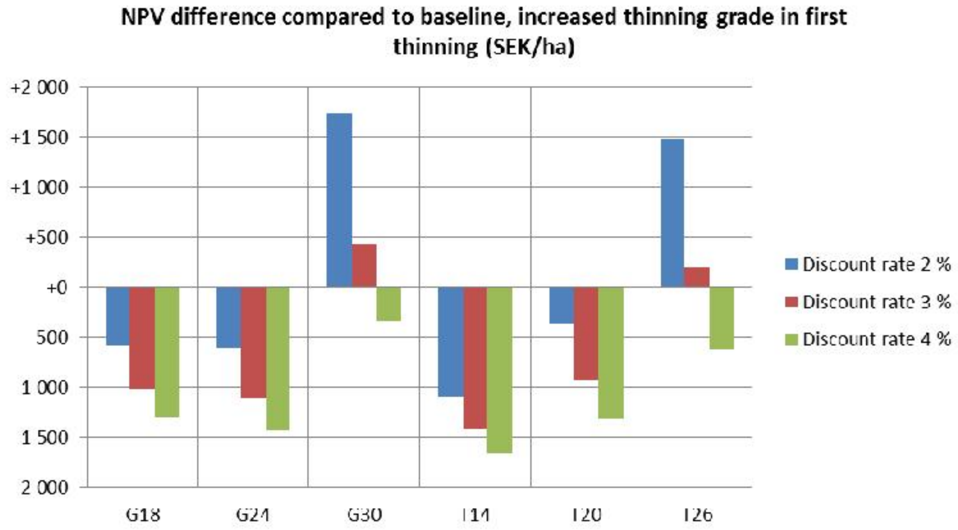

Figure 3. Difference in net present value (SEK/ha) for *Early fertilization* compared to baseline for different discount rates.

Table 6. Volume and growth comparison at from year 1 to first thinning in year 10.

Forest site type	MAI net Years 1-10 (m3sk/ha,yr)		Voldiff year 10 (Δ m3sk/ha)	Year 10 (just before first thinning)						
				Dgv (cm)		Gross volume harvested trees (m3sk/ha)		Increased harvest (Δ m3sk/ha)	Wood volume extracted (m3fub/ha)	
	BASE-LINE	FERT		BASE-LINE	FERT	BASE-LINE	FERT		BASE-LINE	FERT
G18	5.4	6.9	14.9	14.0	14.3	61.1	76.0	14.9	47	58
G24	8.8	10.4	15.3	14.2	14.5	67.9	83.9	16.0	52	65
G30	11.3	12.8	14.6	15.5	15.8	64.9	80.1	15.2	53	65
T14	3.0	4.2	12.6	15.1	15.4	47.5	59.4	11.9	33	42
T20	5.7	7.1	13.3	16.0	16.4	63.9	78.4	14.5	48	59
T26	9.4	10.5	11.6	14.4	14.7	53.6	65.9	12.3	39	48

Table 7. Volume and growth comparison at first thinning (year 10). To be profitable within ten years, the discounted increase in first thinning revenues in year 10 should be larger than the fertilization cost in year 1. The fertilization cost was 3200 SEK/ha.

Forest site type	Thinning revenue		Cost		Net revenue		Increased net revenue (SEK/ha)	Discounted increased revenue (10 years)*	
	BASE-LINE	FERT	BASE-LINE	FERT	BASE-LINE	FERT		Rate 2 %	Rate 3%
G18	14834	18592	13231	15174	1604	3418	**1814**	1485	1344
G24	16591	20611	14374	16461	2216	4149	**1933**	1583	1432
G30	16903	21044	12648	14534	4255	6510	**2255**	1846	1671
T14	10163	12979	8612	9870	1551	3109	**1558**	1276	1154
T20	14669	18155	10241	11726	4428	6429	**2000**	1638	1482
T26	11714	14656	10579	11995	1135	2661	**1527**	1250	1131

*To be profitable in ten years, the discounted revenue should be larger than the fertilization cost in year 1.

Sub-step 2d: Sensitivity analysis

The analysis of result sensitivity for varying discount rates between 2 and 4%, showed that the differences in NPV between project and baseline scenarios for PCT were negative, irrespective of discount rate (2 or 3 %). Similar results were achieved for fertilization on low and medium fertile sites. On high fertile sites, the difference was only negative for 4% discount rate.

Step 4: Common practice analysis

As described earlier in the *Baseline Scenario* section, the commercial forestry in Sweden utilizes fairly consistent forest management regimes. This is driven by a low number of large industrial land owners, institutional owners, forest owners associations and purchasing organizations that turn over almost all of the annual harvested volumes. Forest certification and a high degree of mechanization in the logging operations further add to this conformity. Family forest owners generally outsource harvesting and forest management activities to round-wood purchasers that typically follow the standard operating procedures established on the wood market.

The Swedish Forest Agency provides forestry guidelines in its “Skogsskötselserien”, which is in line with forest management policies at e.g. organizations such as Sveaskog, Södra Skogsägarna or Norrskog None of the project activities described in this methodology are considered optional in Swedish common practice forestry. Similarities to the project activities have not been found in Sweden during methodology development. If similar activities occur, they are either not in the scale of the proposed project activities or driven by other than commercial objectives. An example could be a small-scale forest owner focusing on production of high quality pine that is currently not viable on the mainstream market. The project activity modified pre-commercial thinning could be a potential way of obtaining high quality logs, but would rarely be utilized in larger scale forestry due to current market expectations.

Conclusion from the financial viability analysis

None of the project activities are regarded as common practice in Sweden. Furthermore, the suggested Project activities, *Pre-commercial thinning* and *Early fertilization* are considered financially non-viable, according to the calculated Net Present Value results. The conclusion is thus that the activities are additional.

APPENDIX D: THE ACCURACY OF TREE GROWTH PREDICTIONS

From Eflving 2009, Growth modelling in the Heureka system, pages 98-99).

PM for Heureka 2008-05-15 by Björn Elfving

Growth simulators linked to a site index system principally gives the average volume development at a given course of height development. For pure and even-aged stands with given initial density the variation coefficient for volume production to a given height is about 0.15 (Assman 1963). A growth prediction includes both this variation and the residual variation in the height growth prediction.

In order to estimate the total prediction error the following study was performed. Data consisted of long-term thinning trials (the GG trials) that were established in the period 1966-1983 and had been followed for an average period of 30 years. There were 23 blocks in Norway spruce and 47 blocks in Scots pine. Each block contained 4-12 treatments. For this study only the treatments un-thinned control and one heavy thinning from below were selected. The volume growth during the observation period (iV) was regressed on initial stem number per hectare (N1), top height (H1) and height increment during the observation period (iH), either the observed value (iHobs) or the value predicted with site curves (iHpred). There was a difference between the species also that could be modelled by a dummy variable for spruce. The regressions were as follows:

$\ln(iV) = -0.5954+1.1476\cdot\ln(iHobs)+0.4264\cdot\ln(N1)-0.000158\cdot N1+0.0623\cdot H1+0.2249\cdot SPRUCE;$

$n = 136$; $R^2adj = 0.934$; $s(res) = 0.144$;

$\ln(iV) = -1.2310+1.2432\cdot\ln(iHber)+0.5300\cdot\ln(N1)-0.000227\cdot N1+0.0488\cdot H1+0.2079\cdot SPRUCE;$

$n = 136$; $R^2adj = 0.881$; $s(res) = 0.192$;

The residuals of those functions had normal distributions and indicated a smooth fit over included variables and no significant correlation with some other tested variables (site index, latitude). An effort was made to also include an expression for ―local yield class‖ but it was not significant. As expression for local yield class the residuals from the function lnG1=f(lnH1, lnN1) were used, where G1 is initial basal area. The prediction error for the function with iHobs was exp(0,144)=0,15 as expected. The total prediction error (from the function with iHpred) was estimated at exp(0,192)=0,21. Eriksson (1976) also estimated the prediction error for volume growth at 0.21, based on data from spruce stands in the Great Yield Investigation. Söderberg (1986) compared predicted and observed basal area growth on 18 yield plots that had been followed during 44 years.

Observed growth was adjusted to ―normal weather conditions‖ with year-ring indices. The prediction error for adjusted basal area growth was estimated at 0.12. The same prediction error for volume growth was estimated for 26 pine plantations in northern Sweden that had been followed in 20 years. Pretzsch (2002) estimated the prediction error of the model SILVA with data from German long-term yield plots. The error was 0.19 for oak, 0.20 for spruce, 0.29 for beech and 0.39 for pine.

My conclusion of this examination is that the variation coefficient of predicted growth in growth predictions (the prediction error) generally can be expected to be about 0.2.

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APPENDIX E: BIOMASS ESTIMATING FUNCTIONS FOR TREE STEM AND CROWN IN ESTABLISHED STANDS ACCORDING TO PETERSSON (1999).

Table 1. Response (dependent) variables for biomass weight estimation functions for established stands

Biomass fraction	**Scots pine**	**Norway spruce**	**Birch sp**
Stem inclusive bark	Y_{Pstem}	Y_{Sstem}	Y_{Bstem}
Living branches and needles/leaves	$Y_{Plivebranch}$	$Y_{Slivebranch}$	$Y_{Blivebranch}$
Dead branches	$Y_{Pdeadbranch}$	$Y_{Sdeadbranch}$	$Y_{Bdeadbranch}$

Table 2. Input variables for biomass weight estimation functions for established stands.

Input data abbreviations	**Description**	**Unit**
Db	Stem diameter at 1,3 m height from the ground	mm
Gr5	Last five years stem diameter growth at 1,3 m height from the ground	0.1 mm
Age	Tree age at 1,3 m height from the ground	year
SI	Site index	m
soil	Peat or mineral soil	
alt	Altitude above sea level	m
nco	North geographic coordinate, according to the Swedish net RT90	100 m
eco	East geographic coordinate, according to the Swedish net RT90	100 m

Table 3. Function variables, parameters and coefficient of determination (R^2) for tree stem and crown for established stands.

Y_{Pstem}		x_1	x_2	x_3	x_4	x_5	x_6	x_7	R^2
		Ln (db+25)	db	Ln(gr5)	gr5	Ln(age)	SI	nco	
	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	
	7.674621	3.155671	0.002197	0.084427	0.002665	0.253227	0.031435	0.000008342	0.99
$Y_{Plivebr}$		x_1	x_2	x_3					
		Ln(db)	Ln(gr5)	Ln(age)					
	β_0	β_1	β_2	β_3					
	2.533220	1.989129	0.387203	0.105315					0,93
$Y_{Pdeadbr}$		x_1	x_2	x_3	x_4	x_5			
		Ln(db)	Ln(gr5)	Ln(age)	alt	eco			
	β_0	β_1	β_2	β_3	β_4	β_5			
	1.596001	2.441173	0.437497	0.711616	0.001358	0.000129			0,67
Y_{Sstem}		x_1	x_2	x_3	x_4	x_5	x_6	x_7	
		Ln (db+25)	db	Ln(gr5)	gr5	Ln(age)	SI	nco	
	β_0	β_1	β_2	β_3	β_4	β_5	β_6	β_7	
	6.839310	3.578450	0.003042	0.093033	0.002763	0.111347	0.012148	0.000020194	0,99
$Y_{Slivebr}$		x_1	x_2	x_3					

		Ln(db)	Ln(gr5)	Ln(age)					
	β_0	β_1	β_2	β_3					
	0.718621	1.740810	0.348379	0.180503					0,96
$Y_{Sdeadbr}$		x_1	x_2	x_3					
		Ln(db)	Ln(gr5)	Ln(age)					
	β_0	β_1	β_2	β_3					
	1.763738	2.616200	0.745459	0.359509					0,76
Y_{Bstem}		x_1	x_2	x_3[1]	x_4[2]				
		Ln(db+7)	Ln(age)	SI_P	SI_S				
	β_0	β_1	β_2	β_3	β_4				
	3.091932	2.479648	0.243747	0.022955	0.22185				0,98
$Y_{Blivebr}$		x_1	x_2						
		Ln(db)	Ln(gr5)						
	β_0	β_1	β_2						
	2.782537	2.276815	0.228528						0,91
$Y_{Bdeadbr}$		x_1							
		Ln(db)							
	β_0	β_1							

	2.059091	1.657683							0.46

APPENDIX F: VEGETATION AND SOIL MOISTURE CLASSES

Vegetation and soil moisture classes according to the Swedish National Forest Inventory (http://www.slu.se/en/collaborative-centres-and-projects/swedish-national-forest-inventory/)

Vegetation classes

1=Rich-herb without shrubs

2=Rich-herb with shrubs/bilberry
3=Rich-herb with shrubs/lingonberry
4=Low-herb without shrubs
5=Low-herb with shrubs/bilberry
6=Low-herb with shrubs/lingonberry
7=No field layer
8=Broadleaved grass
9=Thinleaved grass
10=Sedge, high, *Carex ssp.*,
11=Sedge, low, *Carex ssp.*,
12=Horsetail,*Equisetum ssp.*
13=European blueberry
14=Lingonberry
15=Crowberry
16=Poor shrub
17=Lichen, frequent occurence
18=Lichen, dominating

Soil moisture classes

1=Dry (subsoil water depth >2 m)
2=Mesic (subsoil water depth = 1-2 m)
3=Mesic-moist (subsoil water depth <1 m)
4=Moist (subsoil water depth <1 m, and pools visible in hollows)
5=Wet (subsoil water pools visible)