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Scenario analysis for the biomass supply potential and the future development of Finnish forest resources

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Abstract

The potential, cost-efficiency and impacts of intensified management of Finnish forests for next 100 years were assessed using a national-level scenario analysis. This document serves as a technical description of the applied models and methods, but also includes a brief synthesis of the results.

Data from the 10th Finnish National Forest Inventory was used to forecast the consequences of alternative management scenarios. Four final scenarios were constructed using MOTTI stand simulator and linear programming package J. Business-as-usual –scenario was compared to three other options that aimed either at high quality raw material, intensive management resulting both quantity and quality of timber, or at low-cost-low-output (extensive) forestry.

If the intensity of forest management will remain at the current level, the growing stock will increase. Increasing amount of high quality raw material for forest industry can be produced but it necessitates also increase in annual management practices. For example, treatment areas of young stand management should be doubled compared to current areas in order to maintain or increase cutting removals of high quality wood. It is possible to increase annual removals in a sustainable manner by applying more intensive forest management that also improves profitability nearly 50%. The annual removals can be ca. 40% higher than the current level, and the annual energy wood removal can be over 10 mill m^3. Despite increased removals, sustainable wood and biomass production during next 100 years can be achieved.

Intensively managed forest are more efficient capturing carbon from atmosphere than extensively managed forests, but the climate impacts depend on the use of removed carbon (end-products made from the removed wood biomass).

Keywords

forest management, carbon, profitability, silvicultural practices, growth model, simulation

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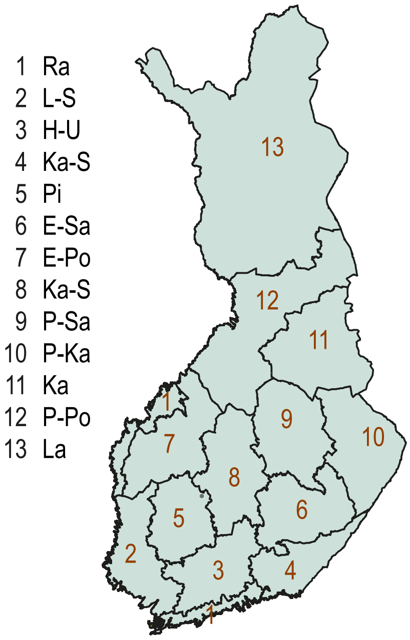
Preface

This working paper is a technical documentation of a large-scale scenario analysis carried out within the EffFibre "Value through Intensive and Efficient Fibre supply" research program of Finnish Bioeconomy Cluster FIBIC Oy. The goal of the three-year EffFibre program (2010–2013) was to improve the competitiveness of whole forest cluster. The programme focused on improving the availability and supply of high-quality raw material from Finnish forests and developing new production technologies for chemical pulping. The programme was financed by the Finnish Funding Agency for Technology and Innovation (Tekes), which provided 60% of the financing. The remainder sourced from the participating companies and research institutes.

One of the central research themes of EffFibre program was to study sustainable availability and cost-efficient supply of domestic forest-based raw material. It is widely acknowledged that productive domestic forests resources and competitive wood supply are crucial for the vitality of Finnish forest cluster. In the EffFibre program, this topic was addressed in Work Package 2 "Potential and feasibility of intensive wood and biomass production". This topic was tackled by carrying out an extensive scenario analysis. It was based on comprehensive information on the current forest resources, and analysis of the operational environment of Finnish forest sector. As the result of close cooperation between the industrial and research partners of EffFibre partners, alternative future scenarios were defined, and for each of them, future forecasts on wood supply and the development of forest resources were calculated. This effort resulted in research-based information on the production potential of Finnish forest resources, and comprehensive information on the impacts of forest management of varying intensity on Finnish forests and forestry.

Abbreviations

- Scenarios:
  BAU: Business as usual
  INT: Active forest sector and intensive biomass production
  QLTY: High quality raw material production for forest industry and bioenergy
  EXT: Extensive forestry due to decreasing activities of forest industry – increasing non-material services
- WS1-WS7; seven working scenarios were produced in order to technically allow a flexible compilation of the final scenarios
- Forestry centres = The Finnish Forest Centre is a state-funded organisation covering the whole country and operating on 13 local Forestry Centres (see the map).
- NPV = net present value
- NFI = National Forest Inventory



1 Introduction

1.1 Changes in operational environment

Globally, the demand for renewable raw material and product will increase in the future. In that context the wood based products are in significant role. The main factors affecting long term demand for wood products globally are the increase in world's population, economic growth in terms of global GDP, regional shifts because of the rapid growth of developing economies, environmental policies and regulation and energy policies (State of the world's forests. 2009).

In Finland, the domestic forest resources are important to Finnish forest industry's ability to produce wood based products to global markets. In the year 2012, 93% of paper and paperboard, 63% sawn goods and 83% of plywood production were exported abroad (Finnish statistical Yearbook of Forestry 2012). Finland's share of the global export trade of forest products in 2011 was 5.7% (Forest Finland in brief. 2013). Comparing this to the fact that the forest area in Finland is tiny at global scale, the role of forest industry and production of wood based products is significant globally. In addition, the proportion of imported wood is in minor part and even decreased from the average of this millennium (24%), being 17% of wood procurement at year 2011 (Ylitalo 2012). Thus, the role of domestic wood as raw material is highly significant.

The forest land area in Finland is 20.3 million ha (Ylitalo 2012). The growing stock volume is 2306 mill m^3 and has increased continuously since the 1970s. Majority (91%) of the total growing stock resides in commercially exploitable forests. Nowadays, the annual increment of the growing stock is 104 mill m^3. It has steadily increased since the 1970s from the level of 60 mill m^3. At the same time, the total drain has continuously remained at lower level than the annual increment. Currently, the total drain amounts only 68% of the annual increment of growing stock (Ylitalo 2012). This unused potential means that the industrial utilization of wood could be increased.

Despite the abundant forest resources, there are trends in the operational environment resulting in considerable challenges for domestic wood supply chain. These trends affect forest resources and forest management, wood supply and wood markets, forest industry, forest policy, forest ownership and multiple-use of forests.

The current forest resources and forest structure have influenced by the management practices of the past. The structure of Finnish forest has changed significantly during the past 80 years. Forest management has aimed at increasing wood production in commercial forests by emphasising intensive silviculture in even-aged stands of coniferous tree species. Draining of peatlands for wood production especially in the 1960s and 1970s has notably increased the amount of growing stock and affected tree species composition on peatland forests. These investments in forest management have resulted in increased cutting possibilities. However, from 1990's there has been ongoing trend in the structure of fellings, which is likely to continue, and even strengthen in the future. The increased cutting potential is not in most cost-efficiently harvestable stands, that is final fellings, but instead in intermediate fellings, and fellings in peatland forests, which are not so cost-efficient to harvest. New management practices with increasing interest in un-even aged forest management will possibly increase in future.

Over 60% of Finland's commercial forest are owned by non-industrial private forest owners (Forest Finland in brief 2011).The average size of these altogether about 347 000 small scale family forest holdings is 30.3 ha (Leppänen and Sevola 2013). Roughly 70% of forest owners are over 55 years old (Hänninen et al. 2011), which gives rise to a gradual change in the structure of private forest ownership. This is likely to lead into the situation where the number of forest owners is increasing while the average size of forest holdings is decreasing. Forest incomes are more important to younger that to elder forest owners but, at the same time, more significant to owners of large forest properties than small ones. The small scale forestry has also effect on stand management practices, the small management units lead low efficiency in management and operations and high unit costs. For many future forest owners, forest management has other priorities than wood production, which leads to favouring of less wood production oriented forest management. Overall this may lead to the situation where only some forest owners focus on wood production. Changes in forest ownership altogether may induce volatility and other negative impacts on wood markets and delayed or even neglected silvicultural operations and other stand management practices.

The above mentioned trends in operational environment of industrial wood supply require new kind of thinking and novel solutions. The situation can be seen as great potential where the Finnish forests meet the different needs of society. Forests are the basis for wood based products, renewable energy and multi-use and protection of forests. All these aims can be met with intensified forest management. Overall this increases the income, job opportunities and welfare of the society. On the other hand, these also give room to more professional forest ownership. One solution to combine these different aims is to consider more intensive, cost-efficient and sustainable management and logging measures in those forest areas, where prerequisites for commercial wood and biomass production are more favourable.

1.2 Scope and the aim of the work

The objective of this work was to assess the potential, cost-efficiency and impacts of intensive management of Finnish forest resources in order to provide high quality raw material for forest industry. The aim was to identify the most cost-efficient, ecologically sustainable, and feasible ways to increase the production of domestic biomaterial with high utility value for current and future forest industry.

This work comprises large-scale scenarios of the development of forest resources under varying intensity of management in commercially exploitable forests in Finland. The potential and requirements of different end-users of forest-based raw-material (such as pulp and paper, bioenergy, saw and veneer industry, other wood products) and the role of forest management and wood supply was emphasized when constructing and analysing the scenarios.

2 Description of scenarios

2.1 Definition process

The “scenarios” can be implemented as visions or aspects of possible future. Scenarios are not predictions about the future but rather simulations of some possible futures. Traditionally scenarios are seen as qualitative method to analyse future alternatives. In parallel there have been also quantitative scenario processes. Recently Amer et al. (2013) reviewed the scenario planning literature. They conducted the conclusion that combining qualitative and quantitative scenario methods will provide more robust scenarios. In this work we used scenarios as tools for analysing and understanding the effects of key competitive decisions on forest resource management, and how the forest resources in the future depend on different management strategies.

The used scenario definition process is based on action scenario process described by Meristö et al. (2000). At first phase of the scenario process, the key points are to define the current situation and identify important factors in operational environment that should be taken into account in the analyses. Thereafter, the alternative possible future scenarios can be defined. This part of our research was based on qualitative analysis (Fig. 1), in which we examined the development of Finnish Forest resources and wood production on each scenario. The predictions were based on several stand management practices based on implications of the defined scenarios. Quantitative analyses will be defined more detailed in the next chapter.

In scenario definition process, the alternative scenarios were implemented by the project group with members from both industrial and research partners of EffFibre program. The group had several meetings during the different stages of planning process. In addition, a one-day workshop addressing the properties of detailed scenarios was organized gathering together project group members, experts of pulp industry and research, forest ownership research, and climate policy and carbon issues .

In the beginning of planning process of scenarios, project group discussed the current operational environment of forest sector, and mapped the most significant ongoing trends (Fig. 1). The discussion led to elaboration of SWOT-analysis. The strengths, weaknesses, opportunities and threats of forest sector were analysed. Evaluation was elaborated from three different viewpoints focusing wood and biomass production, wood and biomass supply and availability and utilization of wood and biomass. SWOT-analysis was the starting point for scenario definitions.

Based on SWOT analyses, research group of Metla sketched the first draft of the scenarios (Fig. 1). These were further elaborated in a workshop. As an output of the workshop, a detailed and structured list of key factors, properties and assumptions under different scenarios were listed.
As a result of the planning process, the following scenarios were agreed to be assessed in the project

1. Business as usual (BAU)
2. Active forest sector and intensive biomass production (INT)
3. High quality raw material production for forest industry and bioenergy (QLTY)
4. Extensive forestry due to decreasing activities of forest industry – increasing non-material services (EXT)

Basic assumptions common to all scenarios were that the area of protected forests will remain at least at the current level and the international agreements and commitments for climate change mitigation hold also in the future.

The scenarios were defined from different viewpoints: forest industry and production, management of forest resources, timber sales, procurement and logistics, forest policy and forest owners and ownership. The viewpoints are used in the next chapters when presenting the identified key factors of the scenarios.

2.2 Scenario 1: Business as usual (BAU)

Overview

Scenario was based on the assumption that the current situation in forest sector and in wood supply will not change, except for the well-known ongoing trends and changes in forest sector. These changes are assumed occur as widely expected today. In this scenario, it was assumed that the intensity of forest management practices, as well as the current levels of annual commercial fellings will remain at current level.

Forest industry and forest-based production

There will be no major changes in the selection of forest-based products. The share of paperboard production will strongly increase, and chemical pulp and tissues will slightly increase while the proportion of mechanical pulp and paper production will decrease. The share of saw timber will remain at the current level. The number of large scale enterprises will remain more or less constant, but the number of small and medium size enterprises will slightly decrease. The degree of integration within forest industry will increase. Number of bio-refineries will increase as well as the amount of bioenergy production.

Management of forest resources

Prevailing forest management and utilization will extend also in the future. Hence, the intensity of silvicultural practices, and the volumes commercial fellings will remain at current level. This implies that the annual areas of completed silvicultural practices, especially tending of young stands, are much lower than recommended areas. In forest regeneration, artificial regeneration maintains its dominant position as a regeneration method. The use of improved regeneration material in artificial regeneration increases slightly.

In commercial fellings, the proportion of commercial thinnings and fellings on peatland forests will increase. Recovery of biomass for bioenergy, that is logging residues and stumps in final fellings, and especially small-sized trees in the first thinnings, will continuously increase.

Timber trade, procurement and logistics

In timber trade, selling by timber assortments will remain as the prevailing method, but timber assortments will be defined in a more flexible manner than today. There will be more buyers in the energy wood markets. Domestic wood supply will be supplemented with imported wood.

In timber procurement, the share of thinnings and loggings on peatland forests will increase. The role of extended entrepreneurship will strengthen in wood procurement, and the average company size will increase. In addition, supply of harvesting, regeneration and stand management services for forest owners will increase. Exchange of timber assortments between companies will increase. In road network, the proportion of unsound forest and local roads will increase. At the same time, other forms of wood and biomass transport will be developed.

Forest policy
There will be no significant changes in forest legislation, neither in the principles and amount of state subsidies to forestry. Taxation practices will remain more or less unchanged. International agreements and commitments do not require any major changes to forest management. Price of emission allowances will remain at current level.

Forest owners and ownership
Current structure of forest ownership will prevail in near future. No significant changes will occur in forest owners' objectives of forest management. Current attitude to multi-use of forests will remain at current level; proportion of multi-objective owners will remain at one third of forest owners and one half of forest holdings land area. Joint ownership of forests will slowly become more common. Wood supply from forests owned by forest industries and state will remain at current level. On one hand, the structure of forests will generate increasing wood supply, but on the other hand, a part of forest owners will become less active in selling timber.

2.3 Scenario 2: Active forest sector and intensive biomass production (INT)

Overview
Scenario is based on the assumption that vitality of forest sector will markedly improve. Increasing business leads to increasing demand for domestic wood and biomass. Measures of intensive wood and biomass production are widely applied.

Forest industry and forest-based production
Overall, the future for forest industry seems optimistic; brand of business is competitive, and profitability is high, which contributes increase of investments. Wide diverse of wood based products have large demand. Vital forest and energy industry generates increasing demand for domestic raw material. In forest industries, degree of integration will markedly increase. The number and capacity of bio-refineries will rapidly increase. The production of paperboard will strongly increase, as well as the production of wood-based panels, such as veneer sheets and plywood. The production of tissues, chemical pulp, and sawn goods increases only slightly. In addition the production of chemicals, other materials such as plastics and composites increase significantly. The role of forest-based bioenergy in energy production will increase notably.

Management of forest resources
Common trend in forest management is differentiation of forest management according to goals of forest owners. In commercial forests, measures of more intensive wood and biomass production will take place. In forest regeneration, artificial regeneration, especially planting with genetically improved material will be prevailing method. Cost-efficiency of silvicultural practices will improve through mechanization of silvicultural operations leading to increased areas of, for example, tending of sapling stands and pre-commercial thinnings. Correspondingly, intensity of intermediate thinnings will increase, and forest fertilization becomes a common measure to enhance wood and biomass production in commercial forests. The early and intensive thinnings

and increased fertilization lead to shorter rotations. Integrated recovery of pulp wood and energy wood in first commercial thinnings, and recovery of biomass of logging residues and stumps in final fellings for energy will increase. Thus, the recovery of energy wood will markedly increase.

Timber trade, procurement and logistics

In timber trade, selling by timber assortments will be, at least partly, replaced by pricing systems based on value yield of the respective end-products. Domestic wood supply will be supplemented with imported wood. The average size of cutting areas and cutting removals increases. The role of extended entrepreneurship will strengthen in wood procurement, and company size will increase. More efforts will be put to maintain the road network. Accordingly, other forms of wood and biomass transport will be developed as well.

Forest policy

Forest legislation and forest policy will be developed to be more supportive to sustainable and cost-efficient wood and biomass production. State subsidies are directed to promote young stand management and energy wood recovery and production. Taxation will be converted to stimulate wood production and to create possibilities to use forest resources enabling economies of scale. Price of emission allowances will remain approximately at the current level. EU climate policy targets to increasing bioenergy production.

Forest owners and ownership

Concentration will be prevailing trend in private forest ownership structure. The number of forest owners will decrease, and average size of forest holdings will increase. Further, new forms of forest ownership will become more common. Willingness to active forest management and timber sales will increase vigorously among private forest owners leading to increased supply of wood and biomass. The forest management strategy of private forest owners will diversify according to diverse management goals. The proportion of multi-objective owners increases vigorously and, at the same time, the proportion of recreationists and indifferent owners decrease significantly.

2.4 Scenario 3: High quality raw material production for forest industry and bioenergy (QLTY)

Overview

Scenario is based on the assumption that volume and vitality of forest industry in Finland will remain at least at the current level, but structure of forest industry will change. Wood products and energy industries will strengthen at the expense of mechanical pulp and paper industries. There will be an increasing demand for high quality raw material of forest industry, especially wood products. Thus, the management of forest resources is based on combined energy wood and timber production, and overall activity of management increases. Wood quality aspects are emphasized in forest management, which promotes thinnings for quality and longer rotations.

Forest industry and forest-based production

The structure of forest industry will change. The number of large scale plants will decrease but, on the other hand, the small and medium size enterprises in wood products industry will increase significantly. In forest industries, degree of integration will decrease. The number and capacity of bio-refineries will rapidly increase. The production of paper and mechanical pulp will decrease. On the other hand, the production of saw timber and wood-based panels (veneer sheets and plywood) will strongly increase. However, chipboard production is going to decrease. The role of forest-based bioenergy will strongly increase in energy production.

Management of forest resources

Forest regeneration areas will decrease due to forest structure and longer rotations. In forest regeneration, planting of spruce will remain at high level, as well as sowing of pine stands. The usage of improved and vegetatively propagated regeneration material increases slightly. In young stand management, silviculture aiming at combined production of timber and energy wood will become more common. It results in increased mean density of young stands. Therefore, the first commercial thinnings will be either energy wood thinnings or integrated pulpwood and energy wood thinnings. In commercial thinnings, more emphasis will be paid on stem quality in tree selection. Thinnings from above will become more common leading to longer rotations. Advanced thinning stands are fertilized. Usage of nitrogen fertilization will increase in order to compensate nutrient loss caused by energy wood thinnings.

Timber trade, procurement and logistics

In timber trade, the number of buyers' of logs and energy wood increase. The proportion of energy wood increases and the proportion of pulp wood decreases with respect to the total removal of thinnings during rotation. Internet-based wood markets gain space substantially. Further, exchange of timber assortments between companies will increase. Number of round wood assortments will increase, including also more energy wood assortments. Pricing systems of timber assortments will be based more strictly on the value yield of the end products. Average transport distances of wood will decrease. Climate and forest policy will increasingly encourage to carbon sequestration, increased use of renewable raw materials and bioenergy, and maintaining of forest biodiversity. State subsidies to forestry will be targeted more precisely to promote desired activities. Price of emission allowances will remain at current level.

Forest owners and ownership

Concentration will be a prevailing trend in private forest ownership structure. The number of forest owners will decrease, and average size of forest holdings will increase. New forms of forest ownership will become more common. Willingness to active forest management for quality timber and sell timber will increase among private forest owners leading to increased supply of timber and energy wood. The forest management strategy of private forest owners will diversify according to diverse management goals.

2.5 Scenario 4: Decreasing activities of forest industry – increasing non-material services (EXT)

Overview

Scenario is based on an assumption that the global trends affecting forest and energy industries will decimate the profitability of forest industry in Finland. Especially the volume of pulp and paper industry decreases significantly. Consequently, there will be less demand for domestic industrial wood. In forest management, more emphasis will be put on protection and forest externalities.

Forest industry and forest-based production

In forest industries, both the number of plants and the average size of companies will decrease. The degree of integration will strongly decrease. Throughout the forest industry, production volumes will decrease. Especially, the production of mechanical pulp will decrease to marginal level, and paper and chemical pulp production will decrease as well. Within wood product industries, especially chipboard production is going to strongly decrease or cease completely. The role of forest-based bioenergy will stay on the current level. The brand of the business will be focused on domestic small-scale industry. The relative importance of ecosystem services will increase.

Management of forest resources

More extensive forest management will take place. Areas of forest regeneration will decrease due to forest structure, longer rotations, and increased popularity of low-impact forestry. Along with the regeneration areas, the areas of artificial regeneration will decrease as well. Natural regeneration gains space over planting and sowing. Extensive, low-cost forest management practices will be more popular. Areas of intermediate thinning will decrease due to poor demand and low price of pulp-size wood. Rotations will be longer. The popularity of uneven-aged forestry will strongly increase among private forest owners. Permanent and temporary protection of private forests will increase.

Timber trade, procurement and logistics

In timber trade, the number of local buyers of logs and energy wood increases. Pricing according to the work site will increase. More robust pricing systems will replace the current system based on timber assortments. In wood procurement, part-time entrepreneurship will be more common. Logging conditions will get worse due to extensive forest management. Wood transport conditions are affected by worsening condition of road network. Average transport distances of wood will decrease due to increased local use of timber and biomass.

Forest policy

Climate and forest policy will be more rigid with respect to utilization of forest resources leading to new restrictions on forest management. Climate policy emphasizes importance of carbon sequestration management. On the other hand, forest protection will get more emphasis, and will be encouraged by state subsidies. As a result, extensive management becomes more common.

Forest owners and ownership

The number of forest owners will increase, and the average size of forest holdings will decrease. Due to increasing emphasis on immaterial goods on one hand, and poor timber markets on the other hand, forest owners have no motivation to expand their forestry business and increase the size of their forest properties. For increasing number of forest owners, wood and biomass production is not anymore on the top of the list of their forest management priorities.

3 Calculation of scenarios

3.1 Overview of calculation process

In a nutshell, the following procedure was applied in the calculation of the scenarios ( ). Data from the 10th Finnish National Forest Inventory were applied as initial data and starting point of the simulations. Measurement data from sample plots of NFI10 located on forest land in commercial forests were used to represent current forest resources. For each plot, a set of pre-defined management regimes reflecting the management principles of a given scenario was simulated with MOTTI-stand simulator (Hynynen et al. 2005, Salminen et al. 2005) over 100-year time period. For simulations, seven alternative working scenarios (see chapter 3.4.) were defined. After the simulation stage, linear programming package J (Lappi and Lempinen 2013) was applied as a tool to select a management program for each scenario that met the given constraints. For a detailed description of the optimization procedure, see chapter 3.6 below. The final four scenarios were compilations of the one or more working scenarios (see chapter 3.7 below). The calculation was completed by Forestry Centres, which was also the lowest level at which the final results of scenarios are presented.

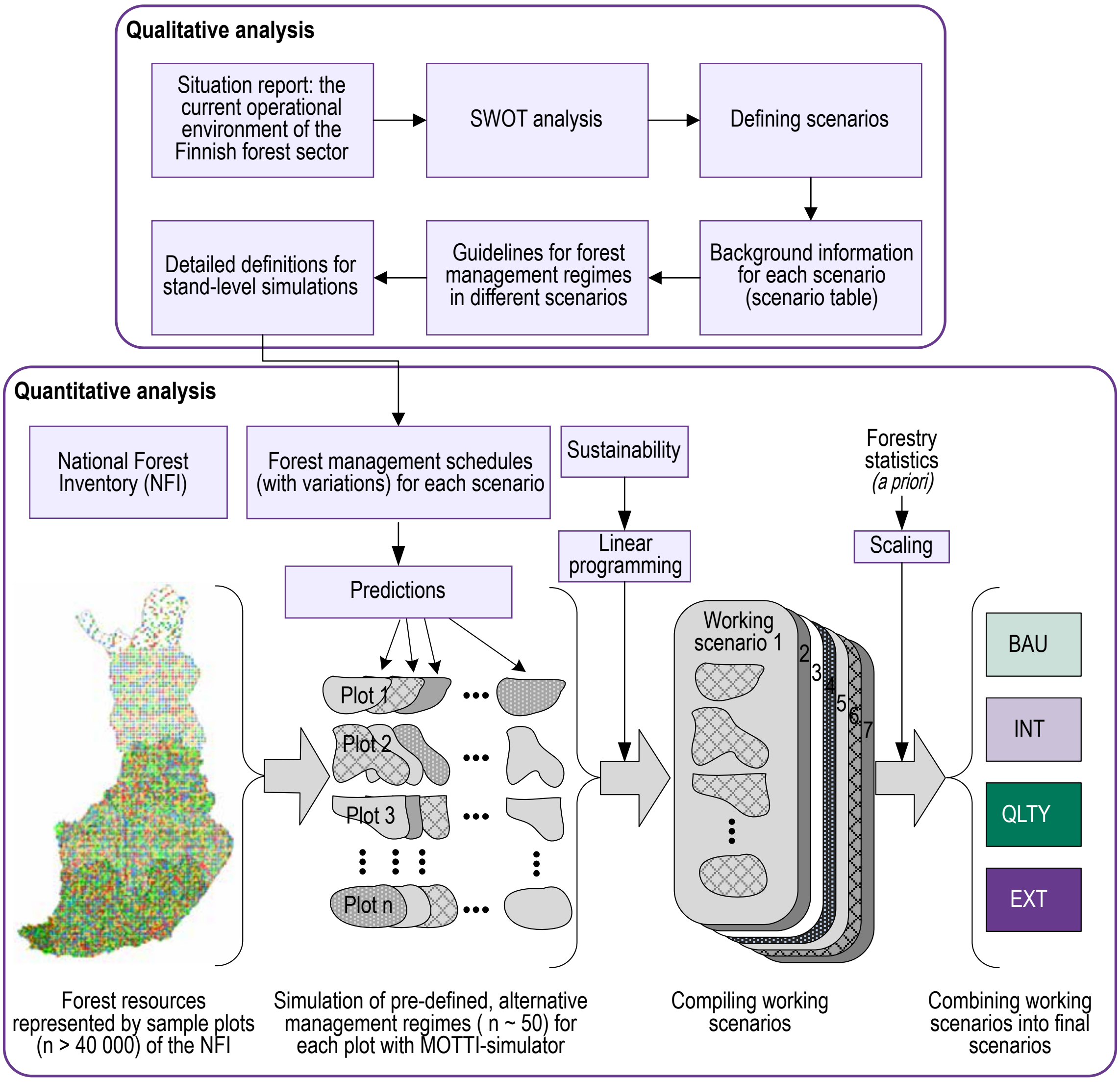


Figure 1. Scenario process: a qualitative phase followed by a quantitative phase.

3.1.1 Description of data

Data of this study were collected from altogether 46 297 sample plots of the 9th and 10th national forest inventory (NFI9, NFI10) of Finland that was carried out during the period from 2004 to 2008. Majority of the inventory data comprised of a systematic grid of NFI10 sample plots laid over the whole country, excluding the northernmost Lapland where the two-phased stratified sampling technique of NFI9 was applied (see Korhonen et al. 2006, Tomppo et al. 2009). In the NFI10, more than 100 variables were observed to describe the site, growing stock, damages and need for silvicultural operations. The sample plots were distributed over the Forestry centres and covered wide range of site fertility classes (Table 1).

Table 1. Number of sample plots with respect to site fertility classes in Forestry Centres.

		Fertility class						
Center	**Soil type**	**1 (OMaT)**	**2 (OMT)**	**3 (MT)**	**4 (VT)**	**5 (CT)**	**> 5 (Clt)**	**Total**
1	Heath	83	350	995	282	26	57	**2233**
	Peat	14	116	177	86	44	3	
2	Heath	43	470	1359	519	118	57	**3162**
	Peat	10	126	197	163	97	3	
3	Heath	184	996	995	212	12	28	**2816**
	Peat	12	100	149	64	62	2	
4	Heath	128	471	912	459	22	13	**2375**
	Peat	20	54	130	111	54	1	
5	Heath	117	628	1119	360	65	22	**2817**
	Peat	9	62	165	158	108	4	
6	Heath	127	1013	1458	465	22	15	**3844**
	Peat	22	149	303	208	62	0	
7	Heath	15	166	1126	792	129	20	**3744**
	Peat	19	120	369	588	391	9	
8	Heath	62	814	1527	660	57	19	**3960**
	Peat	16	107	252	294	151	1	
9	Heath	130	1022	1306	388	19	2	**3808**
	Peat	33	156	339	285	125	3	
10	Heath	81	604	1357	812	125	5	**4143**
	Peat	24	119	335	397	279	5	
11	Heath	19	110	1600	878	127	7	**4102**
	Peat	34	125	295	643	263	1	
12	Heath	50	136	1749	970	166	22	**5304**
	Peat	59	264	566	999	322	1	
13	Heath	6	57	1793	1101	156	10	**3989**
	Peat	35	232	174	379	46	0	
Total		**1352**	**8567**	**20747**	**12273**	**3048**	**310**	**46297**

3.1.2 Converting NFI data into input data of MOTTI simulator

NFI sample plot data were converted into the format compatible with MOTTI simulator,i.e., tree lists representing the stand data. The stand-level characteristics initially assessed in the field in young stands (D < 8 cm, D_{dom} < 10 cm) were the number of stems (N) and mean height (H). Other stand characteristics that were assessed only in advanced stands were basal area (G) and basal area-median diameter (D_{GM}) and the corresponding height (H_{GM}). In addition, dominant diameter (D_{dom}) and dominant height (H_{dom}) were calculated from measured or predicted characteristics of tally trees. Diameters at breast height were obtained for all relascope-sampled tally trees, whereas only every 7th tree was treated as a sample tree and measured for age, height, crown height, diameter and height increment (see Korhonen et al. 2006). Dominant tree characteristics were regarded practical input variables for models if at least four trees were measured. Otherwise, they were predicted.

The NFI10 inventory data were used to convert stand characteristics into tree list for MOTTI simulator. Weibull distribution model (unpublished) that was fitted especially for NFI data, utilized G, D_{GM} and D_{dom} as input variables for predicting diameter distribution. Tree heights and crown ratios of tally trees were obtained with the linear mixed-effects models by Eerikäinen (2009).

Sapling stands having the dominant height of less than 8 m were not converted into tree lists. Instead, the vector of stand characteristics was completed and saved for their further development, respectively. The development predictions were based on the family of species-specific models for stand characteristics (see Siipilehto 2006) taking into account tending and thinning-effects of young stands (see Siipilehto et al. 2014). The NFI10 stand characteristics for young stands (N, H) were used as calibrating variables for the aforementioned family of models.

In simulations, open areas were immediately regenerated according to guidelines presented in 3.2.1. The stand development after regeneration was simulated using the stand dynamic models of MOTTI (see Appendix 1).

3.2 Forest management assumptions, rules, and calculation parameters

3.2.1 General forest management principles

Forest management schedule, i.e. a set of practices applied in a given stand, was derived from scenarios. Therefore, the intensity, timing and type of management practices varied according to scenario. However, in MOTTI-simulator, there are some general pre-defined principles and rules for a given silvicultural or logging operations. Silvicultural guidelines for private forests of Finland (Hyvän metsänhoidon suositukset 2006) were applied as standard management schedule in managed scenarios (BAU, INT and QLTY). However, when management schedules for a given stand were elaborated these guidelines were modified in order to be in line with management principles of a given scenario.

Regeneration was simulated on initially open areas, and during the simulation after regeneration felling. Regenerated species and regeneration type were selected according to silvicultural guidelines for private forestry (Hyvän metsänhoidon suositukset. 2006) based on site fertility.

In general, the most fertile sites from OMT to MT were planted with Norway spruce. Sub-xeric, VT sites were seeded for pine whereas poorer sites CT and ClT were naturally regenerated for pine. During a simulation period of 100-years, most stands were regenerated once. MT sites are suitable for both Scots pine and Norway spruce as well. Therefore, when the given MT site was regenerated during simulation, it was regenerated with pine if pine was the main tree species in the former generation. As a result, drastic changes in the species structure were avoided. If there were other exceptions in species selection, they were due to different scenarios.

Artificial regeneration: Soil preparation was always preceding planting and sowing. In intensive scenarios (INT, QLTY), improved regeneration material was assumed to have been applied in planting and seeding of Scots pine. Based on empirical evidence form progeny trials of Metla, it was assumed that genetic gain in growth was 7% in tree diameter and height growth (Haapanen and Mikola 2008). The implementation of genetic gain into the growth models is described by Ahtikoski et al. (2010).

Natural regeneration: The number of seed trees left standing was fixed to 80 per hectare. Their volume and value was assessed at the time of the seed-tree cutting thereby neglecting their growth up to their final removal but at the same time increasing their net present value with any interest rate higher than 0%. This simplification was due to practical reasons; it enabled the removals and incomes to be technically allocated to the right rotation and not to the new tree generation. The volume of seed trees was underestimated but, as a compensating error, their net present value overestimated thus decreasing the total effect of the simplification. A light soil preparation was usually included in the operational chain of natural regeneration.

Cleaning of a sapling stand: all the seedlings that are supposed to eventually develop into crop trees were left: remaining stem number was usually 3000–4000 seedlings per hectare

Pre-commercial thinning: Aim was to provide adequate growing space to the best crop trees by removing all competitors. The stem number after pre-commercial thinning varied according to dominant tree species and geographical location, site and management scenario.

Commercial thinnings: Timing, intensity and type of commercial thinnings varied according to management scenario, dominant tree species, site type, and geographical location. The possible thinning types were thinning from above, thinning from below and systematic thinning. Thinning guidelines for private forests of Finland (Hyvän metsänhoidon suositukset. 2006) were applied as a standard procedure. However, depending on the management scenario, these guidelines were modified into more intensive or extensive direction. In the first commercial thinnings, opening of strip roads were mimicked by removing 18% of stand basal area by systematic thinning.

Recovery of energy wood: In thinnings, energy wood was recovered only in the first commercial thinning, either as integrated pulpwood and energy wood thinning or as energy wood thinning only. In combined pulp- and energy wood thinning, recovered energy wood included tops of harvested pulpwood stems and stems of those small trees that were undersized as a pulpwood. The minimum diameter of trees harvested as energy wood was 4 cm. In pure energy wood thinning, all the thinning removal was regarded as energy wood. In all thinnings, only stems were recovered for bioenergy meaning that all branches and foliage were left on site. When energy wood recovery was simulated in final fellings, the applied recovery rates were 100% for stem wood, 80% for branches, 60% for needles, and 70% for stumps.

Fertilization: On mineral soils, nitrogen fertilization was applied. The assumed type of fertilizer was ammonium nitrate. The fertilization dose varied from 160 to 180 kg N ha^{-1} depending on the scenario. In spruce stands, fertilizer was assumed to include also phosphorus in addition to nitrogen. On peatland forests, ash was used as a fertilizer. The assumed dose of ash was constant, equal to 4000 kg ha^{-1}.

Ditch maintenance: The need for ditch network maintenance (DNM) at peatland forests were predicted using model by Hökkä et al. (2000, model 3b, p. 4). Model predicts a stand level probability for ditch network condition being poor using the time from the previous ditching and site properties as driving variables. A need for DNM was alarmed if ditch network condition was predicted to be poor. It also resulted in a lower level of basal area growth. The actual DNM was scheduled together with the next thinnings or the final cutting. Growth response to DNM comprised both the growth shift back to normal level and, when DNM was applied for the first time, an additional growth reaction (Hökkä et al. 2000, Hökkä and Kojola 2002).

3.2.2 Economical parameters

Forest management costs and stumpage prices

Stumpage prizes and those silvicultural costs, which were presented in euros/ha, were based on nominal time series covering the years 1995–2010. Nominal costs and prices were then deflated according to cost-of-living index (base 1951:10=100, and year 2010 reflecting index value of 1751). Since statistics on separate stumpage prices for different thinnings (first thinning, other thinning, and final felling) have not been kept until during the recent few years, an additional comparison was carried out. First we set stumpage prices of final felling to 100% (reference level). Then we compared the real stumpage prices (i.e. deflated) of the first thinning and other thinnings to that of final felling, creating two ratios. Finally according to the two ratios the deflated original time series data were converted to the real stumpage prices for first thinning, other thinnings and for final felling (Table 2).

Some of the silvicultural costs were expressed as a function of time consumption (see Table 2). Unit costs were based on averages of the year 2010 (obtained from several sources: e.g. private companies and public organizations). In regeneration, planting density (the number of planted seedlings) was based on the silvicultural guidelines for private forestry (Hyvän metsänhoidon suositukset. 2006).

Table 2. Real (i.e. deflated) stumpage prices and silvicultural costs.

STUMPAGE PRICES €/m³	Logs			Pulp wood			Energy wood
	Pine	Spruce	Birch	Pine	Spruce	Birch	
First commercial thinning	46.3	43.9	43.1	15.5	20.2	14.8	3.0
Other commercial thinning	49.8	45.9	47.1	16.6	21.7	15.5	3.0
Final felling	57.5	53.7	52.8	19.3	26.7	19.1	3.0

REGENERATION COSTS				SILVICULTURAL COSTS		
Labour cost of planting	pine	€/plant	0.147	Cleaning of sapling stand	€/h	30.0
	spruce		0.163	Pre-commercial thinning	€/h	30.0
	birch		0.183	Initial clearing of thinning area	€/ha	200.0
Material costs of planting	pine	€/plant	0.179	Fertilization	€/ha	204.5
	spruce		0.199	Ditch network maintenance	€/ha	156.5
	birch		0.224			
Seeding		€/ha	193.1			
Soil preparation	mounding	€/ha	283.0			
	disc trenching		174.6			
	scarification		174.6			

3.2.3 Logging parameters

The merchantable stem volume for logs and pulpwood was calculated using the assortment rules that are widely applied in Finland. The minimum length applied for pulpwood was 3.0 m, and the minimum top diameter over bark for Scots pine and broadleaves trees was 6.0 cm, and for Norway spruce 7.0 cm. The minimum log length was 3.1 m for Scots pine and broadleaved trees, and 3.7 m for Norway spruce. The maximum log length was 6.1 m for Scots pine and Norway spruce and for broadleaved trees 7.3 m. The minimum top diameter for log over bark was 20.5 cm for Scots pine, 21.5 cm for Norway spruce and 16.5 cm for birch. For birch this minimum value was constant. However, the minimum top diameter decreased progressively with increasing log length, being 14.5 cm for Scots pine and 16.5 cm for Norway spruce when the log length was 4.3 m or more.

3.3 Implementation of scenarios at stand-level / Simulation of management alternatives

The basic principles and general properties of four future scenarios (BAU, INT, QLTY and EXT) are presented in Chapter 2. For calculations, detailed management descriptions were elaborated to be applied as simulation rules (Table 3) for each sample plot of NFI10 data (see Chapter 3.2).

The following working scenarios (WS) were calculated for each stand (sample plot)

WS1. Management according to silvicultural guidelines of Tapio
WS2. Management without silvicultural practices in young stands
WS3. Intensive management for effective wood and biomass production (INT)

WS4. Intensive management for producing high quality raw material (QLTY)
WS5. Low-cost management with one intermediate thinning
WS6. Low-cost management without thinnings
WS7. Unmanaged - no activities at all

Within each scenario, several management alternatives were simulated for a given stand. These alternatives within a scenario were needed in order to allow flexibility for LP analysis (see chapter 3.6).

Table 3. An example of management chains of each working scenarios in Southern Finland at fresh site type (MT) for Norway spruce dominated stands.

Scenarios	1 BAU 1		2 BAU 2				3 INT		4 QLTY		5 EXT 1	6 EXT 2	7 EXT 3
Regeneration													
Tree species	Norway spruce		Norway spruce				Norway spruce		Norway spruce		Norway spruce	Norway spruce	Norway spruce
Method	planting		planting				planting		planting		natural regeneration	natural regeneration	No management
Density (N ha^{-1})	1800		1600				2000		2000				
Soil preparation	spot mounding		scarification				spot mounding		spot mounding				
Early cleaning													
Timing, m	1.5						1.5		1.5				
Growing density, (N ha^{-1})	ca. 3000						ca. 3000		ca. 3000				
Precommercial thinning													
Tree species selection	(10% of growing birch mixture)								(10% of growing birch mixture)				
Timing, (dominant height, m)	4						3	5	5				
Growing density, (N ha^{-1})	1700						1600	2000	2000				
First commercial thinning													
Method	below		integrated energy and pulp wood thinning				below	integrated energy and pulp wood thinning	integrated energy and pulp wood thinning			energy wood thinning	
Timing, (dominant height, m)	13	16	12	14	16	18	12	14	12			15	
Growing density, (N ha^{-1})	1000	900	1000	900	800	700	700	1000	1100			900	
Other thinnings													
Method	below	above	below				below	above	below	above			
Timing, (dominant height, m)	thinning guide lines	thinning guide lines	thinning guide lines				thinning guide lines	thinning guide lines	thinning guide lines	thinning guide lines			
Growing density, (N ha^{-1})	thinning guide lines	thinning guide lines	thinning guide lines				350	thinning guide lines	thinning guide lines	thinning guide lines			
Final felling													
Mean diameter, cm	26/28/30	28/30/32	26/28/30				25/27/29	25/27/29	28/30/32	28/30/32	25/27/29	25/27/29	
Stand age (yrs)	70/80/90	80/90/100	70/80/90				50/60/70	50/60/70	80/90/100	80/90/100	90/100/110	90/100/110	
Recovery of logging residues and stumps	YES/NO	YES/NO	YES/NO				YES	YES	YES	YES		YES	
Fertilization													
Time of 1st fertilization (amount of Nitrogen)							5 years after first commercial thinning (180 kg ha^{-1} (N+P))	5 years after first commercial thinning (180 kg ha^{-1} (N+P))					
Time of 2nd fertilization (amount of Nitrogen)							5 years after second commercial thinning (180 kg ha^{-1} (N+P))	5 years after second commercial thinning (180 kg ha^{-1} (N+P))	5 years after second commercial thinning (160 kg ha^{-1} (N))	5 years after second commercial thinning (160 kg ha^{-1} (N))			
	6	6	24				3	3	3	3	3	3	1

3.4 Simulation procedure

The 100 year-long development of NFI-stands under defined scenarios was predicted by 5-year-periods using the models of forest dynamics (Appendix 1) and obeying the general forest management principles and parameters. Every stand had several optional management regimes resulting in as many alternative predictions within each scenario.

The alternative stand-wise simulations were engineered in to batch processes that were computed by one forest centre at a time. The results were saved into six data sets; site properties, stocking, removals, incomes, costs and events. The amount of output data was reduced by aggregating individual observations whenever possible. For example, all incomes and costs were discounted to present values, and thereafter time-dimension of the original results could be reduced. Stocking, removals and events were saved by 5-year periods, which were later on summed up into 10-year results. The simulation results were pre-processed with the statistical software (SAS Institute 2011) that served as a main data-base of this study. The main tasks of pre-processing were to cross-check the data and to retrieve the required variables from the six output sets and compose a data set to be used in the next step, which was linear programming. In addition, some statistical measures were produced, mainly mean and cumulative values.

3.5 Linear programming

After having simulated alternative management regimes within each scenario for each stand, they were congregated as a variable space. This variable space consisted of a total of over 14 million individual management regimes. However, for each forestry centre the variable space was smaller, depending on the initial number of NFI stands in that region. In general, linear programming is designed to solve efficiently planning problems (Lappi 1992). Principally, in linear programming alternative schedules are usually simulated (here the management regimes), and each schedule is associated with a vector of input and output variables over time (Lappi 1992). It is assumed that the goal(s) of the decision maker can be described as a linear programming optimization problem. For instance, decision maker may want to maximize the net present value of future incomes, subject to constraints such as constant annual incomes or minimum drainage per 10-year time horizons (Lappi 1992).

In this study, we chose to maximize random number (instead of e.g. the net present value), emphasizing the constraints of the linear programming problem. These constraints played a crucial role in this study since through the constraints we could steer the aggregate outcome of numerous (simulated) management regimes to follow the principles of each working scenario (1–7). For optimization algorithm we constructed a specific control file in which e.g. annual cutting removals were restricted to follow a particular pattern in accordance with original working scenario. In this connection it should be emphasized that to some extent this procedure was ad hoc, depending on the initial structure of forests in each forestry centre. The first optimization task was carried out without any constraints. By this we could find out the underlying growth potential (which in turn indicates the potential cutting removals) of each forestry centres. After that the minimum removal for the first ten-year period was searched by an iterative process, leaving other 10-year periods intact. Having found the minimum cutting removal of the first 10 years, further constraints were formulated according to specific constraints such as similarity of annual cutting removals between all 10-year periods or minimum growing stock at the end of time horizon.

The underlying idea was to create such a control file that under the formulated constraints the optimum solution would resemble the initial working scenario as much as possible. The overall linear programming procedure is presented in the flowchart (Figure 2).

Similar optimization package based on linear programming has been applied in earlier studies covering e.g. carbon sequestration issues (Matala et al. 2009) and peatland wood production (Nuutinen et al. 2000).

The results of linear programming set the management regime for each stand in each working scenario. The results were imported back to SAS, and the final forest-centre results for each scenario were produced by cross-tabulating stand-wise figures.

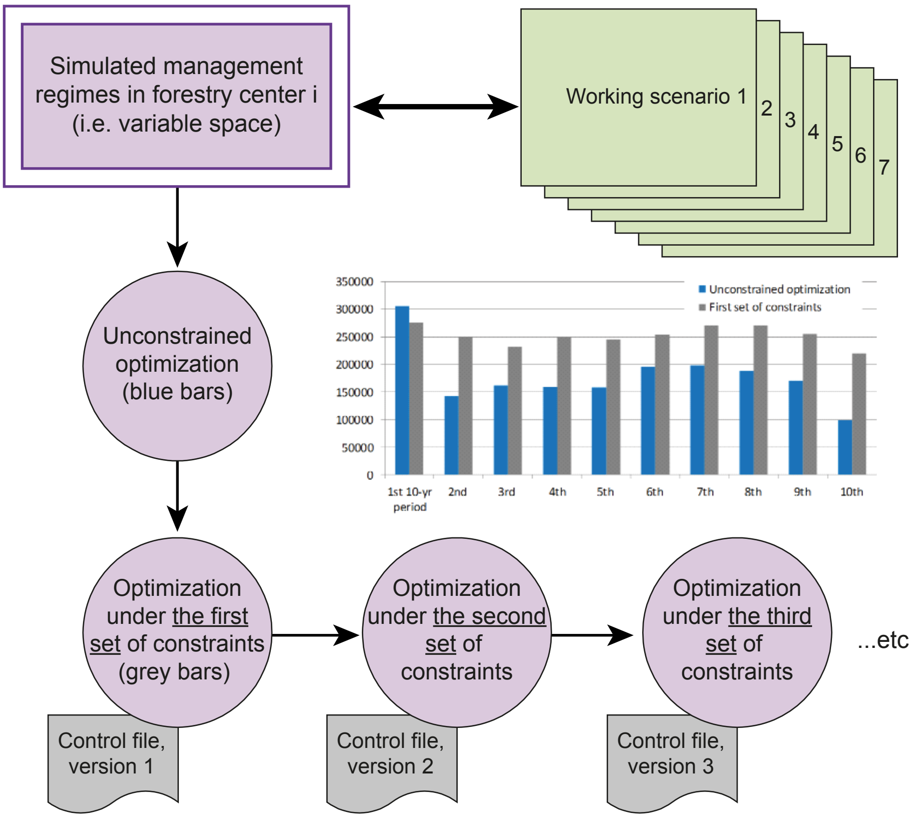


Figure 2. Flowchart on the linear optimization procedure. The graph in the background is an illustration representing working scenario 1 of a forestry centres in which the unconstrained optimization resulted in a too large cutting removal (the leftmost blue bar for years 0-9). After the first constraint set the cutting removals were balanced (grey bars).

3.6 Compilation of the final scenarios

The seven working scenarios WS1–WS7 were calculated using the simulation and optimization procedure described above. Working scenarios WS3 (Intensive management for effective wood and biomass production), and WS4 (Intensive management for producing high quality raw material) were used as such for final scenarios INT and QLTY (see chapter 2.4 and 2.5.). However, Business as Usual (BAU) scenario and scenario of extensive management (EXT) were compiled by mixing the working scenarios. The mixture of working scenarios was carried out for aggregated results presented in six data sets at forestry centre-level (see chapter 3.5.2).

Business as usual scenario (BAU) was designed to reflect the situation, in which the most important silvicultural activities and annual cuttings will retain at current level also in the future. Young stand management practices, i.e. cleaning of sapling stands and pre-commercial thinnings, have crucial impact on the future development and the production potential of forests. According to assessments made in 10th National Forest Inventory (Korhonen et al. 2013), 53% of the area in the need of young stand management practices has been completed annually during 2001–2010 on the average. Information available by forestry centres on completed vs. recommended treatment areas (Korhonen et al. 2013) was applied in compiling the BAU scenario with the help of the working scenarios. Further, the ratio between the annual cutting removals and maximum allowable cutting removal by forestry centres (see Table 4.xx in Statistical Yearbook of Forestry… 2011) was used as a measure of current degree of utilization of wood production potential. The applied percentages by forestry centres referring to treatment and cutting rates described above are presented in Table 4.

BAU scenario was compiled by mixing the working scenarios in the following manner. The restriction related to current activity in young stand management was taken into account by

Table 4. Statistics by Forestry Centres on percentages of the performed areas of young stand management practices with respect to recommended areas of 10th National Forest Inventory (Korhonen et al. 2013), and percentage of removed volumes with respect to maximum sustainable removals (Ylitalo 2013).

Forestry Centre	Percentage of completed young stand treatment areas of the recommended areas, %	Percentage of actual cutting volumes of the maximum sustainable removals, %
1	41.5	65.9
2	53.5	71.1
3	51.7	87.5
4	64.8	85.1
5	49.3	71.1
6	66.2	88.3
7	53.0	78.6
8	61.6	84.2
9	58.2	80.4
10	61.3	77.9
11	67.9	74.9
12	41.9	84.3
13	41.9	67.4
Average	54.8	78.2

setting the proportion of WS1 (management according to silvicultural guidelines of Tapio) in BAU scenario equal to the percentage of completed vs. recommended treatment areas by forestry centre (Table 4). The remaining proportion of BAU scenario was composed as the mixture of WS2, WS5 and WS7 working scenarios, in which young stand management practices were not applied.

Restriction related to cutting removals was taken into account with the help of calculated mean annual removals of the working scenarios. It was assumed that annual removals of WS1 will reflect the maximum allowable volume of harvest removals (100% cutting level). The removals of BAU scenario by forestry centres were set to the percentages presented in Table 4 with respect to the removal of WS1.

The mixture of working scenarios in BAU scenario, agreeing with the constraints presented above was obtained by solving optimization problem using Solver of MS Excel. The analysis resulted in the optimal mixture of WS1, WS2, WS5 and WS7.

Scenario of Extensive Management (EXT) was based on the assumption that industrial utilization of forests radically decreases in the future. This decrease was assumed to result in forest management intensity in the following manner:

– 25% of forest area will be managed according to BAU scenario
– on 25% of forest area only one intermediate thinning and regeneration felling will be carried out during the rotation
– on 25% of forest area, only natural regeneration and final fellings will be completed
– 25% of forest area will be left unmanaged and outside commercial wood production

EXT scenario was compiled by mixing of BAU scenario (25%) with WS5 (25%), WS6 (25%), and WS7 (25%) working scenarios.

4 Results and discussion

4.1 Forest management practices

The forest management practices in the early years of rotation consist of silvicultural operations such as regeneration and precommercial thinning. In more advanced stands, the silvicultural operations, such as fertilization, and ditch maintenance and the commercial cutting operations are carried out. The intensity of forest management varied notably between the scenarios (Figure 3). The annual areas of forest regeneration were significantly higher in INT scenario compared to other scenarios or completed regeneration areas between 2001–2010. In INT scenario the rotations were shorter than in QLTY, BAU or current situation. Areas of young stand management showed the largest contrasts between the scenarios. In intensively managed scenarios (INT and QLTY) annual areas of pre-commercial thinnings were at much higher level than in BAU or EXT scenarios. In INT scenario, the treatment areas were double compared to those of BAU scenario, and triple compared to the actually completed areas. Accordingly, forest fertilization areas were highest in INT and QLTY scenarios.

In addition to differences in the treatment areas between the scenarios, there were also some temporal trends within scenarios, especially in the regeneration areas (Figure 4). Due to the current structure of forest resources, which was characterized by great proportion of mature forests, regeneration areas increased markedly during the first decade of the simulation period. The increase was greatest in INT scenario, in which shorter rotations were favoured more than in the other scenarios.

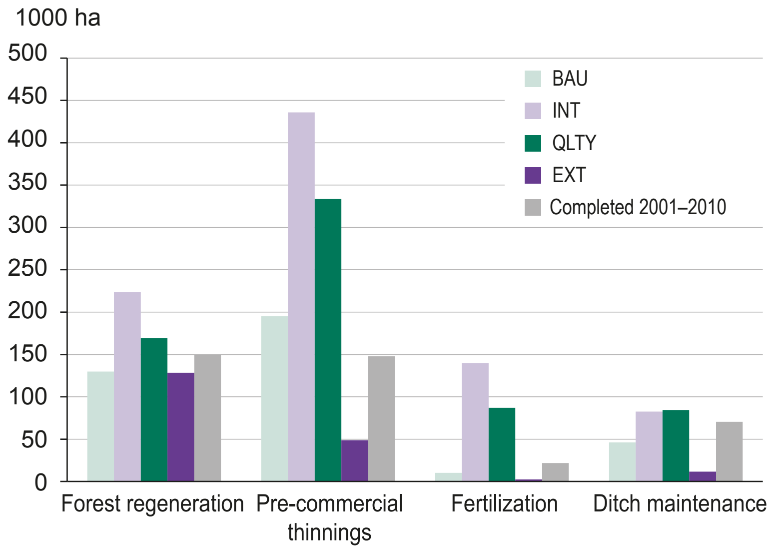


Figure 3. Annual area of different forest management practices 2010–2110 for different scenarios. Completed 2001-2010 refers to treatment areas based on Finnish forest statistics (Ylitalo 2013).

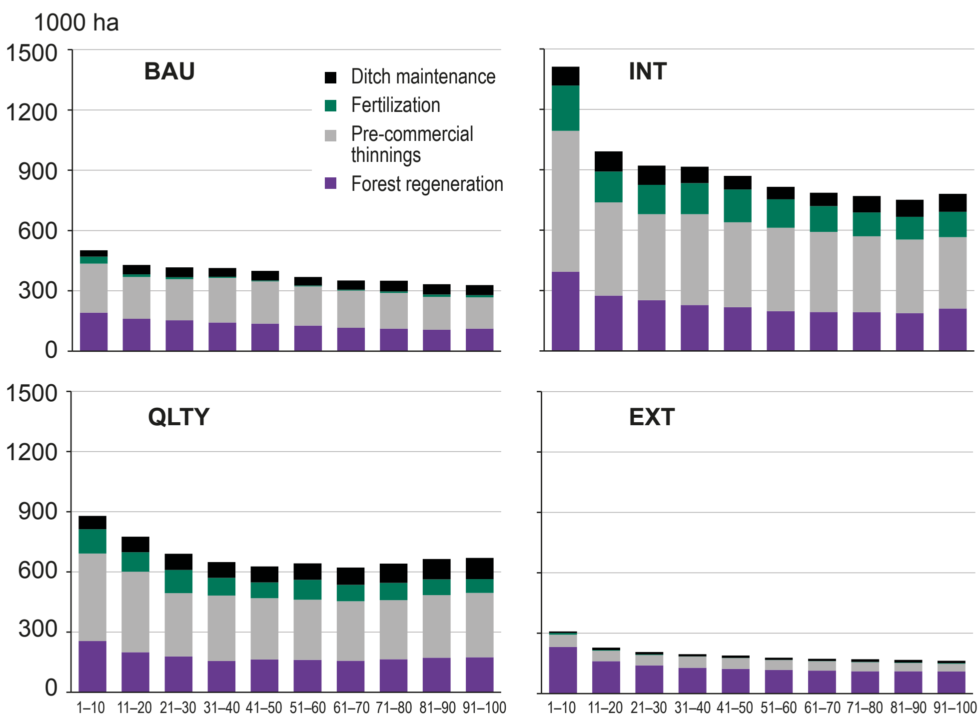


Figure 4. Temporal variation of annual area of different forest management practices 2010–2110 for different scenarios.

Commercial cuttings include first commercial thinning, other commercial thinnings and regeneration fellings (Figure 5). In INT and QLTY scenario, the annual area of first commercial thinnings was clearly larger than in BAU and EXT scenario, as expected. The share of "other commercial thinnings" was greatest in QLTY scenario. This was driven by the management goal of QLTY scenario aiming at growing high quality large-size timber. In order to meet the goal, longer rotation and successive intermediate thinnings were applied.

The temporal trend in cutting areas during the first decades of 100-year period was similar to that of regeneration areas, and arose from the age class structure of forests (Figure 6). After the sharp decrease in cutting areas after the first 10-year period, areas started to steadily increase in intensively managed scenarios, and especially in QLTY scenario due to increase in the areas of intermediate thinnings.

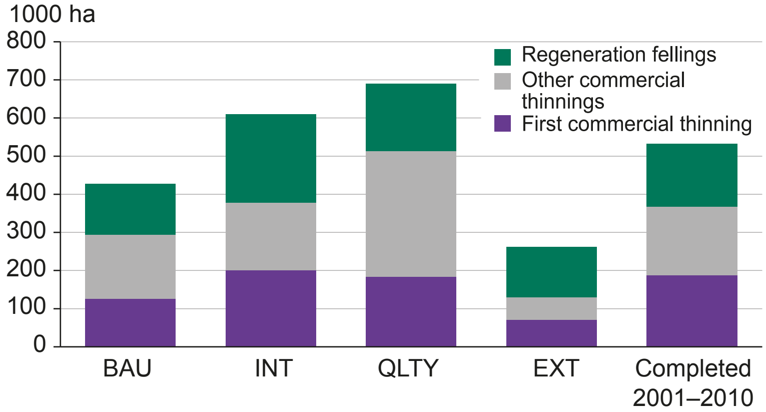


Figure 5. Mean annual area of cuttings during 2010–2110 for different scenarios. Completed 2001-2010 refers to cutting areas based on Finnish forest statistics (Ylitalo 2013).

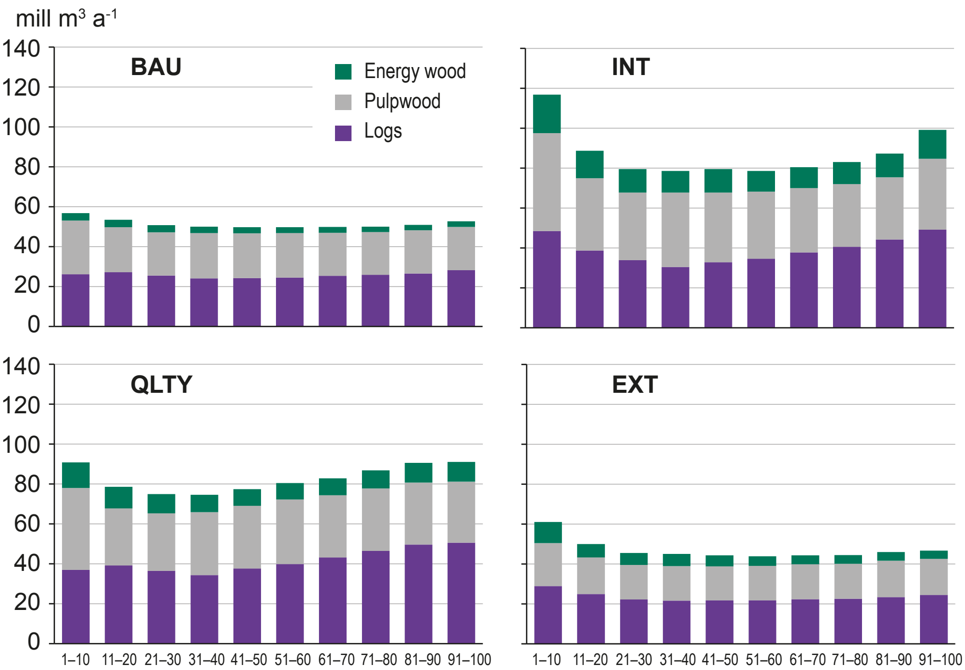


Figure 6. Temporal variation of annual area of cuttings during 2010–2110 for different scenarios.

Intensive management requires considerable investments in silviculture in order to maintain or increase cutting removals of high quality wood. Results strongly suggest that due to current structure of forest resources, the main focus in Finnish forestry today and in the near future should be in increased regeneration and silvicultural practices of young stands, if the goal is to maintain or increase wood and biomass production in the long run. Young stand management is one of the most obvious bottlenecks of forestry that needs to be tackled.

4.2 Harvesting removals

Intensive forest management enables a significant potential to increase annual removals in a sustainable manner. The annual removals increased ca. 40% in intensive management scenarios (INT and QLTY) (Figure 7) compared to the current level of removals. As expected, the EXT scenario led to the lowest removals. BAU scenario resulted in only slightly greater removals compared with EXT scenario. The result indicated that the intensity of current forest management in commercial forests is actually at rather low level.

The annual removals of logs were highest in QLTY scenario, but the difference was small compared to INT scenario. The energy wood removals consisted only of small-size stem wood below the pulpwood dimensions and logging residues and stumps from final fellings. Despite this rather strict definition set to energy wood, the annual energy wood removal was nearly 13 mill m^3 in INT scenario and 10 mill m^3 in QLTY scenario (Figure 7).

The temporal variation of removals showed the similar pattern to cutting areas, as expected. There was only small variation in the cutting removals of BAU and EXT scenarios throughout the 100-year simulation period, but temporal trends occurred in the removals of intensive scenarios, INT and QLTY (Figure 8). In the beginning of calculation period, removals were at higher level in these scenarios compared to following 10-year periods due to high harvesting reserves. Further, in INT and QLTY scenarios, harvesting removals started gradually increase during the second half of 100-year period. The increasing trend in harvesting removals towards the end of 100-year period was the result of increased intensity of forest management activities (Figure 8).

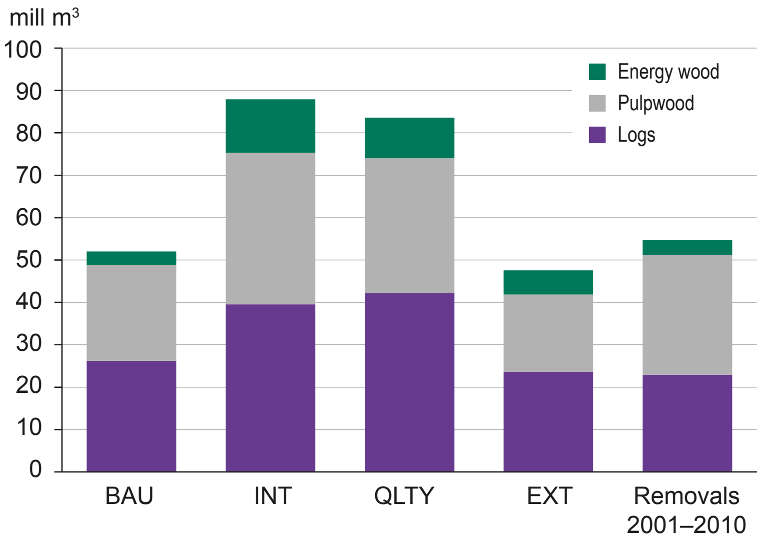


Figure 7. Mean annual harvesting removals 2010–2110 by timber assortments for different scenarios. Removals 2001-2010 refers to completed removals based on Finnish forest statistics (Ylitalo 2013).

In order to assess the economic potential of the scenarios at national level, the gross stumpage earnings of each scenario were calculated applying the stumpage prices, which were presented in chapter 3.2.2. Annual cutting removals in BAU scenario with 51 mill m^3 refers to 1807 mill. euros in gross stumpage earnings (Figure 9). Applying INT scenario, the annual gross stumpage earnings could be increased by 57% compared to BAU, being 2847 mill. euros on the average. In all the scenarios the temporal variation of gross stumpage earnings was quite similar to that of annual removals. (Figure 9).

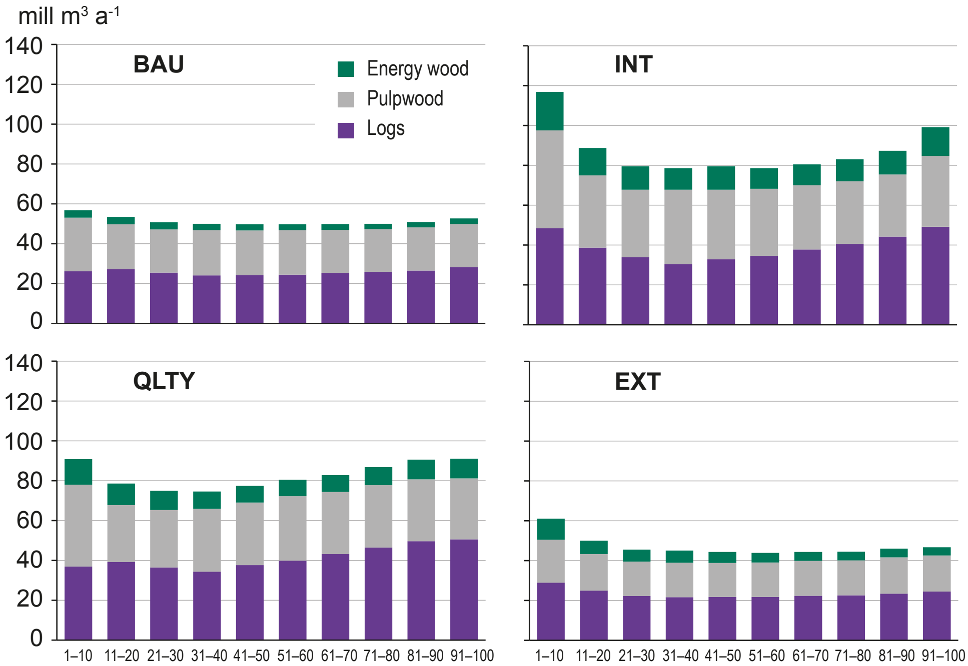


Figure 8. Temporal variation of mean annual removals (mill m^3a^{-1}) 2010-2110 by timber assortments for different scenarios.

Figure 9. Temporal variation and average of gross stumpage earnings during 2010–2110 for different scenarios. 2010 present the completed level of gross stumpage earnings at year 2010.

In a country with large geographical and climatic variation, there are notable regional differences in wood production potential, and conditions for forestry and forest management. The annual harvesting removals varied significantly by Forestry centres because of differences in forest area, structure of forests and climatic conditions (Figure 10, Figure 11). However, throughout the country, the comparison of scenarios showed the great potential to increase the annual removals with more intensive forest management (INT and QLTY scenario). In some regions the annual harvesting removals are at nearly same level in BAU scenario as in EXT scenario.

In Northern Finland (forestry centres 11–13), the difference between INT and BAU scenarios in terms of the mean annual removal per hectare was 1.2 $m^3ha^{-1}a^{-1}$, whereas the difference in Southern and Central Finland (forestry centres 1–10) was 2.7 $m^3ha^{-1}a^{-1}$, respectively. Despite the fact that intensive management in Northern Finland resulted in much smaller gain in removals per hectare (Figure 11), the increase in terms of the total removal of the whole forestry centre was at the same level as in southern parts of the country due to large areas of commercial forests in Northern Finland (see Figure 10).

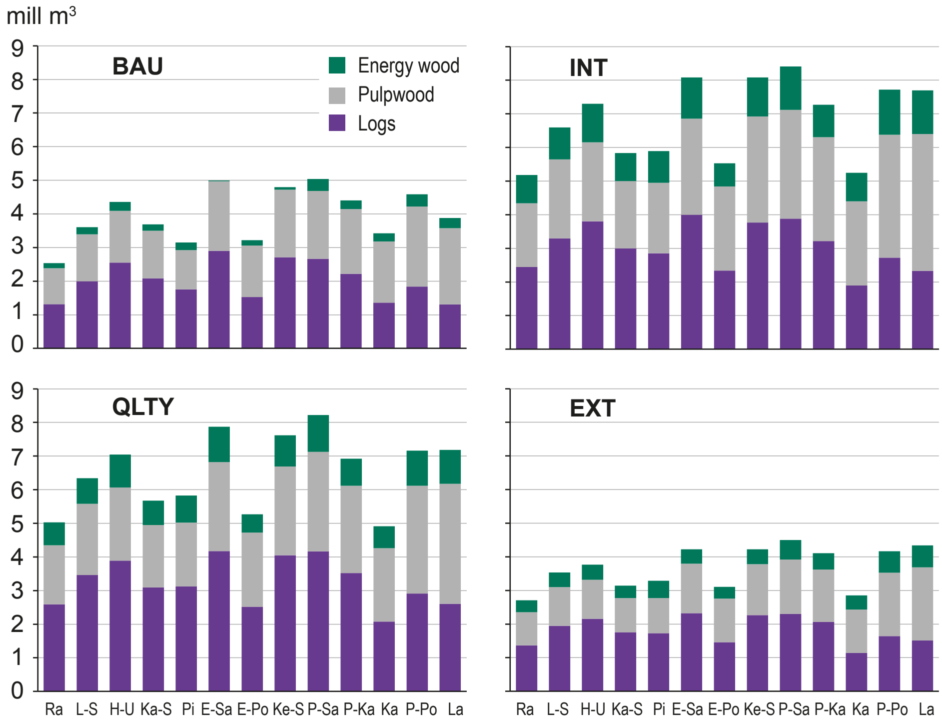


Figure 10. Mean annual harvesting removals (mill m^3) by Forestry centres on the average during the years 2010–2110 by timber assortments for different scenarios.

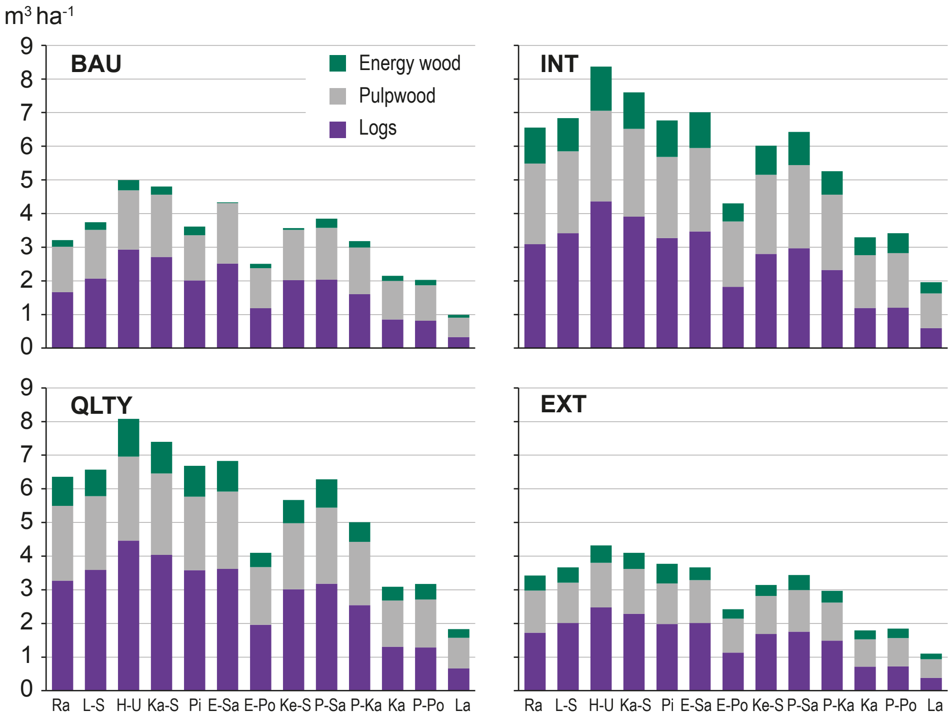


Figure 11. Mean annual harvesting removals per hectare (m^3 ha^{-1}) by Forestry centres on the average during the years 2010–2110 by timber assortments for different scenarios.

4.3 Growing stock

During the 100-year simulation period the volume of growing stock increased in BAU and EXT scenarios compared to the current level of growing stock (Figure 12). Intensive management scenarios resulted in lower stocking levels. INT scenario led to the lowest standing volumes of the growing stock due to shorter rotations and intensive intermediate thinnings.

In Finland, like in many other European countries, the growing stock has increased during decades because the annual drain has been below the annual increment of growing stock. During the years 2001–2010, ca. 78% (Table 4) of the maximum sustainable removal was actually removed in cuttings resulting in constant increase of growing stock volumes. In BAU scenario it was assumed that the ratio between annual removals and maximum sustainable removals will remain at the current level also in the future. Thus, the results showed that the volume of growing stock will increase from the current volume of 2 billion m^3 gradually up to the level above 3 billion m^3 by the end of the 100-year calculation period in BAU scenario (Figure 12). The EXT scenario followed nearly same temporal pattern in growing stock than BAU scenario. In EXT scenario, low level of annual removals promoted the increase of accumulation of wood in forests more than in BAU scenario. By the end of calculation period, growing stock in EXT scenario is expected to be only 7% greater than in BAU scenario (Figure 12). The slight difference was due to extensive forest management resulting in lower growth, especially in young stands, compared to that of BAU scenario.

Scenarios of intensive management (INT and QLTY) resulted in lower stocking levels than BAU and EXT scenarios. The most significant reduction occurred during the first decades of the simulation period due to intensive cuttings (Figure 12). In INT scenario, there were 20% lower volumes of growing stock compared to QLTY scenario because of shorter rotations and intensive commercial thinnings in INT scenario. However, the intensified silviculture resulted in increasing stocking levels after 20 to 30 years in both INT and QLTY scenarios. Results showed that INT and QLTY scenarios ensured sustainable long-term wood and biomass production despite increased removals during next 100 years (Figure 12).

The regional variation in growing stock showed that in Southern Finland the total volume of growing stock, in terms of mill. m^3, was lower compared to Northern Finland but on the other hand, the growing stock per hectare, in terms of m3 per hectare, was higher in Southern Finland (Figure 13). The differences in growing stock per hectare with BAU and INT scenario were greatest in Southern Finland (Figure 13).

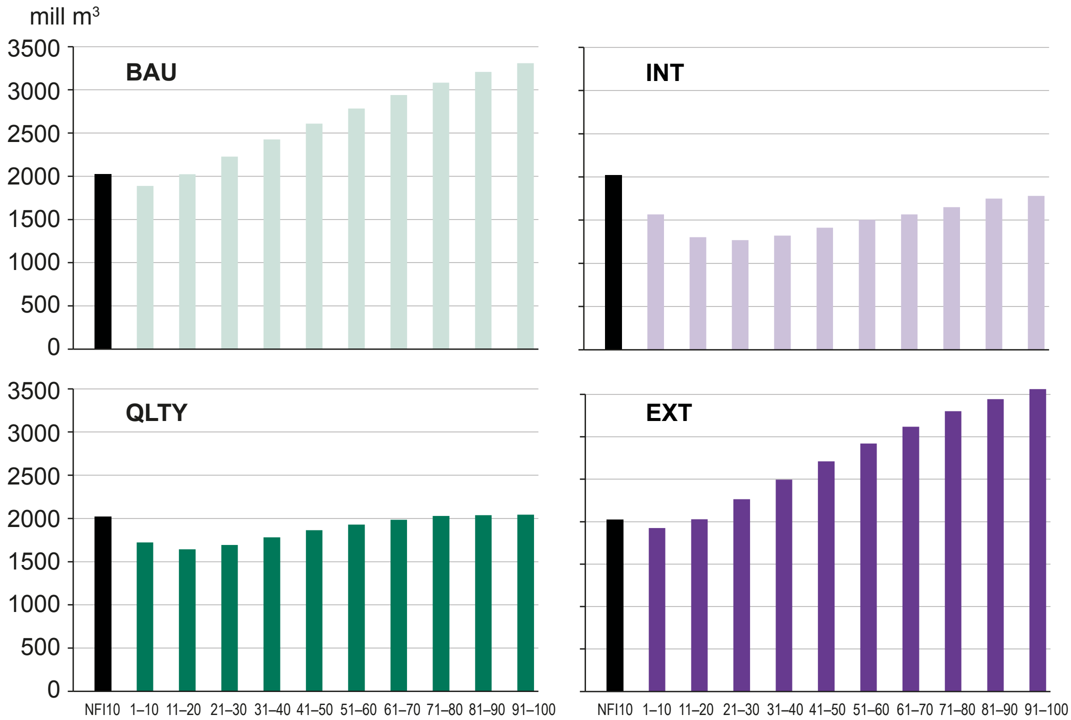


Figure 12. Volume of the growing stock by 10th Finnish National Forest inventory (NFI10), and temporal variation of growing stock 2010-2110 mill m^3 by scenarios.

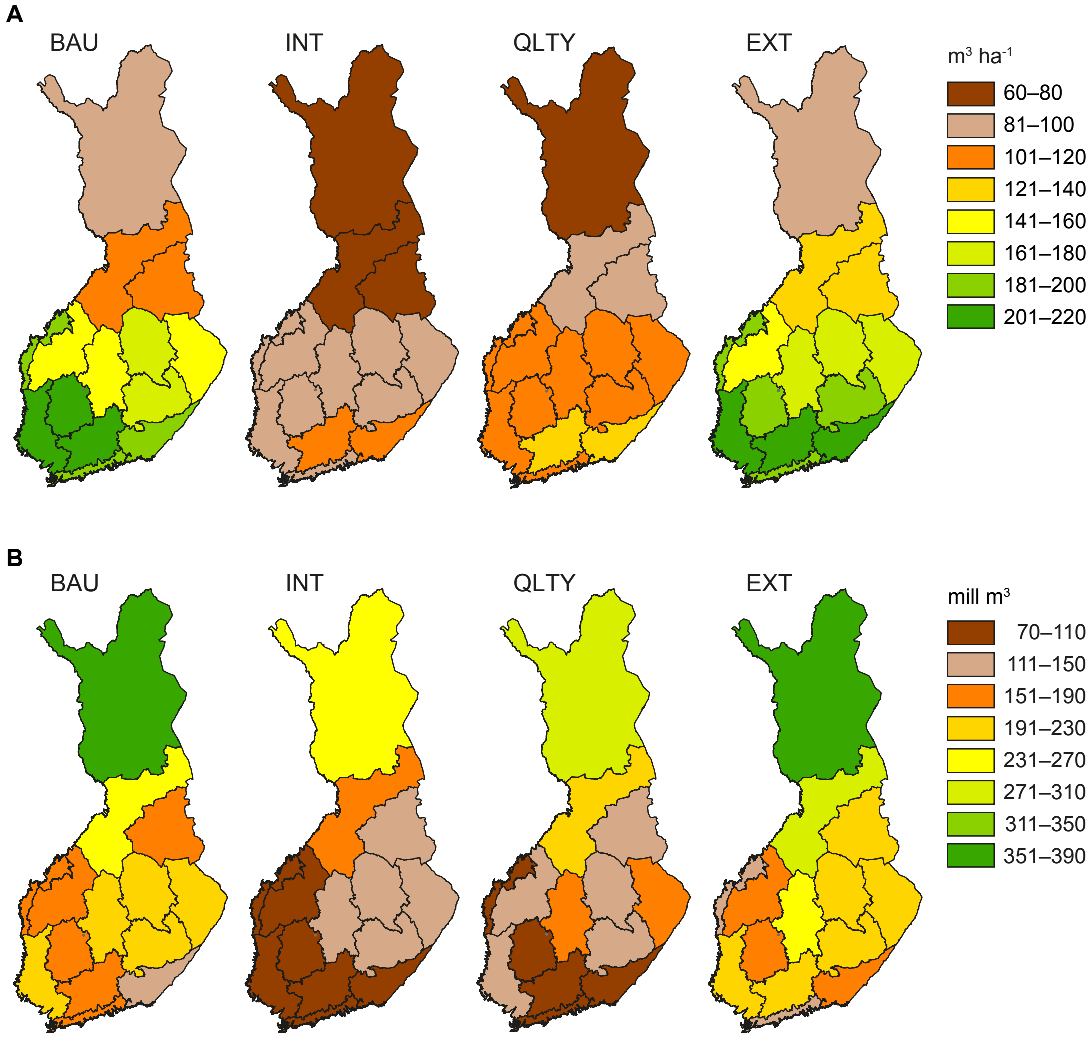


Figure 13. Mean growing stock per hectare (A) $m^3\ ha^{-1}$ and (B) mill m^3 2010–2110 by Forestry Centres for different scenarios.

4.4 Carbon stock and removed carbon

Forest management has well-known impact on the magnitude of carbon sequestration to forests. With extensive management, more carbon will be stored in forest biomass, as the results of this scenario analysis also confirmed (Figure 14).

The carbon stock increased in business as usual (BAU) and extensive management (EXT) scenarios during next 100 years by 61% and 76%, respectively (Figure 14). In intensive management scenario (INT), carbon storage in living and dead biomass remained at the level of 55% from that of EXT scenario. The aim in QLTY scenario was to produce large size logs by applying extended rotations. Thus, amount of carbon in forest was, on the average, 23% greater than in INT scenario. Compared to the carbon storage in the beginning of calculation period, no significant loss of carbon sequestration occurred in QLTY scenario, although the amount of recovered carbon in cuttings was 53% greater compared to current removals. The results also indicated that in the long run, intensively managed forests were capable to capture more carbon from the atmosphere than extensively managed forests. Already within 40 years the amount of captured carbon in QLTY scenario exceeded that of EXT scenario. Because of intensive management, majority of captured carbon was bound to biomass removed from forests in logging operations. Thus, climate impacts finally depend on how harvested wood and biomass will be utilized, i.e. for how long time carbon will be stored in the products, and to what extent forest-based raw materials and energy products will substitute non-renewable materials and fossil-based energy. Finally, in the assessment of climate impacts, the question of time span of the analysis is crucial.

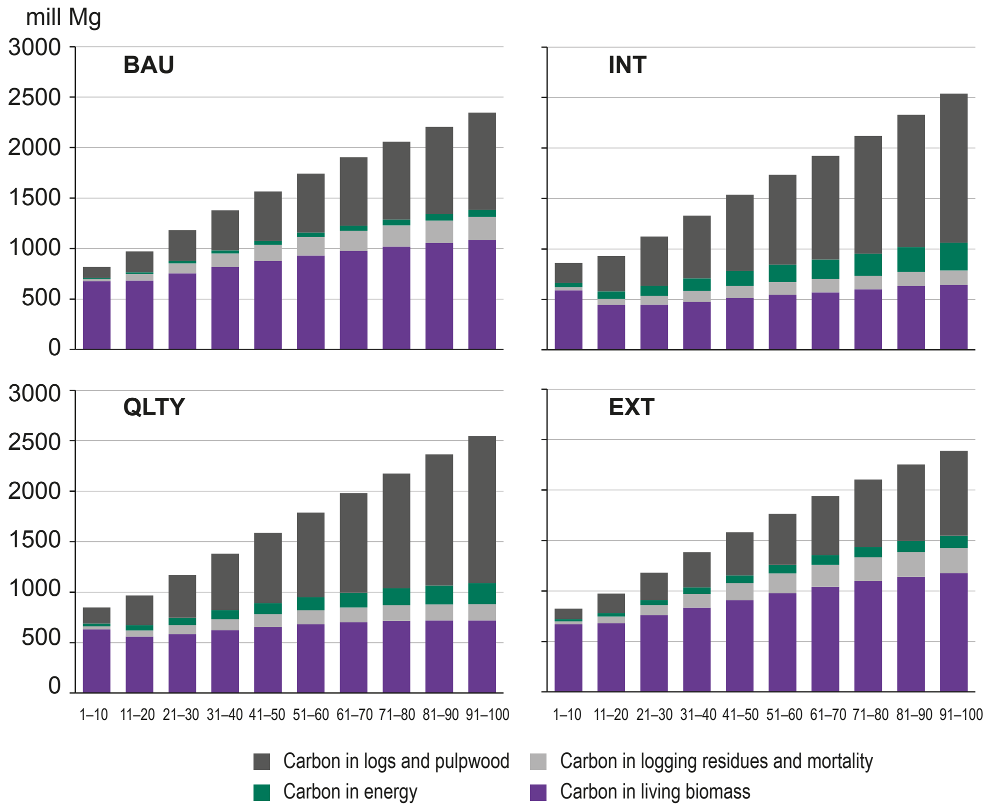


Figure 14. Temporal variation of carbon stock 2010-2110 mill Mg by scenarios.

4.5 Profitability of forest management

Profitability of scenarios was analysed by calculating net present values of future incomes during 100-year calculation period. In the analysis, current stumpage prices and management costs (see chapter 3.2.2.), and discount rates from 1% to 5% were applied. Results showed clearly that intensive forest management revealed superiority of in terms of profitability compared to business as usual management (BAU), or extensive management (EXT) (Figure 15). In INT scenario, present values of net incomes were highest being ca. 1.5-times greater than in BAU scenario in spite of the applied discount rate.

Profitability of INT and QLTY scenarios were equal with 1% discount rate. With higher discount rates, profitability of INT scenario was higher than in QLTY. The explanation for the difference is that the higher discount rate promotes the effect of short rotations and intensive thinnings. Thus, INT scenario resulted in the highest profitability from 2% to 5% discount rate.

Results showed the large variation in profitability between geographical regions (Figure 16). The regional analysis revealed a clear decreasing trend in profitability from south to north. Further, between the scenarios the absolute differences in profitability at 3% discount rate was much greater in Southern and Central Finland compared to Northern Finland. This was due to differences in climate, production potential of forest sites and the structure of forests.

The differences between Forestry centres were also considerable in management costs, incomes and net incomes (Figure 17). The management costs were lower in Northern Finland due to the greater proportion of infertile sites, where less intensive and more affordable silvicultural practices (e.g. regeneration methods) could be applied. The highest management costs were found in intensive forest management scenarios, INT and QLTY, but similarly the incomes were also highest. On the average, INT scenario resulted in 144% greater net incomes per hectare compared to BAU scenario.

Profitability of scenarios was calculated applying current stumpage values and management costs. Applying today's prices and costs in 100-year scenarios was general assumption and may not predict well the situation in future. For example, management costs may differ from the current situation in the future because of the increased mechanization of management practices. Thus, the results on profitability solely reflected financial potential of alternative management strategies in current market situation and operational environment. Based on results, in current situation intensive forest management is profitable strategy. In the long run, it is obvious that increased wood supply can only be realized with favourable market conditions and increased demand for wood. However, this viewpoint was not analysed in this study, but the results will serve as basis for further analysis from the viewpoint of wood supply potential.

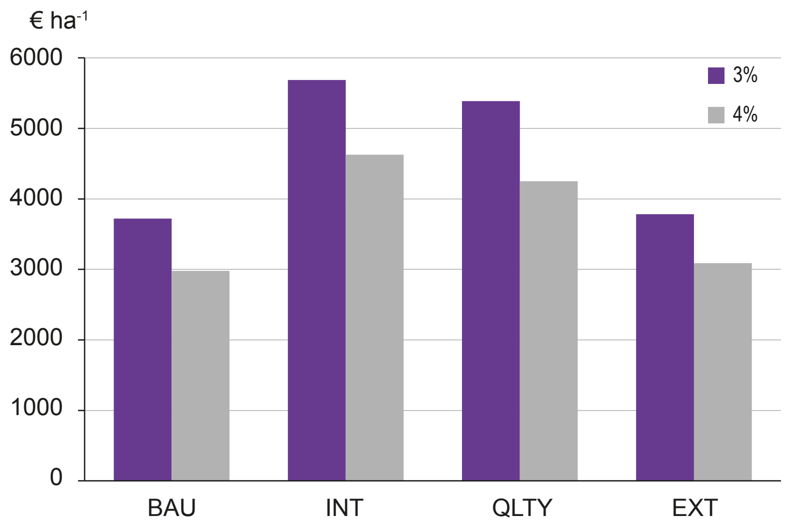


Figure 15. Profitability (net present values) at 3% and 4% discount rates by scenarios.

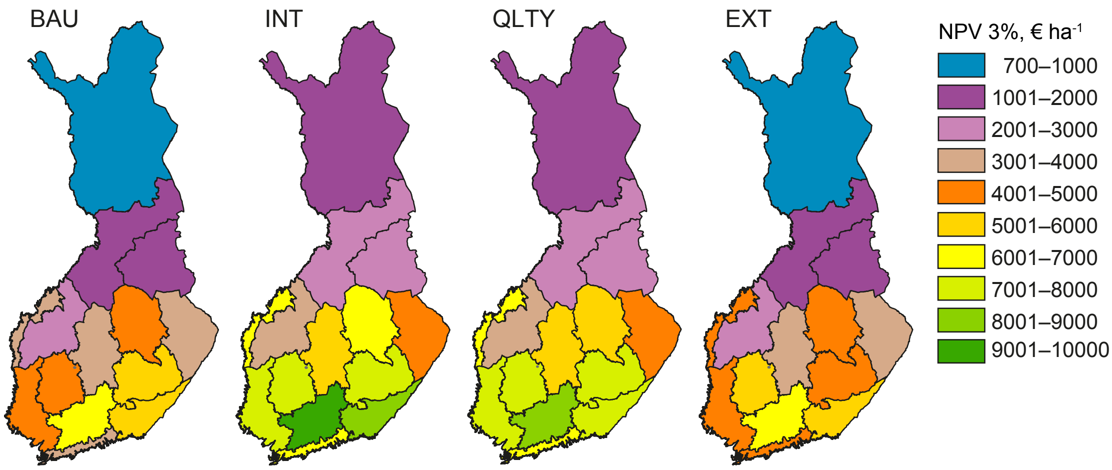


Figure 16. Profitability (net present values) by Forestry centres at 3% discount rate by scenarios.

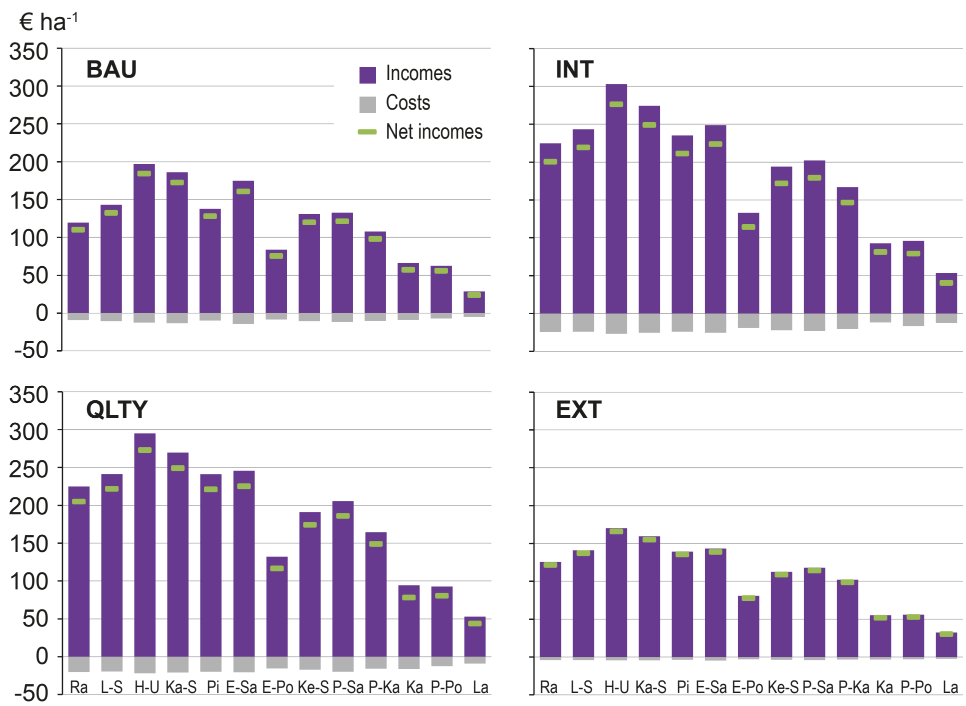


Figure 17. Incomes, costs and net incomes by Forestry centres and by scenarios.

5 Highlights

- This study assessed the potential, cost-efficiency and impacts of intensified management of Finnish forests for next 100 years.
- If the aim is to produce high quality raw material for forest industry, higher inputs in annual management practices are required.
- Young stand management is in the main focus in the forest management. Treatment areas of young stand management should be doubled compared to current areas in order to maintain or increase cutting removals of high quality wood.
- Intensive management allows increase of annual removals ca. 40%.
- The annual energy wood removal can nearly met the target supply level of 13 mill m^3 with intensive forest management by recovering only small-size stem wood, logging residues and stumps.
- If the intensity of forest management will remain at current level, , the growing stock will increase. Intensive management does not decrease the amount of growing stock in the long run, despite increasing removals.
- Intensively managed forest are more efficient capturing carbon from atmosphere than extensively managed forests, but the climate impacts depend on the use of removed carbon i.e. end-products made from the removed wood biomass.
- Intensive forest management improves profitability nearly 50%. Especially the positive effect of intensive management on profitability is notable in Southern Finland

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Appendix 1: Prediction models for stand dynamics in Motti simulator

1 Natural regeneration and early growth

The early growth of stands in MOTTI simulator comprises stand establishment and the development of the stand characteristics from establishment to dominant height (Hdom) of height meters. Thereafter, the stand-level predictions are replaced by individual-based models for tree growth. The general approach to early growth prediction applied in MOTTI is described by Siipilehto et al. (2014).

Species composition in natural regeneration follows species of seed trees. In artificial regeneration, trees are established according to user-defined rules covering tree species, origin and number of plants or seeding points. In addition to seeded or planted trees, naturally regenerated mixture is predicted using models that are based on data from the Finnish National Forest Inventory (NFI7). Species mixture and species specific stem number is affected by soil type (mineral or organic), site fertility, regeneration method and dominant tree species (see Hynynen et al. 2002, Tables 15 and 17). Corrections to numbers given by Hynynen et al. (2002, Table 15) are calculated according to site preparation method and stand location. After early cleaning of sapling stand (Hdom < 2 m), a new seedling storey is established and its density is scaled according to the time of cleaning.

The models for stand characteristics are assumed to be multiplicative, and they were fitted using linear regression after logarithmic transformations. The following dependent variables (Y) were fitted simultaneously: 1) total basal area (G, m2ha-1), 2) total stem number (N, ha-1), 3) arithmetic mean diameter (D, cm), 4) basal area median diameter (dgM, cm), 5) dominant diameter (Ddom, cm), 6) mean height (H, m), 7) basal area median height (hgM, m), 8) dominant height (Hdom, m). The basic models represented the average development of each stand variable over the stand total age. The common structure of the candidate model was as follows:

$$\ln Y = a_0 + a_1 \ln(T) + a_2 T^k + a_3 \ln DDY + a_3\, Origin \times T^k + a_j\, Site_j + \varepsilon \qquad \text{Eq. 1}$$

where T = total age (yrs), and the candidate power k was either -0.5 or -1, DDY = degree days (i.e. average annual sum of the mean temperatures above +5 °C), “Origin” is a dummy (value either 0 or 1) for artificial regeneration methods and “Site” consists of dummy variables associated with a certain site (j) defined as forest type by Cajander, and the supplementary site characteristic such as stoniness and paludification, a_0–a_i, are estimated parameters of the model and ε is the random error.

The models were fitted simultaneously in order to estimate the cross-model error variance-covariance matrix. The matrix is needed when calibrating the expected value using linear prediction theory to define the best linear unbiased predictor (BLUP). Theoretically, the models could be calibrated with any combination of the presented variables. However, in a practical application for young stands calibration is made with N and sometimes with inventory data, such as D, H and N (see Siipilehto 2006). Cleaning and thinning of stand means decreasing number of trees. Its effect on the dimensions is estimated through the covariance between stem number N and corresponding mean characteristic. The negative correlation between N and D was -0.50, whereas between N and H or N and Hdom it was -0.25 and -0.15, respectively (Siipilehto 2006).

2 Growth of established stands

2.1 Approach and data

The general approach to growth prediction applied in MOTTI is described by Hynynen et al. (2002). The system was updated in 2006 with a new generation of tree growth models, which covered the development of mineral soil stands with dominant height over 8 m. The construction of the growth models aimed at reliability considering all Finnish forests managed according to even aged forestry. Furthermore, the models were supposed to cover different features of stand dynamics including, for example, the effect of thinnings

The trees of a stand are expressed as tree lists where each list member, a sample tree, represents a certain number of trees per hectare. The basic sample tree variables are tree species, breast height diameter, height and the number of trees per hectare. Tree growth is predicted with diameter growth and height growth models. Moreover, tree crown size has a significant role to predict tree's reaction to thinning. Length of tree crown is expressed using crown ratio that is given as a function of tree size and tree's competitive status in the stand. After thinning, the adaption to the new competitive situation has been modelled using theoretical model for crown length adaption.

The modelling process was aiming at both a) reliability for all Finnish forests, and b) sufficient description of within stand dynamics. Reliable modelling of within-stand dynamics based on between-tree competition necessitates large sample plots (Stage and Wykoff 1998). Because nationwide and representative data with sufficient sample plot size was not available, the models were developed in two phases.

First, the diameter- and height growth models and the crown ratio model were constructed using combined INKA- and TINKA data sets. They are based on sample plots big enough for reliable competition modelling (Hynynen and Ojansuu 2003). The data sets are samples from restricted strata of Finnish forests including only single-storied healthy stands on forest site types typical for each tree species with the proportion of major tree species at least 50% of total growing stock. For a detailed description, see Hynynen et al. (2002).The models were estimated with linear or nonlinear regression method taking into account the hierarchal structure of the data, i.e. plots with sample trees in a stand.

Secondly, the models were calibrated (Hynynen et al. 2002) with 8^{th} National Forest Inventory temporary sample plots (NFI8) based on small relascope sample plots (Tomppo et al. 2001).

2.2 Competition measures

The effect of stand dynamics on tree growth is based on competition effects. Competition effect is modelled with stand density (relative density factor, RDF) describing symmetric competition and trees position in the stand (relative density factor of the larger trees than the subject tree, RDFL) describing asymmetric competition (Hynynen et al. 2002). Both competition measures can be also used tree species wise indicated with subscripts $_{Sp}$ for Scots pine and $_{bl}$ for deciduous trees.

RDF attributes the ratio between the actual stand density and the density of a stand undergoing self-thinning. The self-thinning line was determined with Reineke's (1933) formula

$$N = C0 \cdot D_k^{C1}, \qquad \text{Eq. 2}$$

where N is the maximum number stems per hectare, d_k is the mean diameter at stump level and $C0$ and $C1$ parameters. Competition is expressed as the sum of the minimum growing spaces of a tree per hectare:

$$ga_i = \sum_{i=1}^{n} [C0^{-1} \cdot d_{ki}^{-C1}] \qquad \text{Eq. 3}$$

where dk is tree diameter at stump level, i is indicator for tree and n is number of trees per hectare. The asymmetric competition measure RDFL includes only trees bigger than the subject tree and half of the subject trees minimum growing space. The parameters $C0$ and $C1$ are based on Reineke's (1933) self-thinning model estimated from data with ongoing self-thinning (see Hynynen et al. 2002). The parameter $C0^{-1}$ is given directly as a function of site variables:

$$C0^{-1} = a_{C0} \cdot \left(a_{C1a} + \frac{TS}{1000}\right)^{a_{C1b}} \cdot exp\left(a_{C2} \cdot OMat + a_{C3} \cdot OMT + a_{C4} \cdot VT + a_{C5} \cdot CT + a_{C6} \cdot ClT + a_{C7} \cdot Stony + a_{C8} \cdot Palud + a_{C9} \cdot Humus + a_{C10} \cdot Lake + a_{C11} \cdot Sea + a_{C12} \cdot Alt + a_{C13} \cdot TS * Alt + ClT \cdot \left(a_{C141} + \frac{TS}{1000}\right)^{a_{C142}}\right), \qquad \text{Eq. 4}$$

where ***TS*** is temperature sum with three 5 °C threshold, ***OMaT, OMT, VT, CT*** and ***ClT*** are dummy variables indicating fertility classes from the most fertile to the least fertile, ***Stony, Palud*** and ***Humus*** are dummy variables expressing specifications reflecting lower yield capacity, are indexes for the lake and sea coverage in the neighbourhood and ***Alt*** is the altitude in meters (see detailed description of the site variables in Hynynen et al. 2002).

For trees with stump height diameter less than 12 cm, the relationship between stem number and diameter was assumed to be linear with a same slope as the first derivative of self-thinning line (see Hynynen et al.2002).

Table 1. Parameter values of the minimum growing space model (Eq. 2 and Eq. 4).

	Scots pine	Norway spruce	Silver birch	Pubescens birch
$-C1$	2.067	1.593	2.218	1.855
1000*a_{C0}	0.0007666	0.003292	0.0003292	0.001914
a_{C1a}	-0.17	-0.60	-	-
a_{C1b}	-0.4269	-0.1645	-	-
a_{C2}	-0.003178	-0.02072	-	-
a_{C3}	-0.003178	0.002699	-	-
a_{C4}	0.03012	0.01562	-	-
a_{C5}	0.07614	0.05627	-	-
a_{C6}	-0.7614	-0.9653	-	-
a_{C7}	0.05279	0.04533	-	-
a_{C8}	0.01913	0.03494	-	-
a_{C9}	0.08891	0.06530	-	-
a_{C10}	0.1012	-0.03203	-	-
a_{C11}	0.01459	-0.05316	-	-
1000* a_{C12}	-0.3249	-0.4245	-	-
1000000* a_{C13}	-0.03374	-0.06554	-	-
a_{C141}	-0.35	0.00	-	-
a_{C142}	0.01252	0.03391	-	-

2.3 Basic structure of the growth models

The height and diameter growth models base on growth function presented by Richards (1959)

$$W = A \cdot (1 - \exp(-k \cdot t))^{\frac{1}{1-m}}, \qquad \text{Eq. 5}$$

where W is size of the entity, t is age and A, k alike m are parameters. A is the maximum size of W, k affects to the growth rate and m affects to the shape of the growth function. The time derivative can be written in form

$$\frac{\Delta \mathrm{W}}{\Delta t} = n \cdot W^m - K \cdot W, \qquad \text{Eq. 6}$$

where n and K are parameters, which can be derived from the parameters of Eq. 5:

$$K = \frac{k}{1-m} \quad \text{and} \qquad \text{Eq. 7}$$

$$n = A^{(1-m)} \cdot K. \qquad \text{Eq. 8}$$

The parameters of Eq. 6 are difficult to interpret if they are statistically estimated from an inventory type of sample. In these growth models, Eq. 5 is reformulated in to a more interpretative form:

$$\frac{\Delta \mathrm{W}}{\Delta t} = A^{(1-m)} \cdot K \cdot W^m - K \cdot W = K \cdot \left(A^{(1-m)} \cdot W^m - W\right). \qquad \text{Eq. 9}$$

A is the maximum size, K affects to the growth rate and m affects to the model shape, especially to location of the inflection point. Equation 9 was applied as difference model for next five years growth $iW5$:

$$iW5 = A^{(1-m)} \cdot K \cdot W^m - K \cdot W = K \cdot \left(A^{(1-m)} \cdot W^m - W\right). \qquad \text{Eq. 10}$$

2.4 Height growth model

The height growth model is based on three assumptions that restrict the parameter estimation. First, height growth of the dominant trees is supposed to be independent of between-tree competition. Secondly, site properties affect only to the maximum size parameter A. Finally, the inflection point locates always at the same height independent of site properties and constant competition.

Height growth model for dominant trees is

$$ih5 = K_{h0} \cdot \left({A_h}^{(1-m_h)} \cdot h^{m_h} - h\right) * \varepsilon, \qquad \text{Eq. 11}$$

where h is tree height, K_{h0} is a constant parameter, and the maximum size parameter A_h is a function of site variables:

$$A_h = a_{h0} + a_{h1} \cdot TS + a_{h2} \cdot OMaT + a_{h3} \cdot OMT + a_{h4} \cdot VT + a_{h5} \cdot CT + a_{h6} \cdot ClT + (a_{h12} \cdot Gro + a_{h13} \cdot OMT + a_{h14} \cdot VT + a_{h15} \cdot CT + a_{h16} \cdot ClT) \cdot TS. \qquad \text{Eq. 12}$$

The shape parameter m_h is set to a value that results in the height growth maximum to be approximately at 2 meters height:

$$m_h = -0.00889 + 3.10486/A_h - 4.09872/{A_h}^2 + 94.04536/{A_h}^3 \qquad \text{Eq. 13}$$

When the height growth model is applied to trees that are smaller than the dominant trees, parameter K_{h0} is replaced with parameter K_h which affects growth rate asymmetrically after the following formulation

$$K_h = K_{h0} + b_{h1} \cdot RDFL + b_{h2} \cdot RDFL_{Sp} + b_{h3} \cdot RDFL_{bl}\,, \qquad \text{Eq. 14}$$

where b_{h1} is a negative parameter. Thus, the height growth model (Eq. 11, 12 and 14) includes parameters A_h and K_h, which are dependent on exogenous variables describing site properties and competitive status of the tree.

Table 2. Parameter values of the height growth model (Eq. 11, 12 and Eq. 14).

	Scots pine	Norway spruce	Birch and aspen	Other deciduous
a_{h0}	6.07	3.45	0.00	0.00
a_{h1}*1000	21.70	28.10	32.00	33.90
a_{h2}	0.33	0.00	0.00	0.00
a_{h3}	0.33	0.00	0.00	0.00
a_{h4}	4.11	8.99	0.00	0.00
a_{h5}	10.16	8.99	0.00	0.00
a_{h6}	10.16	8.99	0.00	0.00
a_{h12}	0.00	6.51	1.35	3.33
a_{h13}	0.00	6.51	1.35	3.33
a_{h14}	-6.38	-10.5	0.00	0.00
a_{h15}	-17.20	-10.5	0.00	0.00
a_{h16}	-17.20	-10.5	0.00	0.00
K_{h0}	-3.08	-3.45	-3.04	-3.81
b_{h1}	-0.86	-1.50	-1.48	-0.86
b_{h2}	0.00	0.70	0.00	0.00
b_{h3}	0.00	0.07	0.00	0.00

2.5 Diameter growth model

Diameter growth model applies a stump diameter function (Laasaneaho 1975)

$$d_k = 2 + 1.25 \cdot d \qquad \text{Eq. 15}$$

where d is breast height diameter in cm. The basic form of the diameter growth model is

$$id5_k = K_d \cdot \left(A_d^{(1-m_d)} \cdot d_k^{m_d} - d_k \right) * \varepsilon \qquad \text{Eq. 16}$$

It is based on three assumptions. First, the maximum diameter (A_d) does not depend on the site variables. Secondly, the growth rate parameter K_d depends on the site variables and the between-tree competition. The growth rate parameter K_d is

$$ln(K_d) = a_{d0} + a_{d1} \cdot TS + a_{d2} \cdot OMaT + a_{d3} \cdot OMT + a_{d4} \cdot VT + a_{d5} \cdot CT + a_{d20} \cdot RDF + a_{d21} \cdot RDF_{Sp} + a_{d22} \cdot RDF_{bl} + a_{d25} \cdot RDFL + a_{d26} \cdot RDFL_{Sp} + a_{d27} \cdot RDFL_{bl}, \qquad \text{Eq. 17}$$

Thirdly, the shape parameter m_d is determined so that the diameter growth maximum is always at the breast height diameter of 2 cm (equation 18a) for conifers and 1 cm (equation 18b) for deciduous trees corresponding to stump diameters 4.5 cm and 3.25 cm, respectively:

$$m_d = -0.00889 + 6.9859/A_d - 20.750/{A_d}^2 + 1071.2/{A_d}^3, \text{ and} \qquad \text{Eq. 18a}$$

$$m_d = -0.00889 + 5.0453/A_d - 10.823/{A_d}^2 + 403.6/{A_d}^3 \qquad \text{Eq. 18b}$$

Thus, the diameter growth model (Eq. 16) includes only two free parameters. Parameter A_d is spcies specific constant and parameter K_d depends on exogenous variables describing site properties and competitive status of the tree.

Table 3. Parameter values of the diameter growth model (Eq. 16 and Eq. 17).

	Scots pine	Norway spruce	Birch and aspen	Other deciduous
A_d	65.2	99.2	56.7	66.7
a_{d0}	-3.95	-5.47	-4.64	-4.63
a_{d1}	0.95	1.61	1.30	0.61
a_{d2}	0.02	0.30	0.17	0.17
a_{d3}	0.02	0.22	0.17	0.17
a_{d4}	-0.09	-0.12	0.00	0.00
a_{d4}	-0.34	-0.12	0.00	0.00
a_{d20}	-1.83	-1.51	-0.50	-0.21
a_{d21}	0.00	0.46	0.00	0.00
a_{d22}	0.00	0.60	0.00	0.00
a_{d25}	-0.20	-1.76	-2.25	-2.25
a_{d26}	0.00	1.08	0.00	0.00
a_{d27}	0.00	1.20	0.00	0.00

2.6 Calibration with NFI8 data

The growth models were calibrated with NFI8 data in two phases that represented different levels: tree-level growth calibration (calibration 1), and the dominant height calibration at stand level (calibration 2). The first phase aimed at catching the actual growth level of the current Finnish forests. It resulted as a clear overprediction of dominant height at the end of the rotation period compared to the current forests of comparable age and development phase. This indicates that current young stands grow faster that the current old stands did during their earlier development. The age/dominant height calibration assures that modelled stand development will not evolve faster than the mature stand at the time period of NFI8. On the other hand, growth underestimation of the current young stands is possible if they continue to develop faster than past stands. Nevertheless, calibration 2 was justified according to precautionary principle.

The growth calibration (calibration 1) was done with a relative correction factor that was estimated for tree basal area growth ($COR1 = \frac{ig5}{\widehat{ig5}}$). Same correction factor was used for tree height growth. Because the aim of the calibration was to find a reliable growth level, only site variables were used in calibration leaving stand dynamics unchanged.

The correction factor was modelled in logarithmic scale as function of direct site variables and predicted maximum height of the tree (in Eq. 11) as follows:

$$ln(COR1) = c_{1,0} + c_{1,1} \cdot \frac{ts}{1000} + Sp1200\left[c_{1,2a} \cdot \left(\frac{ts-1200}{1000}\right) + c_{1,2b} \cdot \left(\frac{ts-1200}{1000}\right)^2\right] + c_{1,3} \cdot OMaT + c_{1,4} \cdot OMT + c_{1,5} \cdot VT + c_{1,6} \cdot CT + c_{1,7} \cdot ClT + c_{1,8} \cdot Rock + c_{1,9} \cdot Fell + c_{1,10} \cdot Stony + c_{1,11} \cdot Palud + c_{1,12} \cdot Humus + c_{1,13} \cdot Lake + c_{1,14} \cdot Sea + c_{1,15} \cdot Plant + \varepsilon_{calib1}\ ,$$ Eq. 19

where $Sp1200$ is a dummy variable for spruce with temperature sum greater than 1200, $Rock$ is a dummy variable for rocky soil, $Fell$ is it for fell land and $Plant$ is it for planted tree.

The growth calibrated prediction for tree basal area growth is

$$\widehat{\iota g_{calib1}} = \exp\left[ln(\widehat{\iota g}) + ln(\widehat{COR}1) + \frac{var(\varepsilon_{calib})}{2}\right],$$ Eq. 20

where $\widehat{\iota g} = \left[\left((d + \widehat{\iota d})/2\right)^2 - (d/2)^2\right] \cdot \pi$

The corresponding prediction for height growth is

$$\widehat{\iota h_{calib1}} = \exp\left[ln(\widehat{\iota h}) + ln(\widehat{COR}1) + \frac{var(\varepsilon_{calib})}{2}\right]$$ Eq. 21

Table 4. Parameter values of the model for calibration 1 (Eq. 19).

	Scots-Pine	Norway-Spruce	Silver birch	Pubescens birch	Aspen	Alder	Other conifer	Other deciduous
$c_{1,0}$	-0.104	0.337	-0.958	-0.958	-0.745	-0.354	0.983	-0.354
$c_{1,1}$	0.165	-0.371	0.839	0.839	0.629	0.141	0.386	0.141
$c_{1,2a}$	0.000	13.2	0.000	0.000	0.000	0.000	0.000	0.000
$c_{1,2b}$	0.000	-5.720	0.000	0.000	0.000	0.000	0.000	0.000
$c_{1,3}$	0.453	0.117	0.317	0.317	0.205	0.341	0.510	0.341
$c_{1,4}$	0.268	0.034	0.119	0.119	0.116	0.213	0.287	0.213
$c_{1,5}$	-0.061	-0.600	-0.235	-0.235	-0.600	-0.600	-0.600	-0.600
$c_{1,6}$	0.032	-1.200	-1.200	-1.200	-1.200	-1.200	-1.200	-1.200
$c_{1,7}$	-0.327	-1.500	-1.500	-1.500	-1.500	-1.500	-1.500	-1.500
$c_{1,8}$	0.103	-1.500	-1.500	-1.500	-1.500	-1.500	-1.500	-1.500
$c_{1,9}$	-0.500	-1.500	-1.500	-1.500	-1.500	-1.500	-1.500	-1.500
$c_{1,10}$	-0.172	-0.141	-0.238	-0.238	-0.288	-0.136	-0.144	-0.136
$c_{1,11}$	-0.343	-0.405	-0.677	-0.677	-0.480	-0.197	-0.356	-0.197
$c_{1,12}$	-0.365	-0.652	0.000	0.000	0.000	0.000	0.000	0.000
$c_{1,13}$	0.000	0.524	0.457	0.457	0.335	0.500	0.000	0.500
$c_{1,14}$	-0.223	-0.184	-0.113	-0.113	0.058	-0.599	-0.243	-0.599
$c_{1,15}$	0.098	0.128	0.122	0.122	0.890	0.000	0.000	0.000
6	0.333	0.434	0.399	0.399	0.366	0.438	0.286	0.438
$var(\varepsilon_{calib1})$	0.577	0.659	0.632	0.636	0.605	0.662	0.535	0.662

Also the age/height calibration (calibration 2) was done with a relative correction factor ($COR2 = \frac{Age_{simulated}}{Age_{measured}}$) , which is the ratio between the measured age of a NFI8 plot ($Age_{measured}$) and the age when (with growth calibrated model) simulated dominant height reach the measured dominant height ($Age_{simulated}$). The age/height correction is expressed as a function of the maximum height parameter in Eq. 11 (A_h) and temperature sum (TS):

$$ln(COR2) = c_{2,0} + c_{2,1} \cdot A_h + c_{2,2} \cdot \frac{TS}{1000} + \varepsilon_{calib2}. \qquad \text{Eq. 22}$$

Possible positive values of COR2 were truncated to 0. The age/height calibrated prediction for tree basal area growth is

$$\widehat{\iota g_{calib2}} = \exp\left[ln(\widehat{\iota g}) + ln(\widehat{COR}1) + ln(\widehat{COR}2) + \frac{var(\varepsilon_{calib})}{2}\right], \qquad \text{Eq. 23}$$

and the corresponding prediction for tree height is

$$\widehat{\iota h_{calib2}} = \exp\left[ln(\widehat{\iota h}) + ln(\widehat{COR}1) + ln(\widehat{COR}2) + \frac{var(\varepsilon_{calib})}{2}\right]. \qquad \text{Eq. 24}$$

Table 5. Parameter values of the model for calibration 2 (Eq. 22).

	Scots pine	Norway spruce	Silver birch	Pubescens birch
$c_{2.0}$	-1.686	0.39	-0.131	-0.944
$c_{2.1}$	0.0137	-0.0088	-	0.268
$c_{2.2}$	0.829	0.300	-	-

It can be assumed that the difference that COR2 captures is mainly due to intensive silvicultural management; efficient regeneration methods, cleaning of sapling stands, pre-commercial and commercial thinning's. Calibration 1 reflects the situation where stands are managed according to current guidelines already from their establishment while the calibration 2 is based most on stands that are naturally regenerated and extensively managed during their early stages.

2.7 Crown ratio model

The crown ratio (cr) model is a linear logit model

$$ln\left(\frac{cr}{1-cr}\right) = \boldsymbol{a} * \boldsymbol{X} + \varepsilon, \qquad \text{Eq. 25}$$

where

$$\boldsymbol{a} * \boldsymbol{X} = a_{cr0} + a_{cr1} \cdot TS/1000 + a_{cr2} \cdot OMaT + a_{cr3} \cdot OMT + a_{cr4} \cdot VT + a_{cr5} \cdot (CT + ClT) + a_{cr6} \cdot Dgk + a_{cr7} \cdot ln(1 + RDF) + a_{cr8} \cdot ln(1 + RDFl) + \varepsilon \qquad \text{Eq. 26}$$

Dgk is mean diameter at stump height weighted with tree basal area. For the economically unimportant tree species the value of the equation 26 (***a*X***) is multiplied for with a correction coefficient as follows: aspen (0.99), common alder (0.98), grey alder (0.97) other conifers (0.96) and other deciduous (0.95).

Table 6. Parameter values of the crown ratio model (Eq. 25).

	Scots pine and other conifers	Norway spruce	Silver birch and aspen	Pubescens birch and other deciduous
a_{cr0}	3.861	5.524	2.218	2.197
a_{cr1}	-0.462	-0.187	-0.595	-0.595
a_{cr2}	-0.172	0.218	0.248	0.248
a_{cr3}	-0.172	0.229	0.084	0.084
a_{cr4}	0.066	0.381	0	0
a_{cr5}	-0.09	0.381	0	0
a_{cr6}	-0.635	-0.884	-0.198	-0.198
a_{cr7}	-2.079	-1.833	-0.988	-0.988
a_{cr8}	-0.996	-1.362	-0.889	-0.889

2.8 Adaption of thinnings

Thinnings change the competition structure of stand, and the trees adapt gradually to the new conditions. Straight after thinning, tree growth is slower than in a comparable stand without recent thinning. The adaption effect has been simulated by using crown length dynamics.

Crown ratio is predicted as a function of site, tree size and competition variables (Eq. 25). Thinning reduces competition, and the predicted crown ration increases suddenly, i.e. the predicted height of crown base falls. In reality, height of crown base cannot fall, it just stays on same level than before thinning, which can be presented as the maximal possible crown ratio (cr_{max}). The relationship between predicted crown ratio based on actual competition (cr_0) and the maximal possible crown ratio (cr_{max}).) has been used as an indicator of thinning adaption.

To utilize this adaption principle, the dependence between crown ratio and tree growth must be described. Therefore, new models for diameter and height growths were estimated where the competition variables were replaced by crown ratio. The growth reduction was then predicted by multiplying the original growth prediction (Eq. 11 for height growth and Eq. 16 for diameter growth) with a correction factor based on the ratio of two predictions with the respective crown ration based growth models (Eq. 26 for height growth and Eq. 27 for diameter growth):

$$CORh_{thin} = \frac{\iota h(\widehat{cr_0})}{\iota h(\widehat{cr_{max}})} \text{ and } CORg_{thin} = \frac{\iota g(\widehat{cr_0})}{\iota g(\widehat{cr_{max}})}, \qquad \text{Eq. 26 and Eq. 27}$$

where $\iota h(\widehat{cr_0})$ and $\iota g(\widehat{cr_0})$ are tree growth predictions for tree height and basal area based on the actual competition. Correspondingly, $\iota h(\widehat{cr_{max}})$ and $\iota g(\widehat{cr_{max}})$ the corresponding prediction based on maximal possible crown ratio.

The height growth model including crown ratio is a linear regression model where the dependent variable is natural logarithm of five years height growth and the independent variables are site variables, tree height and natural logarithm of crown ratio ($ln(cr)$. Because of the log-linear form of the model, the correction factor is reduced to form

$$CORh_{thin} = \frac{{cr_0}^{a_{hcr}}}{{cr_{max}}^{a_{hcr}}}, \qquad \text{Eq. 28}$$

where a_{hcr} is the regression coefficient of variable $ln(cr)$. The coefficient values for different tree species are 0.521 for Scots pine, 0.966 for Norway spruce, and 0.354 for deciduous trees.

General form of the diameter growth model based on crown ratio is similar than the original diameter growth model (Eq. 16) and the correction factor for diameter growth is reduced to form:

$$CORd_{thin} = \frac{\frac{2\cdot m_{dcr0}+2}{(1-m_{dcr0})^2}\cdot\left(A_{dcr}{}^{1-m_{dcr0}}\cdot d_k{}^{m_{dcr0}}-d_k\right)\cdot cr_0{}^{a_{dcrp}}}{\frac{2\cdot m_{dcrmax}+2}{(1-m_{dcrmax})^2}\cdot\left(A_{dcr}{}^{1-m_{dcrmax}}\cdot d_k{}^{m_{dcrmax}}-d_k\right)\cdot cr_{max}{}^{a_{dcrp}}} \quad \text{Eq. 29}$$

Parameter A_d^{cr} depends on site variables as follows:

$$A_{dcr} = a_{dcr0} + \left(a_{dcr1} + a_{dcr2}\cdot(OMaT+OMT) + a_{dcr3}\cdot VT + a_{dcr4}\cdot(CT+ClT)\right)\cdot\frac{TS}{1000} \quad \text{Eq. 30}$$

The shape parameter m_{dcr0} is determined so that the diameter growth maximum is constant with constant crown ratio:

$$m_{dcr0} = \left(-0.00889 + \frac{22.51023}{A_{dcr}} - \frac{215.439}{A_{dcr}{}^2} + \frac{35838.63}{A_{dcr}{}^3}\right)\cdot a_{dcrm}\cdot(1-cr_0) \quad \text{Eq. 31}$$

for actual competition and

$$m_{dcrmax} = \left(-0.00889 + \frac{22.51023}{A_{dcr}} - \frac{215.439}{A_{dcr}{}^2} + \frac{35838.63}{A_{dcr}{}^3}\right)\cdot a_{dcrm}\cdot(1-cr_{max}) \quad \text{Eq. 32}$$

for maximum competition.

Table 7. Parameter values of the thinning correction factor for diameter growth (Eq. 29–32).

	Scots pine	Norway spruce	Silver birch	Pubescens birch
a_{dcr0}	26.8	10.11	12.8	6.4
a_{dcr1}	13.80	39.05	31.65	31.20
a_{dcr2}	-1.2	0.0	0.0	0.0
a_{dcr3}	-2.69	-13.88	0.0	0.0
a_{dcr4}	-15.39	-14.28	0.0	0.0
a_{dcrp}	0.445	1.816	0.528	0.528
a_{dcrm}	4.3	0.0	4.4	4.4

3 Growth prediction in unmanaged stands

Growth and yield models of MOTTI-system are designed to provide predictions for assessing the impacts of alternative forest management practices in forest stands, where rotation periods are close to those applied in commercial Finnish forests today. In this study, compilation of extensive management scenario (EXT), however, required long-term simulation of forest stands without any management (WS7). In practice, simulations were carried out for stands that were near or past rotation age already in the beginning of 100-year simulation period, and dynamics of those stands was simulated for 100-years from now. Thus, the age of the oldest stands at the end of simulation period varied between 200 and 350 years. Being so, growth and yield models of MOTTI were applied outside the limits of their intended application range.

Unfortunately, applicable empirical measurement data do not exist for evaluating of model performance in "over-mature" stands. The best available information on stand growth and yield in unmanaged stands can be obtained from growth and yield tables of Ilvessalo (1920) based on naturally normal stands. We compared the output of MOTTI-simulations with these old growth and yield tables, and used that information for assessing the model behaviour. The comparison revealed that MOTTI over-predicted the total yield of unmanaged coniferous stands by 1.5-times to that of with yield tables of Ilvessalo during the 130-year time period (=stand ages up to 130 years). It is likely that commercial forests today are much more productive than natural normal stands in early 20th century (Spiecker 1999, Metslaid et al. 2011). Therefore, it can be assumed that even without any further management, wood production of these forests in the future will be on higher level compared to forests that Ilvessalo measured. However, it seems unlikely that difference would be as much as 50%. As the result of a priori information discussed above, the reduction of 20% was done to total yield prediction of Motti for scenario WS7.

We assumed that the over-prediction of total yield in unmanaged stands gradually increases as simulation proceeds, and that over-prediction is 20% at the end of the 100-year simulation period. Respectively, the predicted 5-year yields were downsized by a factor that decreased in time from 1.0 to 0.8.

4 Mortality

Mortality in managed stands

Natural mortality was predicted with models and according to the prediction procedure reported in Hynynen et al. (2002). Mortality models applied in MOTTI include an individual-tree survival model, individual-tree model for age-related mortality, and stand-level model for self-thinning. These models account for mortality related to within-stand competition in the absence of large-scale disturbances. These mortality models are applicable for predicting natural mortality of managed stands, with relatively short rotation periods. When applied to long-term prediction of unmanaged stands, models are likely to under-predict mortality rates, because prediction system ignores the risks for extensive abiotic and biotic damages, caused by, e.g., wind, snow, fire, pathogens or insects. However, it is known based on previous studies, such as Yli-Kojola (2002, 2005) that damage risks increase with increasing stand age, and are more frequent in unmanaged than in managed stands. Based on models of Yli-Kojola (2005), for example, the risk of wind damage in 90-year-old unmanaged Norway spruce stand is ca. 25%, when the risk in 70-year old managed spruce stand is ca. 8%.

Mortality in unmanaged stands

In scenario analysis, there was a need to predict long-term dynamics of stands without any management practices (EXT-scenario, and especially working scenario WS7). Therefore, predicted mortality rates were modified for simulation of unmanaged stands. It was assumed that under-prediction of mortality models gradually increases along with simulation period in unmanaged stands, and that under-prediction is 30% at the end by the 100-year simulation period. In practice, the predicted amounts of mortality by 5-year growth periods were corrected so that in the first five-year simulation period, no correction was made, but in the last 5-year period predicted mortality was multiplied by constant equal to 1.3.

5 Biomass and carbon stock

Goal of carbon stock calculation was to study the differences between carbon sequestration of the scenarios. Amount of carbon was estimated based on predicted living and dead biomasses. Carbon mass was then obtained by multiplying biomass by constant equal to 0.5. In the analysis, only carbon dynamics related to stocking was considered, i.e. carbon sequestrated in growing stock and in dead wood including logging residues and natural mortality. Loss of carbon mass due to decomposition of dead wood and logging residues was also taken into account. Both above-ground and below-ground carbon compartments were considered. Despite the decomposition of dead biomass no other processes related to soil carbon were considered (Fig 1).

In the beginning of simulation period, only the information on living biomass/carbon was known in NFI data applied in the analyses. Therefore, carbon storage in the beginning of observation period refers only to carbon in the growing stock. However, during the 100-year simulation period, carbon dynamics of logging residues and deadwood formed during the simulation period is considered.

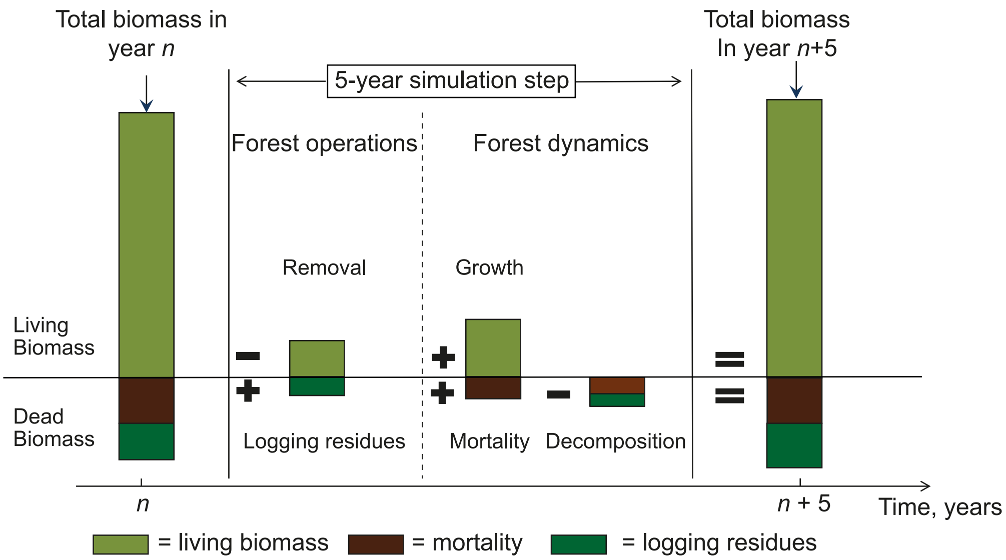

Figure 1. A schematic presentation of calculation principle of stocking biomass. Both living and dead biomass were calculated by biomass compartments (needles and leaves, branches, stems, stumps and roots).

In MOTTI-simulator, living biomass is estimated by biomass compartments (stems, branches, needles/leaves, stumps and roots) using the biomass models of Repola (2008, 2009). Dead biomass consists of natural mortality and logging residues. The prediction of natural mortality is described earlier in this chapter. Decomposition of above-ground dead biomass, including stems and branches, was estimated using the models of Mäkinen et al. (2006). Models predict the actual amount of dead biomass as percentage of the current biomass of the biomass at the time tree was dead or felled. Remaining biomass is predicted as a function of time since death (or felling) of the tree and tree diameter at breast height. Separate models were developed for Scots pine, Norway spruce and birch. Model for birch was applied for all the broadleaved tree species.

The empirical results reported by Shorohova et al. (2008), Melin et al. (2009) and Palviainen et al. (2010) show that measured decomposition rates of stumps and roots of Scots pine, and especially of Norway spruce are faster than predicted decomposition rates of tree stems (Mäkinen et al. 2006) (see Fig 4 and 5). However, no prediction model exists that could have been applicable in predictions of this study. Therefore, a modification of the decomposition model of Mäkinen et al. (2006) was applied in order to predict decomposition rates for below-ground biomass compartments. The parameters of initial models predicting the remaining fraction of wood mass of Scots pine, Norway spruce and birch (parameters b_4, b_5 and b_6 in Table 8, p. 1872 in Mäkinen et al. 2006) were modified so that so that the prediction would be in agreement with results on measured composition rate of stumps and roots. After the modification the predicted percentage of remaining mass 40-years after the death of a tree agreed with the empirical measurement results reported in above mentioned articles (see Figure 2 and Figure 3). The modified model was then applied to predict decomposition rates of stumps and roots.

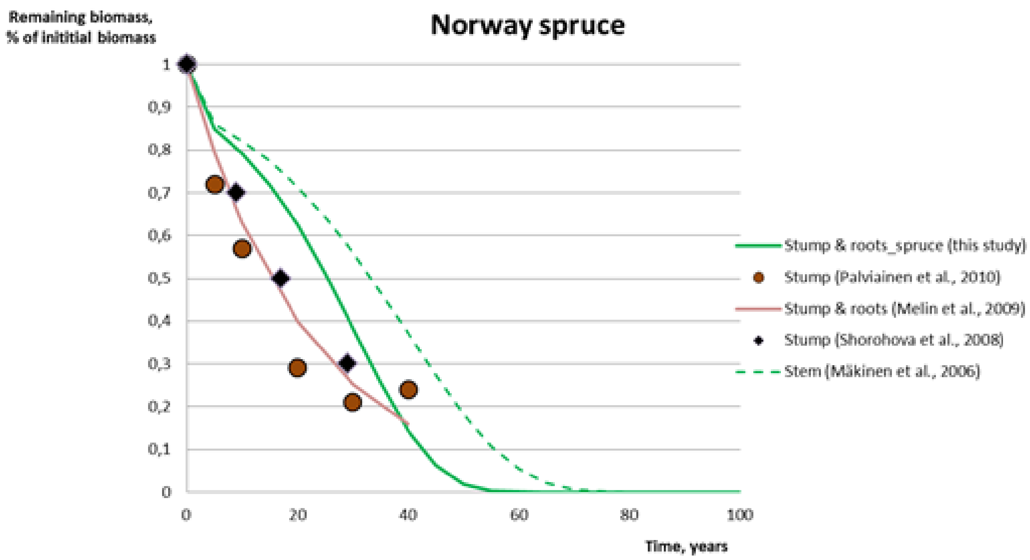

Figure 2 Model for decomposition of stem biomass for Norway spruce by Mäkinen et al. (2006) (dotted green line) and its modification applied in this study to predict decomposition of stumps and roots (solid green line) plotted against the empirical results.

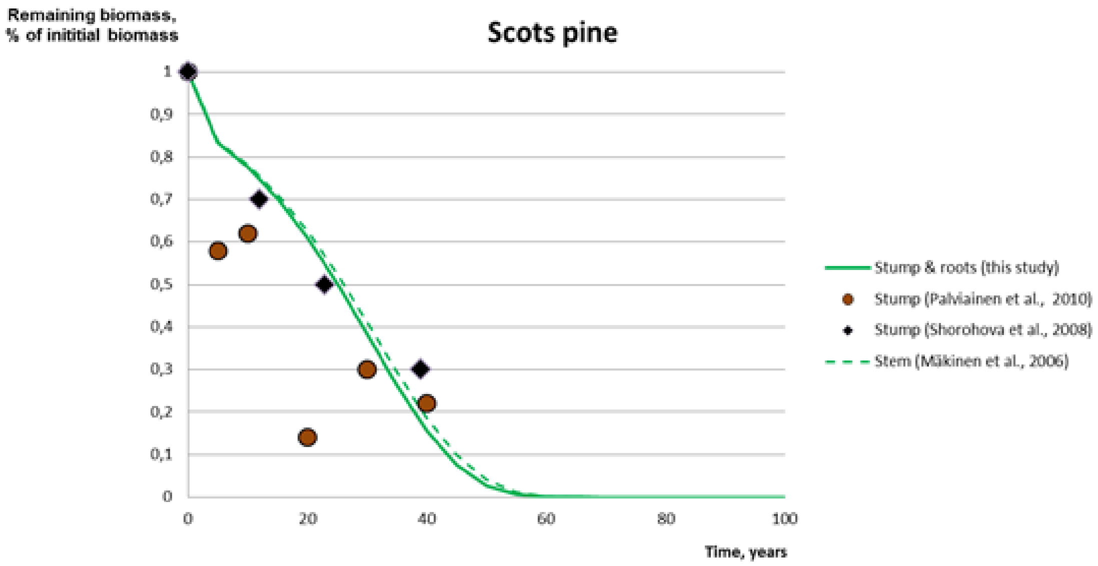

Figure 3 Model for decomposition of stem biomass for Scots pine by Mäkinen et al. (2006) (dotted green line) and its modification applied in this study to predict decomposition of stumps and roots (solid green line) plotted against the empirical results by Palviainen et al. (2010), Melin et al. (2009) and Shorohova et al. (2008).

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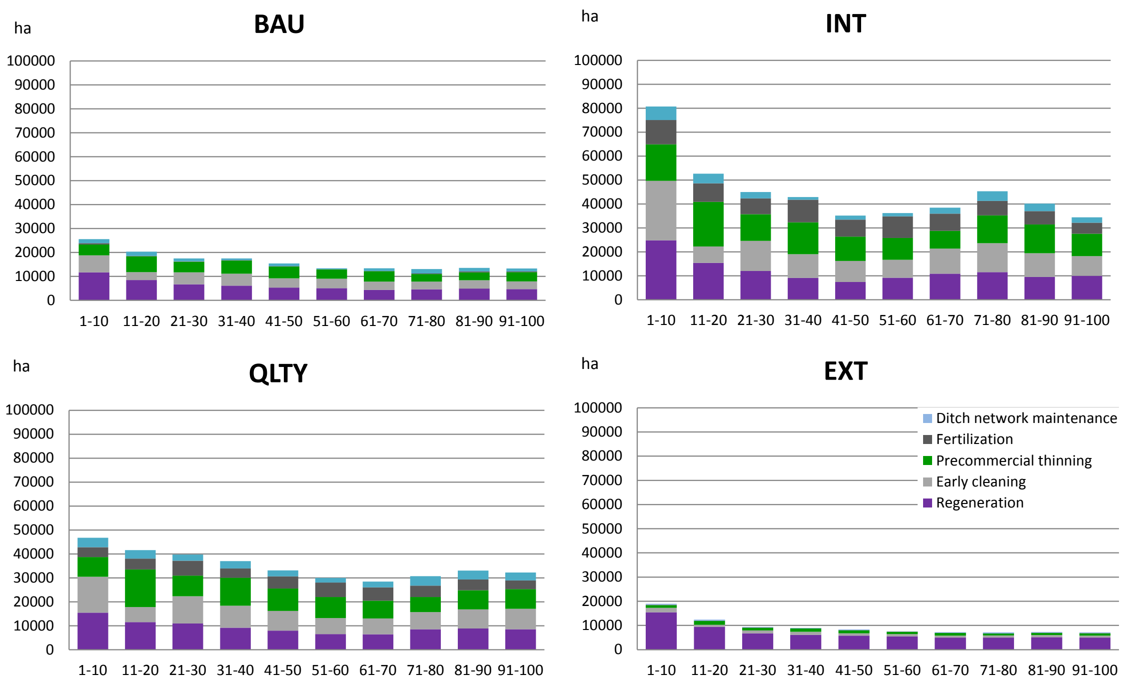
Appendix 2: Forestry centre Rannikko

FOREST MANAGEMENT PRACTICES

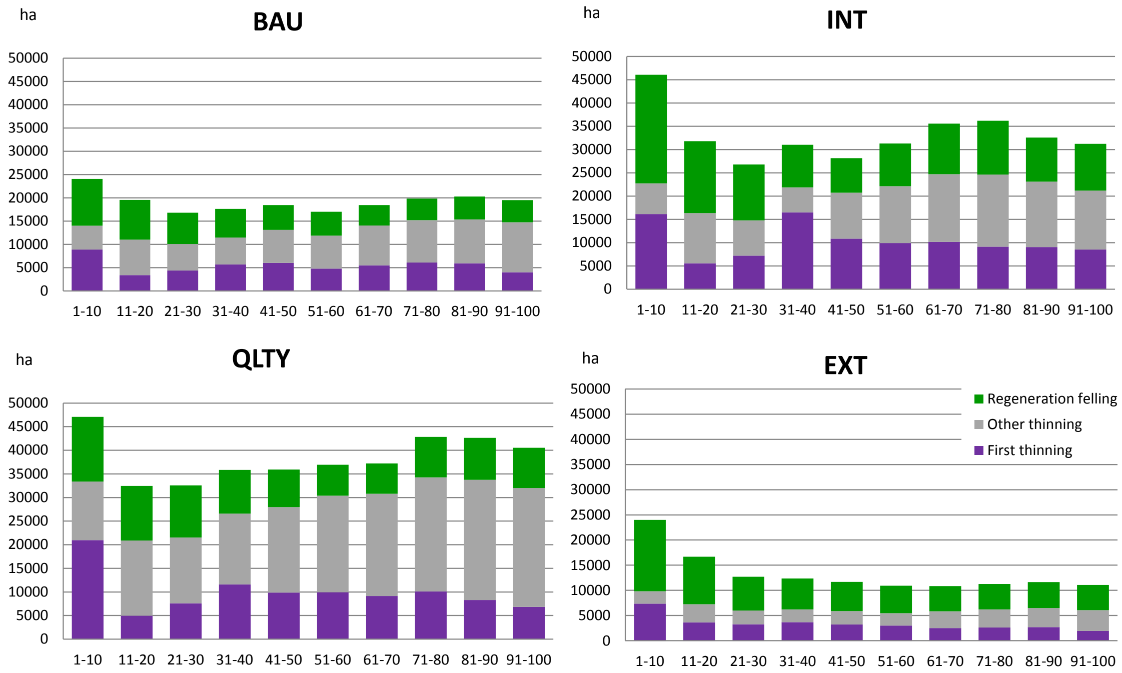
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	5118	11420	8967	2390
Natural regeneration	800	13	13	4204
Total regeneration	*5918*	*11433*	*8981*	*6594*
Early cleaning	3979	10671	8387	995
Precommercial thinning	4332	11383	9008	1083
Fertilization	222	6997	4602	56
Ditch network maintenance	1199	2723	2982	300
First thinning	5289	9925	9585	3273
Other thinning	7383	10570	18622	3032
Regeneration fellings	5864	11460	8967	6554
Total fellings	*18537*	*31955*	*37174*	*12858*

Annual areas of silvicultural practices during the years 2010–2110, ha



Annual area of cuttings during the years 2010–2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010–2110, mill €, undiscounted.

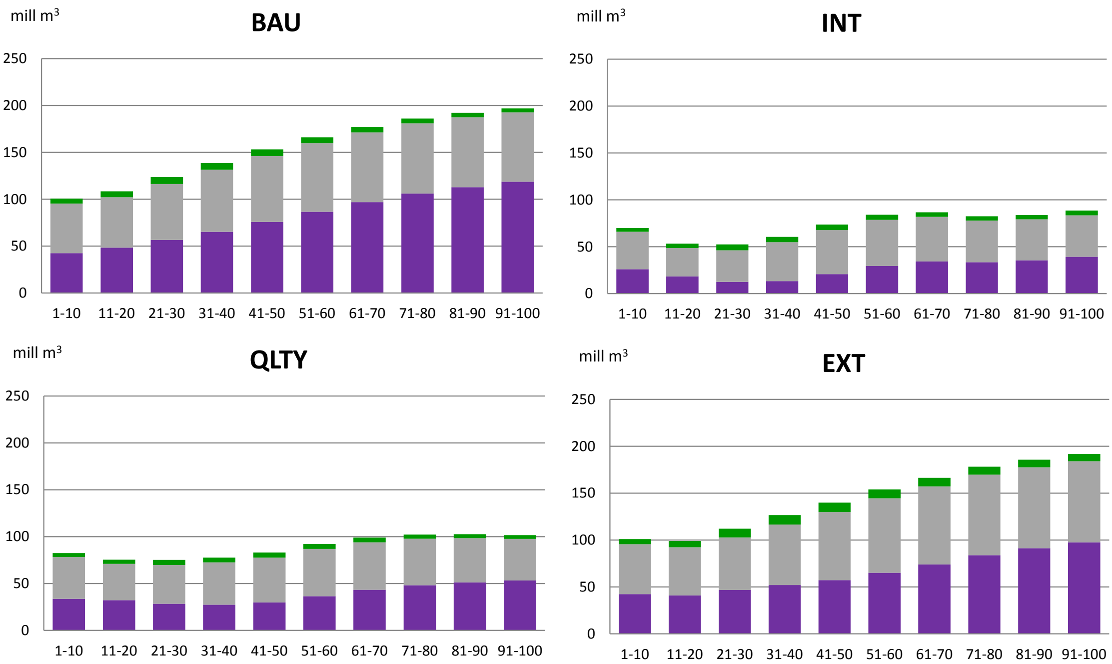
Year	BAU	INT	QLTY	EXT
1-10	120	253	195	146
11-20	106	182	164	117
21-30	90	136	164	93
31-40	85	122	155	89
41-50	81	129	154	87
51-60	84	158	155	87
61-70	84	189	158	86
71-80	90	210	197	87
81-90	96	189	211	92
91-100	94	192	201	95
Average	*98*	*182*	*184*	*102*

Temporal variation and mean of annual harvesting removals during the years 2010–2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	1.71	1.57	0.23	3.46	3.27	1.33	2.72	2.78	0.88	2.09	1.53	0.67
11-20	0.88	0.77	0.09	1.34	1.28	0.38	1.57	1.37	0.37	0.91	0.66	0.33
21-30	1.55	1.16	0.19	2.58	2.03	0.84	2.45	1.62	0.65	1.69	1.13	0.45
31-40	1.30	1.00	0.16	2.14	1.81	0.75	2.44	1.63	0.65	1.41	0.97	0.38
41-50	1.32	0.99	0.17	1.86	1.68	0.64	2.44	1.63	0.65	1.33	0.89	0.36
51-60	1.30	1.07	0.18	1.68	1.95	0.57	2.29	1.84	0.62	1.31	0.91	0.37
61-70	1.19	1.07	0.16	1.48	2.07	0.50	2.22	1.86	0.55	1.27	0.91	0.35
71-80	1.13	1.06	0.15	1.46	1.74	0.48	2.24	1.77	0.53	1.34	0.97	0.34
81-90	1.11	1.12	0.13	1.71	1.83	0.50	2.23	1.85	0.48	1.22	0.95	0.28
91-100	1.18	1.08	0.13	2.02	1.93	0.53	2.10	1.67	0.43	1.17	0.89	0.24
Average	*1.31*	*1.07*	*0.15*	*2.45*	*1.89*	*0.72*	*2.59*	*1.76*	*0.55*	*1.36*	*0.99*	*0.31*
Scots pine												
1-10	0.69	0.59		1.39	1.30		1.09	1.10		0.82	0.53	
11-20	0.67	0.57		1.13	0.96		0.99	0.76		0.70	0.50	
21-30	0.56	0.50		0.93	0.86		1.11	0.77		0.59	0.41	
31-40	0.56	0.50		0.86	0.80		0.99	0.69		0.60	0.43	
41-50	0.58	0.55		0.56	0.52		1.00	0.63		0.68	0.48	
51-60	0.43	0.45		0.46	0.42		0.80	0.49		0.57	0.45	
61-70	0.44	0.46		0.55	0.44		0.77	0.45		0.48	0.39	
71-80	0.48	0.48		0.51	0.42		0.88	0.46		0.35	0.34	
81-90	0.43	0.48		0.37	0.32		0.76	0.39		0.34	0.33	
91-100	0.49	0.48		0.34	0.29		0.55	0.35		0.41	0.34	
Average	*0.52*	*0.49*		*0.68*	*0.61*		*0.86*	*0.59*		*0.54*	*0.41*	
Norway spruce												
1-10	0.89	0.37		1.83	0.78		1.42	0.62		1.12	0.35	
11-20	0.80	0.25		1.29	0.47		1.35	0.38		0.90	0.28	
21-30	0.69	0.22		0.81	0.36		1.20	0.41		0.67	0.21	
31-40	0.56	0.32		0.56	0.97		1.12	0.74		0.60	0.23	
41-50	0.48	0.36		1.10	1.07		1.11	0.85		0.47	0.21	
51-60	0.73	0.38		1.75	1.19		1.43	0.97		0.59	0.23	
61-70	0.73	0.38		2.20	1.27		1.57	0.94		0.66	0.27	
71-80	0.79	0.39		2.63	1.31		2.13	1.09		0.77	0.31	
81-90	0.96	0.40		2.52	1.18		2.58	1.08		0.89	0.33	
91-100	0.89	0.35		2.52	1.28		2.63	0.98		0.91	0.30	
Average	*0.73*	*0.33*		*1.68*	*0.96*		*1.62*	*0.78*		*0.74*	*0.26*	
Birch												
1-10	0.13	0.61		0.24	1.18		0.22	1.07		0.15	0.66	
11-20	0.08	0.35		0.15	0.59		0.11	0.48		0.08	0.35	
21-30	0.07	0.26		0.12	0.46		0.13	0.45		0.08	0.27	
31-40	0.07	0.25		0.06	0.30		0.11	0.43		0.06	0.25	
41-50	0.05	0.21		0.05	0.24		0.12	0.37		0.07	0.26	
51-60	0.05	0.19		0.06	0.17		0.09	0.29		0.07	0.26	
61-70	0.05	0.18		0.06	0.14		0.08	0.26		0.09	0.28	
71-80	0.06	0.19		0.06	0.14		0.10	0.26		0.12	0.33	
81-90	0.06	0.19		0.04	0.10		0.09	0.22		0.09	0.32	
91-100	0.06	0.18		0.05	0.12		0.12	0.23		0.09	0.31	
Average	*0.07*	*0.25*		*0.09*	*0.33*		*0.11*	*0.39*		*0.09*	*0.32*	

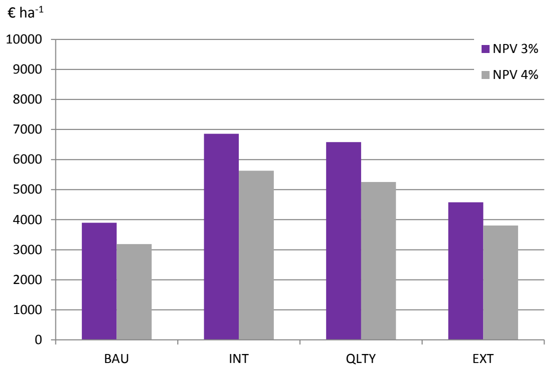
GROWING STOCK

Growing stock during the years 2010–2110, mill m^3

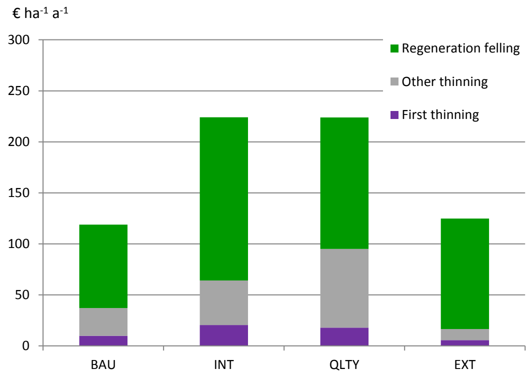


PROFITABILITY

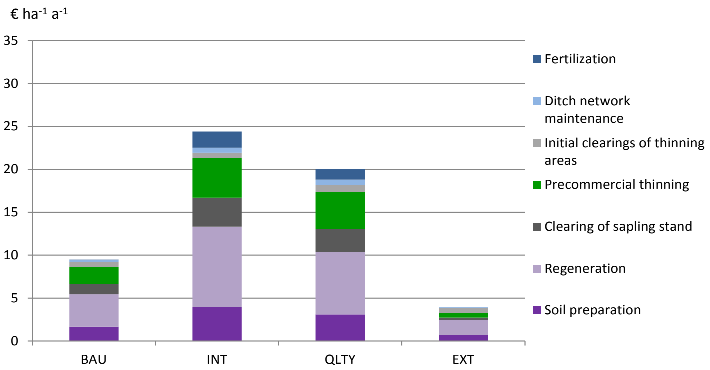
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



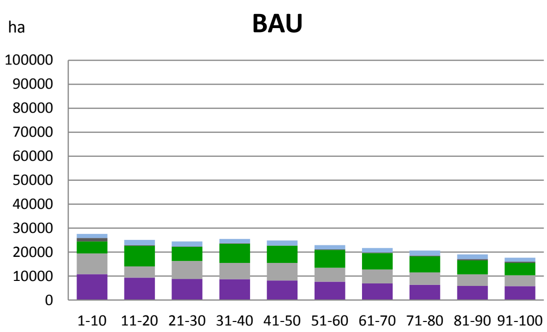
Appendix 3: Forestry centre Lounais-Suomi

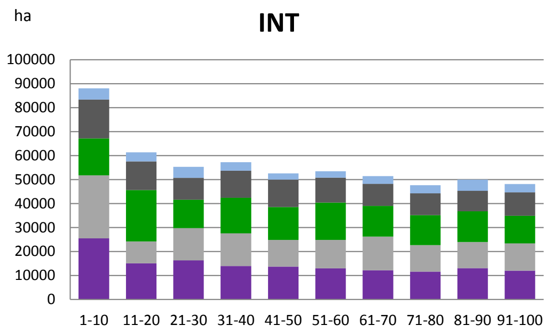
FOREST MANAGEMENT PRACTICES

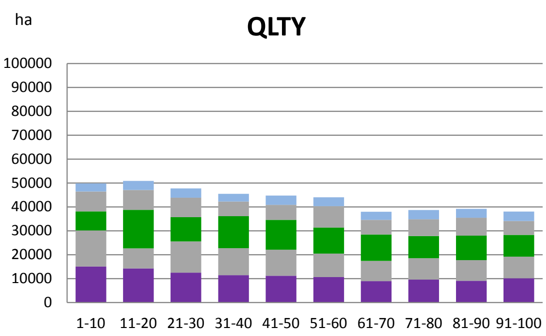
Annual areas of forest management practices, ha

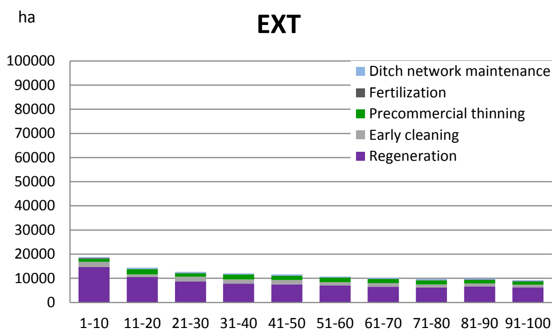
	BAU	INT	QLTY	EXT
Artificial regeneration	6952	13931	10760	2885
Natural regeneration	540	23	23	4899
Total regeneration	*7492*	*13954*	*10783*	*7784*
Early cleaning	5877	12734	9952	1469
Precommercial thinning	6409	13774	10705	1602
Fertilization	397	10199	6932	99
Ditch network maintenance	1832	3526	3531	459
First thinning	7052	12190	11228	3822
Other thinning	11577	14079	23002	4219
Regeneration fellings	7404	14007	10769	7716
Total fellings	*26034*	*40276*	*44999*	*15757*

Annual areas of silvicultural practices during the years 2010-2110, ha

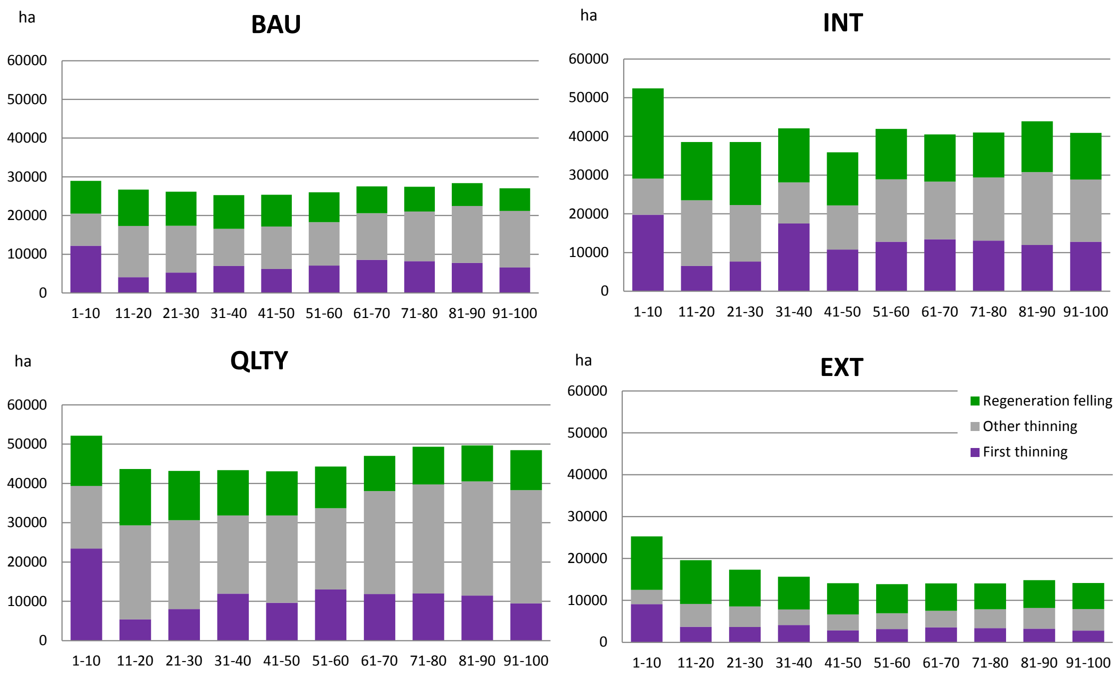








Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010–2110, mill €, undiscounted.

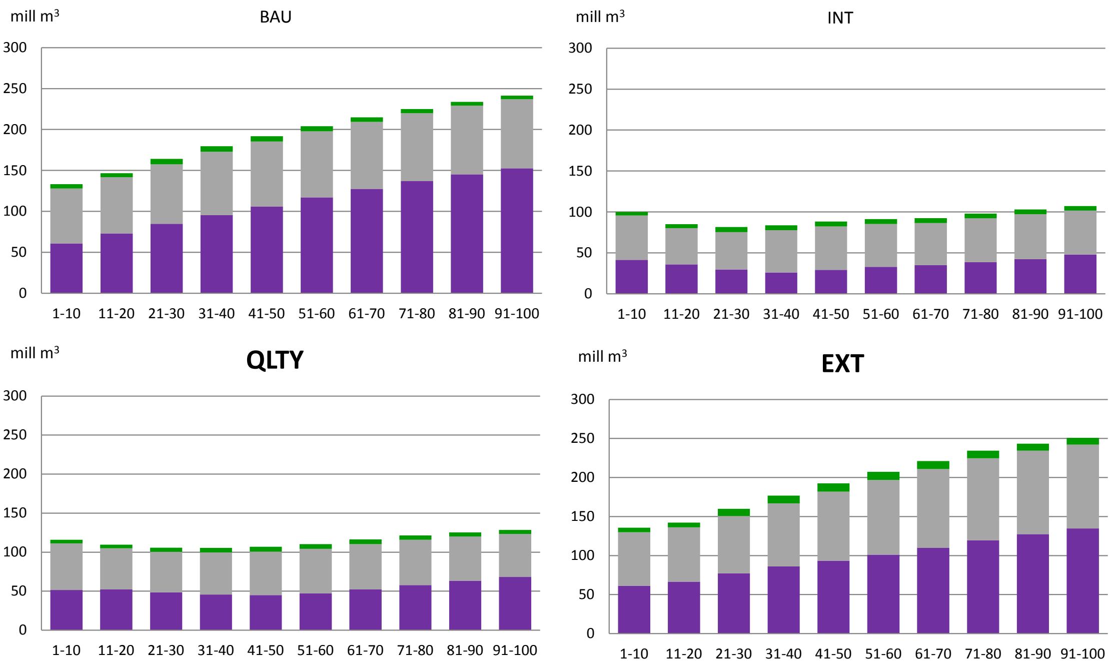
Year	BAU	INT	QLTY	EXT
1-10	134	295	220	154
11-20	143	218	238	145
21-30	143	222	224	135
31-40	140	208	218	130
41-50	134	218	220	128
51-60	133	215	216	127
61-70	135	219	224	126
71-80	133	222	240	124
81-90	132	249	242	133
91-100	133	249	254	132
Average	*143*	*243*	*241*	*139*

Temporal variation and mean of annual harvesting removals during the years 2010–2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	1.94	1.71	0.25	4.16	3.47	1.33	3.17	2.87	0.84	2.25	1.44	0.72
11-20	1.46	1.17	0.14	2.06	1.81	0.48	2.45	1.89	0.47	1.37	0.87	0.34
21-30	2.16	1.46	0.22	3.19	2.31	0.82	3.66	2.14	0.78	2.17	1.24	0.44
31-40	2.20	1.36	0.23	3.01	2.09	0.77	3.69	2.09	0.78	2.11	1.18	0.44
41-50	2.17	1.38	0.23	3.24	2.25	0.84	3.45	2.04	0.71	2.02	1.15	0.44
51-60	1.99	1.31	0.20	2.93	2.33	0.76	3.33	2.11	0.70	1.86	1.07	0.43
61-70	2.09	1.41	0.22	2.84	2.66	0.71	3.26	2.24	0.68	1.94	1.09	0.44
71-80	2.11	1.45	0.22	2.56	2.40	0.63	3.29	2.14	0.67	1.93	1.09	0.40
81-90	1.99	1.43	0.19	3.05	2.44	0.85	3.32	2.18	0.62	1.91	1.09	0.32
91-100	1.90	1.46	0.17	3.26	2.59	0.84	3.28	2.36	0.57	1.88	1.12	0.28
Average	*1.99*	*1.40*	*0.19*	*3.29*	*2.35*	*0.83*	*3.46*	*2.12*	*0.63*	*1.94*	*1.16*	*0.35*
Scots pine												
1-10	0.88	0.81		1.87	1.70		1.44	1.39		1.02	0.65	
11-20	1.02	0.83		1.56	1.27		1.69	1.19		0.92	0.63	
21-30	1.05	0.78		1.75	1.27		1.70	1.12		0.97	0.61	
31-40	1.11	0.72		1.72	1.13		1.75	0.99		1.01	0.58	
41-50	1.10	0.77		1.34	0.88		1.80	0.89		1.08	0.62	
51-60	0.99	0.76		0.95	0.70		1.54	0.80		1.04	0.61	
61-70	0.79	0.75		0.72	0.58		1.15	0.61		0.95	0.59	
71-80	0.74	0.74		0.65	0.55		0.99	0.59		0.78	0.54	
81-90	0.73	0.80		0.61	0.61		0.80	0.52		0.66	0.53	
91-100	0.80	0.75		0.45	0.48		0.70	0.51		0.69	0.54	
Average	*0.89*	*0.75*		*1.12*	*0.88*		*1.31*	*0.83*		*0.88*	*0.57*	
Norway spruce												
1-10	0.89	0.37		1.83	0.78		1.42	0.62		1.12	0.35	
11-20	0.80	0.25		1.29	0.47		1.35	0.38		0.90	0.28	
21-30	0.69	0.22		0.81	0.36		1.20	0.41		0.67	0.21	
31-40	0.56	0.32		0.56	0.97		1.12	0.74		0.60	0.23	
41-50	0.48	0.36		1.10	1.07		1.11	0.85		0.47	0.21	
51-60	0.73	0.38		1.75	1.19		1.43	0.97		0.59	0.23	
61-70	0.73	0.38		2.20	1.27		1.57	0.94		0.66	0.27	
71-80	0.79	0.39		2.63	1.31		2.13	1.09		0.77	0.31	
81-90	0.96	0.40		2.52	1.18		2.58	1.08		0.89	0.33	
91-100	0.89	0.35		2.52	1.28		2.63	0.98		0.91	0.30	
Average	*0.73*	*0.33*		*1.68*	*0.96*		*1.62*	*0.78*		*0.74*	*0.26*	
Birch												
1-10	0.13	0.61		0.24	1.18		0.22	1.07		0.15	0.66	
11-20	0.08	0.35		0.15	0.59		0.11	0.48		0.08	0.35	
21-30	0.07	0.26		0.12	0.46		0.13	0.45		0.08	0.27	
31-40	0.07	0.25		0.06	0.30		0.11	0.43		0.06	0.25	
41-50	0.05	0.21		0.05	0.24		0.12	0.37		0.07	0.26	
51-60	0.05	0.19		0.06	0.17		0.09	0.29		0.07	0.26	
61-70	0.05	0.18		0.06	0.14		0.08	0.26		0.09	0.28	
71-80	0.06	0.19		0.06	0.14		0.10	0.26		0.12	0.33	
81-90	0.06	0.19		0.04	0.10		0.09	0.22		0.09	0.32	
91-100	0.06	0.18		0.05	0.12		0.12	0.23		0.09	0.31	
Average	*0.07*	*0.25*		*0.09*	*0.33*		*0.11*	*0.39*		*0.09*	*0.32*	

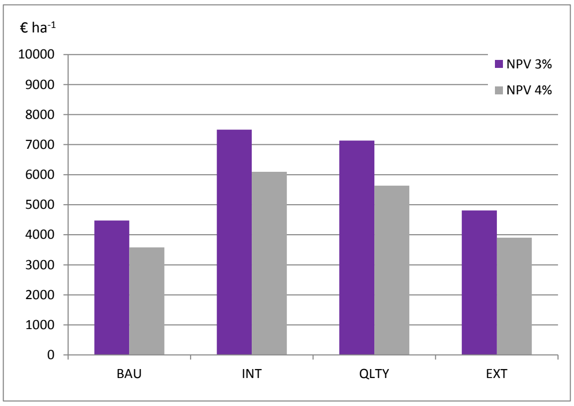
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3

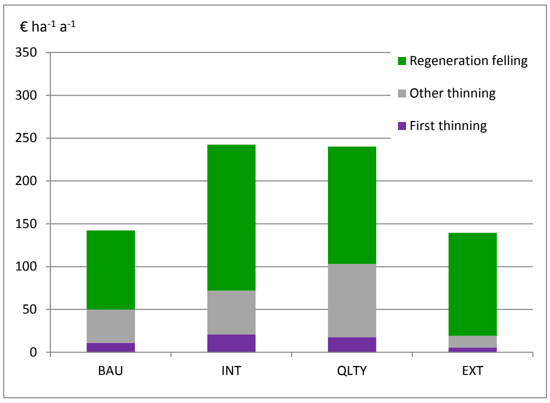


PROFITABILITY

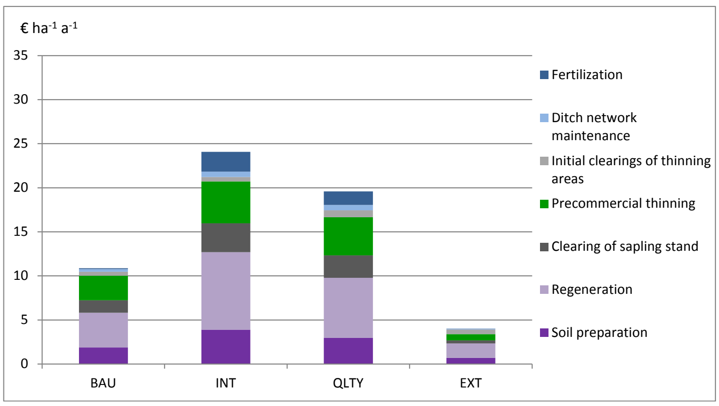
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



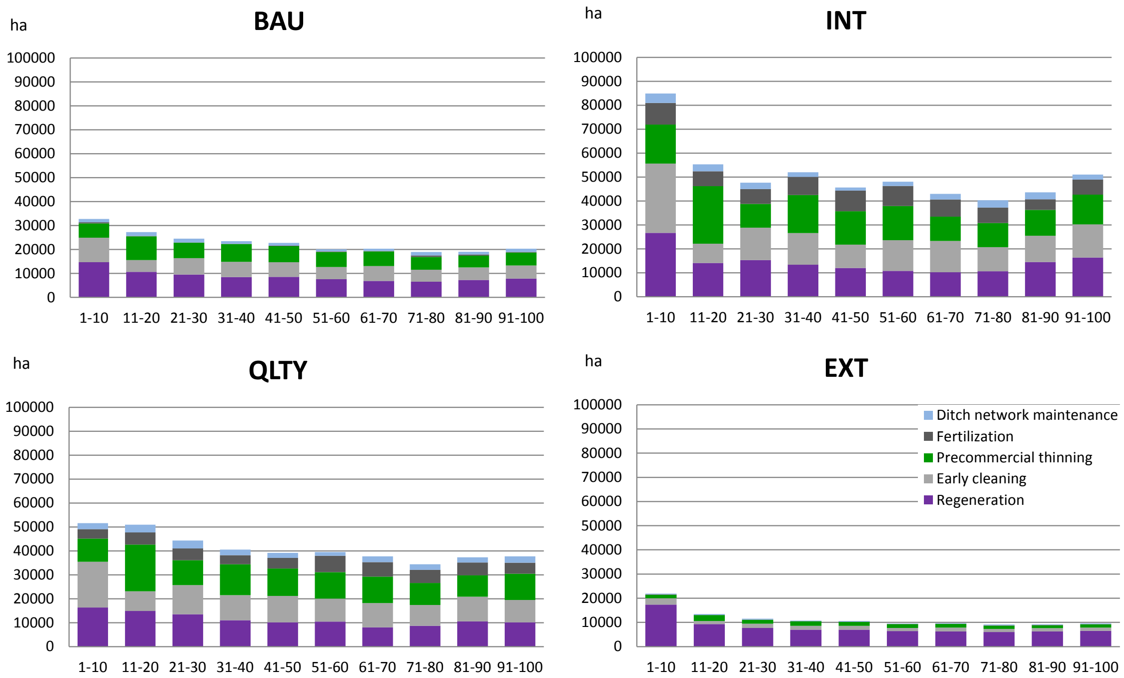
Appendix 4: Forestry centre Häme-Uusimaa

FOREST MANAGEMENT PRACTICES

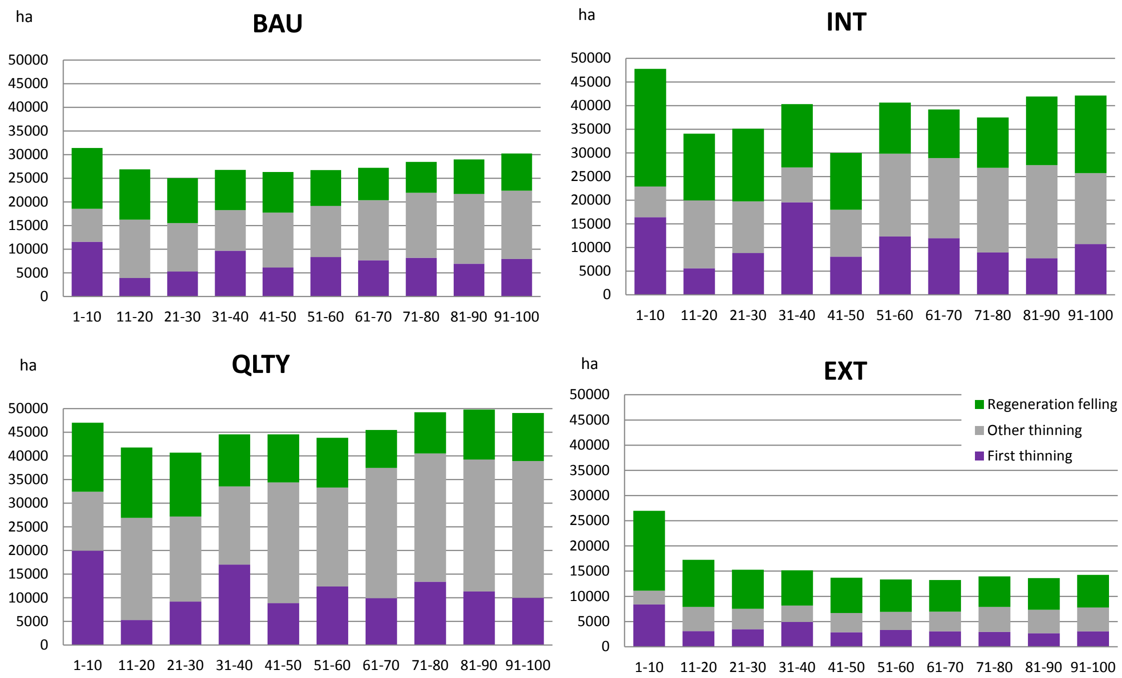
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	7321	13734	10859	2855
Natural regeneration	1061	3	3	4784
Total regeneration	*8381*	*13737*	*10862*	*7639*
Early cleaning	5935	12900	10508	1484
Precommercial thinning	6286	13451	11183	1572
Fertilization	259	6695	4804	65
Ditch network maintenance	1212	2401	2362	304
First thinning	7299	10614	11269	3638
Other thinning	11223	13112	21956	3913
Regeneration fellings	8371	13811	10900	7592
Total fellings	*26892*	*37537*	*44125*	*15143*

Annual areas of silvicultural practices during the years 2010–2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010–2110, mill €, undiscounted.

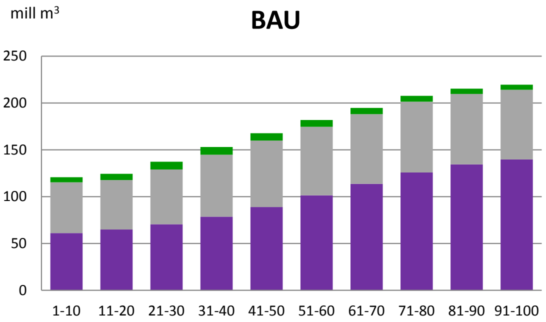
Year	BAU	INT	QLTY	EXT
1-10	199	343	259	215
11-20	186	227	275	153
21-30	166	231	248	139
31-40	156	209	231	134
41-50	156	225	234	133
51-60	154	218	234	129
61-70	155	224	236	127
71-80	155	244	249	129
81-90	172	327	281	135
91-100	189	360	284	156
Average	*177*	*273*	*266*	*151*

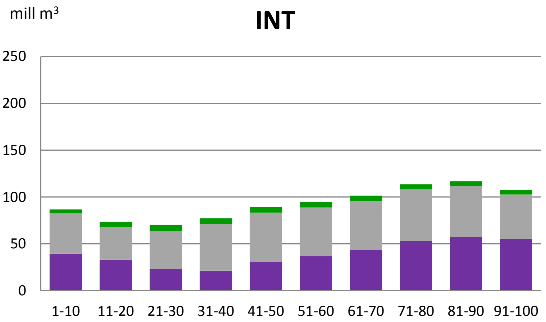
Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

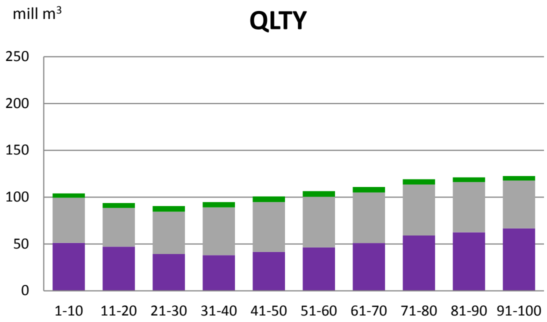
All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	3.03	2.01	0.34	5.07	3.29	1.66	3.90	2.77	1.09	3.30	1.65	0.89
11-20	1.72	1.07	0.18	1.87	1.41	0.50	2.40	1.54	0.53	1.36	0.74	0.33
21-30	2.94	1.52	0.34	3.39	2.18	0.98	4.37	2.13	1.05	2.36	1.16	0.47
31-40	2.65	1.37	0.30	3.38	2.09	1.00	3.94	1.94	0.90	2.18	1.06	0.46
41-50	2.59	1.38	0.30	3.43	2.15	1.02	3.89	2.00	0.94	2.13	1.05	0.47
51-60	2.35	1.43	0.28	2.92	2.21	0.88	3.30	2.15	0.80	2.01	1.05	0.47
61-70	2.35	1.59	0.27	2.82	2.75	0.92	3.44	2.45	0.82	2.01	1.09	0.49
71-80	2.31	1.58	0.25	2.33	2.33	0.73	3.52	2.26	0.80	2.07	1.13	0.46
81-90	2.35	1.58	0.26	3.12	2.45	1.12	3.59	2.29	0.67	2.01	1.10	0.38
91-100	2.34	1.66	0.23	3.87	2.95	1.20	3.77	2.45	0.69	1.94	1.10	0.31
Average	*2.55*	*1.54*	*0.26*	*3.81*	*2.35*	*1.05*	*3.89*	*2.17*	*0.79*	*2.16*	*1.16*	*0.41*
Scots pine												
1-10	0.80	0.63		1.32	1.07		1.00	0.87		0.79	0.47	
11-20	0.65	0.52		0.72	0.74		0.96	0.70		0.52	0.37	
21-30	0.70	0.47		0.96	0.69		1.08	0.66		0.60	0.35	
31-40	0.67	0.44		0.83	0.60		1.05	0.58		0.65	0.38	
41-50	0.71	0.50		0.40	0.29		0.97	0.47		0.72	0.40	
51-60	0.41	0.42		0.43	0.32		0.67	0.39		0.54	0.34	
61-70	0.36	0.39		0.41	0.33		0.32	0.20		0.30	0.24	
71-80	0.38	0.41		0.32	0.24		0.43	0.28		0.32	0.26	
81-90	0.42	0.42		0.35	0.26		0.46	0.25		0.21	0.21	
91-100	0.48	0.42		0.30	0.21		0.28	0.22		0.31	0.26	
Average	*0.54*	*0.45*		*0.58*	*0.46*		*0.69*	*0.44*		*0.48*	*0.32*	
Norway spruce												
1-10	2.10	0.71		3.54	1.20		2.73	0.98		2.38	0.60	
11-20	2.19	0.56		2.54	0.82		3.25	0.78		1.76	0.45	
21-30	1.79	0.52		2.30	0.89		2.65	0.78		1.45	0.40	
31-40	1.56	0.77		1.83	1.63		2.23	1.37		1.27	0.43	
41-50	1.49	0.70		2.58	1.78		2.44	1.36		1.15	0.38	
51-60	1.81	0.90		2.70	1.74		2.73	1.50		1.29	0.47	
61-70	1.95	0.78		2.93	1.64		3.39	1.53		1.47	0.51	
71-80	1.95	0.80		3.48	1.51		3.36	1.63		1.54	0.53	
81-90	2.18	0.77		4.78	1.82		3.98	1.56		1.69	0.56	
91-100	2.43	0.83		5.13	2.45		4.29	1.55		1.98	0.55	
Average	*1.90*	*0.71*		*3.10*	*1.50*		*3.04*	*1.26*		*1.56*	*0.47*	
Birch												
1-10	0.13	0.67		0.20	1.02		0.18	0.92		0.13	0.58	
11-20	0.09	0.44		0.13	0.61		0.15	0.65		0.08	0.35	
21-30	0.10	0.39		0.17	0.57		0.15	0.57		0.08	0.30	
31-40	0.12	0.38		0.16	0.53		0.15	0.50		0.09	0.28	
41-50	0.15	0.38		0.14	0.37		0.18	0.46		0.13	0.32	
51-60	0.10	0.29		0.12	0.27		0.20	0.39		0.12	0.33	
61-70	0.12	0.33		0.09	0.17		0.14	0.30		0.17	0.41	
71-80	0.12	0.33		0.09	0.16		0.19	0.39		0.13	0.36	
81-90	0.14	0.38		0.10	0.20		0.18	0.37		0.17	0.46	
91-100	0.12	0.36		0.08	0.20		0.16	0.31		0.14	0.43	
Average	*0.12*	*0.38*		*0.12*	*0.40*		*0.16*	*0.47*		*0.12*	*0.37*	

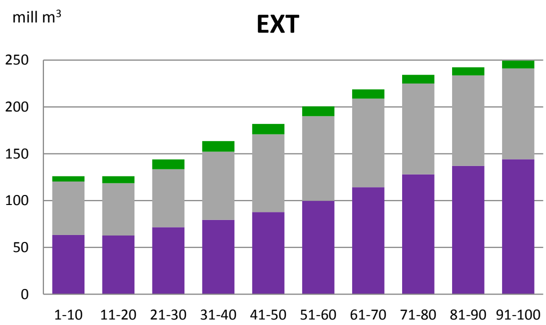
GROWING STOCK

Growing stock during the years 2010-2110, mill m³



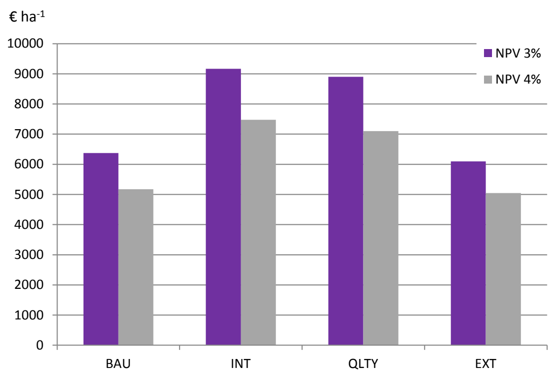




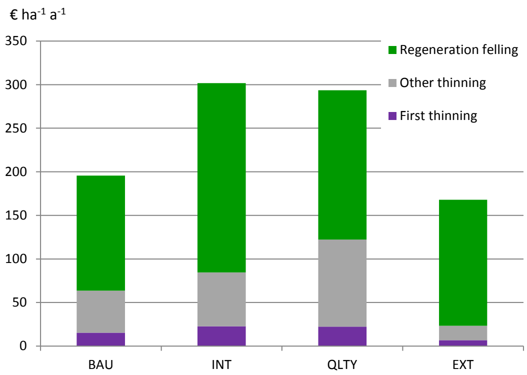


PROFITABILITY

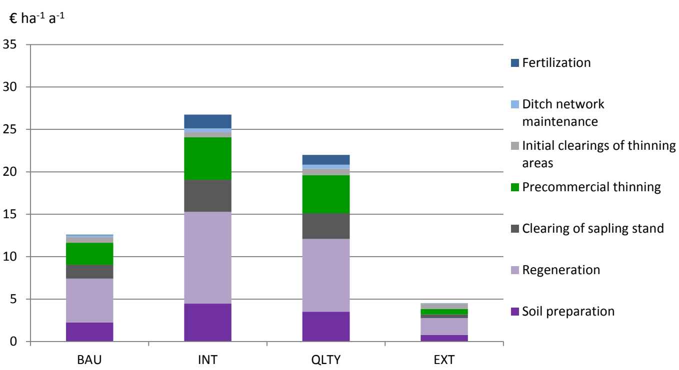
Net present value at 3% and 4% discount rates



Mean annual incomes € ha⁻¹ a⁻¹, undiscounted



Mean annual management costs € ha⁻¹ a⁻¹, undiscounted



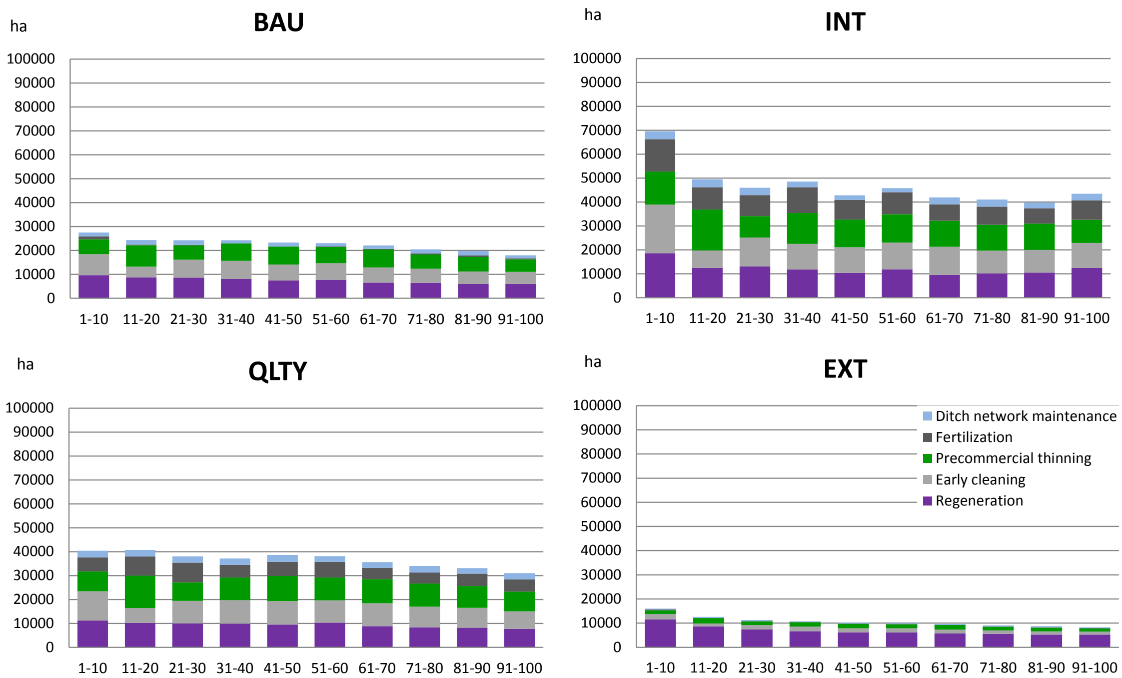
Appendix 5: Forestry centre Kaakkois-Suomi

FOREST MANAGEMENT PRACTICES

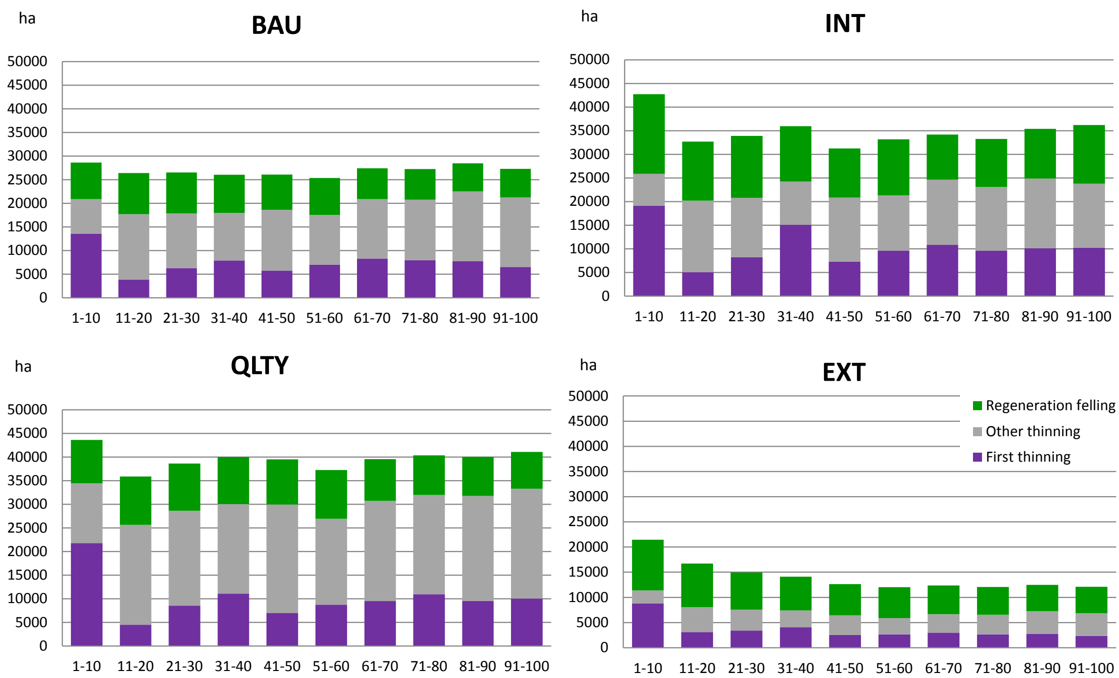
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	6816	11512	8996	2458
Natural regeneration	363	6	6	4063
Total regeneration	*7179*	*11518*	*9003*	*6521*
Early cleaning	6172	10962	8744	1543
Precommercial thinning	6576	11423	9322	1644
Fertilization	353	8467	5653	88
Ditch network maintenance	1564	2556	2488	393
First thinning	7265	10147	9824	3392
Other thinning	11688	12057	19478	3760
Regeneration fellings	7150	11537	9012	6477
Total fellings	*26102*	*33740*	*38314*	*13629*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010–2110, mill €, undiscounted.

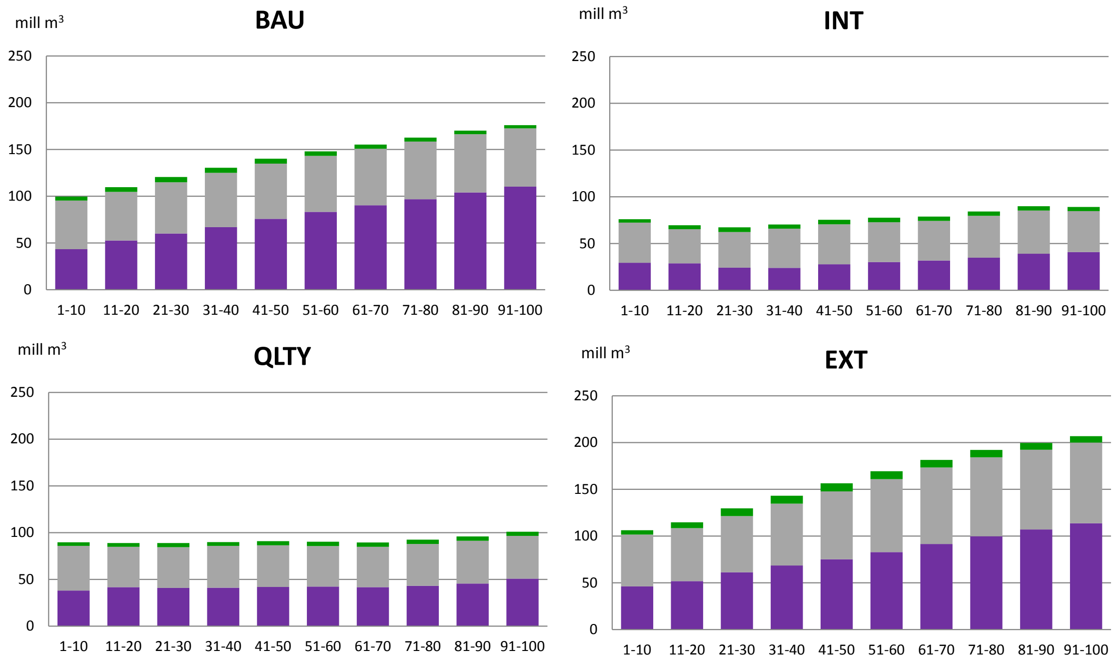
Year	BAU	INT	QLTY	EXT
1-10	138	242	188	137
11-20	149	195	197	133
21-30	145	194	195	122
31-40	141	186	207	119
41-50	140	195	208	118
51-60	141	197	212	117
61-70	138	196	210	115
71-80	138	202	209	114
81-90	136	220	209	112
91-100	141	253	208	116
Average	*148*	*218*	*215*	*126*

Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	2.01	1.75	0.22	3.42	2.87	1.05	2.72	2.44	0.68	2.04	1.19	0.67
11-20	1.37	1.13	0.12	1.69	1.46	0.36	2.02	1.57	0.35	1.05	0.67	0.30
21-30	2.27	1.49	0.23	2.89	1.96	0.69	3.04	1.81	0.62	1.99	1.11	0.42
31-40	2.19	1.40	0.21	2.83	1.94	0.70	3.12	1.87	0.60	1.92	1.07	0.39
41-50	2.20	1.40	0.22	2.81	2.03	0.73	3.00	1.84	0.56	1.83	1.02	0.37
51-60	2.24	1.45	0.22	2.51	2.17	0.62	2.96	2.01	0.59	1.84	1.05	0.39
61-70	2.11	1.44	0.21	2.59	2.25	0.61	3.15	2.03	0.61	1.76	1.00	0.41
71-80	2.03	1.41	0.21	2.52	1.85	0.62	3.15	1.80	0.58	1.79	0.97	0.36
81-90	2.09	1.47	0.20	2.84	2.00	0.73	3.21	1.96	0.53	1.77	1.00	0.28
91-100	2.16	1.49	0.22	3.11	2.23	0.79	3.27	2.02	0.55	1.73	1.00	0.24
Average	*2.08*	*1.42*	*0.19*	*3.00*	*2.00*	*0.73*	*3.10*	*1.86*	*0.56*	*1.75*	*1.02*	*0.32*
Scots pine												
1-10	0.83	0.83		1.42	1.42		1.11	1.17		0.79	0.49	
11-20	0.97	0.82		1.33	1.05		1.24	0.94		0.91	0.59	
21-30	1.04	0.77		1.41	1.05		1.55	1.00		0.89	0.55	
31-40	1.10	0.69		1.43	0.94		1.49	0.83		0.90	0.51	
41-50	1.01	0.69		0.98	0.60		1.49	0.74		0.91	0.51	
51-60	0.78	0.64		0.83	0.56		1.46	0.67		0.87	0.51	
61-70	0.67	0.66		0.71	0.52		0.94	0.49		0.69	0.47	
71-80	0.70	0.71		0.59	0.48		0.79	0.46		0.51	0.39	
81-90	0.77	0.75		0.56	0.47		0.71	0.45		0.44	0.38	
91-100	0.70	0.63		0.55	0.47		0.55	0.43		0.49	0.39	
Average	*0.83*	*0.70*		*0.95*	*0.73*		*1.09*	*0.69*		*0.71*	*0.46*	
Norway spruce												
1-10	1.09	0.46		1.85	0.74		1.48	0.63		1.17	0.32	
11-20	1.22	0.36		1.46	0.54		1.70	0.47		1.02	0.28	
21-30	1.08	0.37		1.26	0.54		1.34	0.47		0.87	0.27	
31-40	0.93	0.49		1.06	0.98		1.52	0.82		0.79	0.28	
41-50	0.98	0.52		1.74	1.11		1.60	0.89		0.79	0.28	
51-60	1.26	0.56		1.98	1.17		1.70	0.88		0.81	0.28	
61-70	1.37	0.55		2.17	1.24		2.27	1.08		0.92	0.30	
71-80	1.35	0.53		2.46	1.15		2.42	1.12		1.10	0.36	
81-90	1.24	0.52		2.77	1.30		2.50	1.09		1.10	0.38	
91-100	1.43	0.52		3.26	1.48		2.67	1.12		1.16	0.33	
Average	*1.16*	*0.47*		*1.96*	*0.99*		*1.88*	*0.83*		*0.95*	*0.30*	
Birch												
1-10	0.09	0.46		0.15	0.71		0.13	0.64		0.09	0.37	
11-20	0.07	0.31		0.09	0.38		0.11	0.40		0.07	0.24	
21-30	0.07	0.26		0.15	0.44		0.11	0.36		0.07	0.20	
31-40	0.08	0.26		0.11	0.33		0.13	0.37		0.08	0.21	
41-50	0.10	0.26		0.12	0.30		0.13	0.33		0.08	0.21	
51-60	0.10	0.23		0.10	0.21		0.14	0.31		0.08	0.21	
61-70	0.08	0.22		0.06	0.14		0.13	0.26		0.11	0.28	
71-80	0.08	0.19		0.07	0.14		0.12	0.26		0.12	0.28	
81-90	0.08	0.21		0.06	0.13		0.15	0.27		0.12	0.34	
91-100	0.09	0.21		0.08	0.16		0.14	0.26		0.11	0.31	
Average	*0.08*	*0.25*		*0.10*	*0.28*		*0.12*	*0.33*		*0.09*	*0.26*	

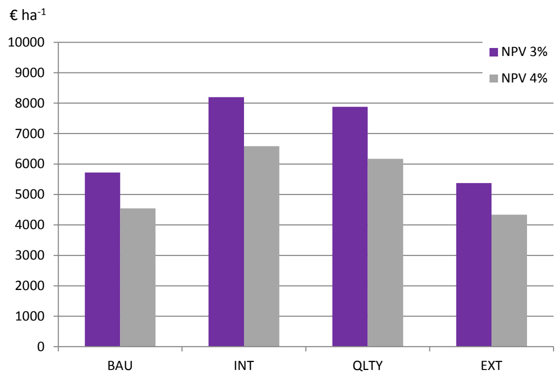
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3

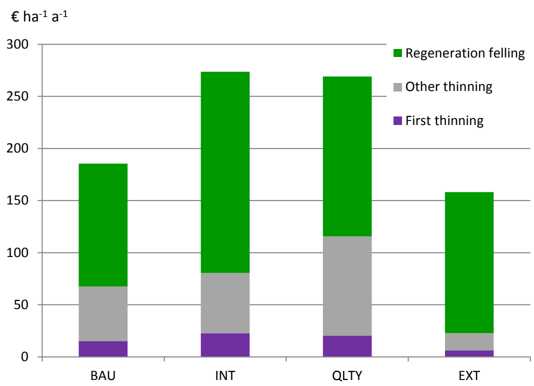


PROFITABILITY

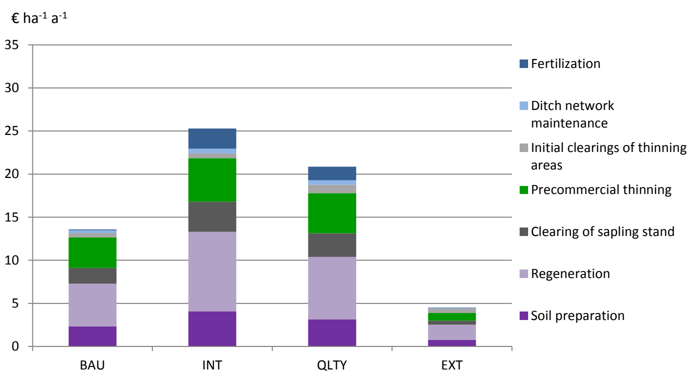
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



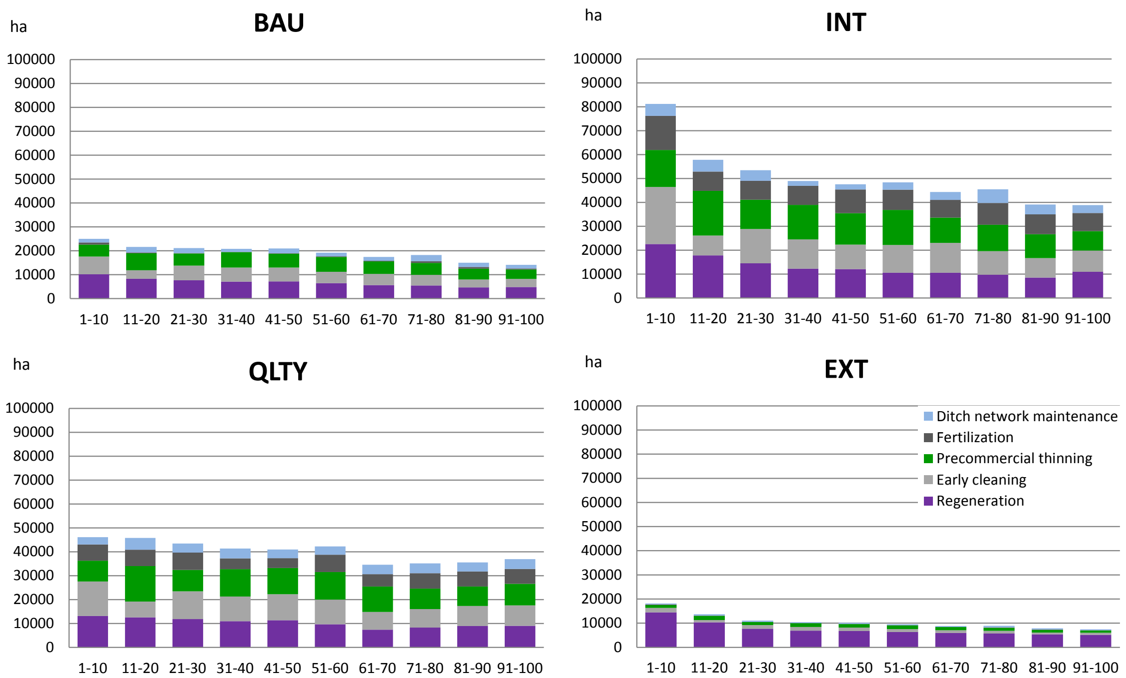
Appendix 6: Forestry centre Pirkanmaa

FOREST MANAGEMENT PRACTICES

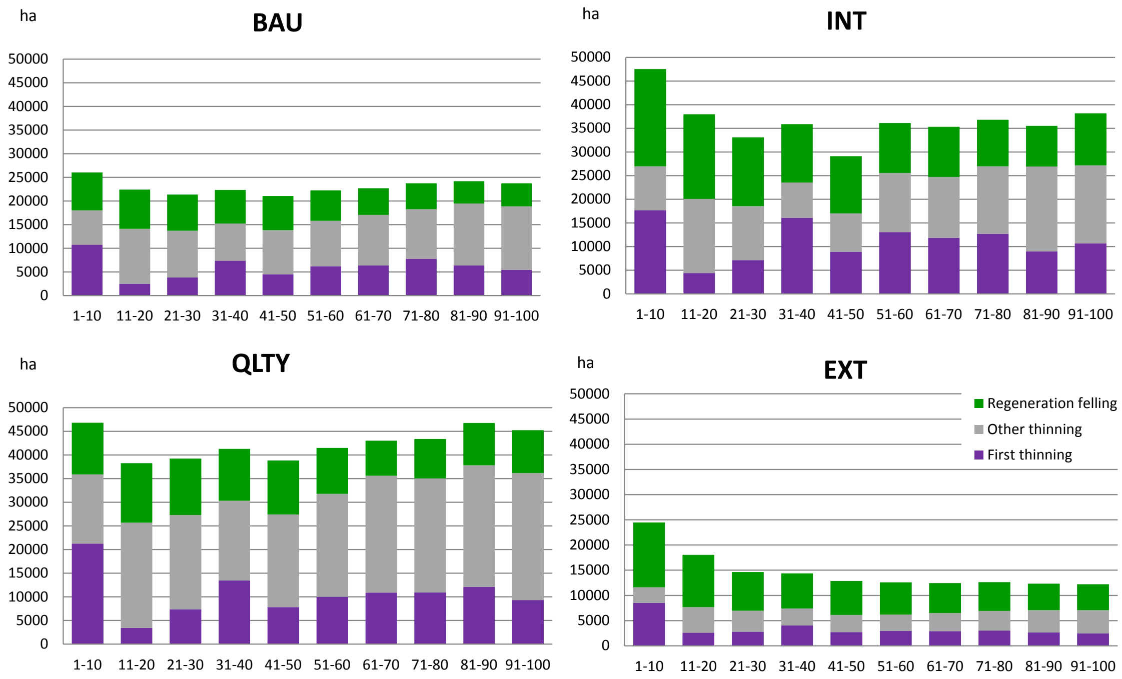
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	5809	12377	9847	2565
Natural regeneration	633	6	6	4551
Total regeneration	*6442*	*12382*	*9853*	*7116*
Early cleaning	4747	11487	9258	1187
Precommercial thinning	5233	12374	10000	1308
Fertilization	379	8469	5792	95
Ditch network maintenance	1747	3693	3763	438
First thinning	5914	10742	10286	3347
Other thinning	9993	12221	20981	3760
Regeneration fellings	6360	12400	9832	7059
Total fellings	*22267*	*35363*	*41099*	*14166*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

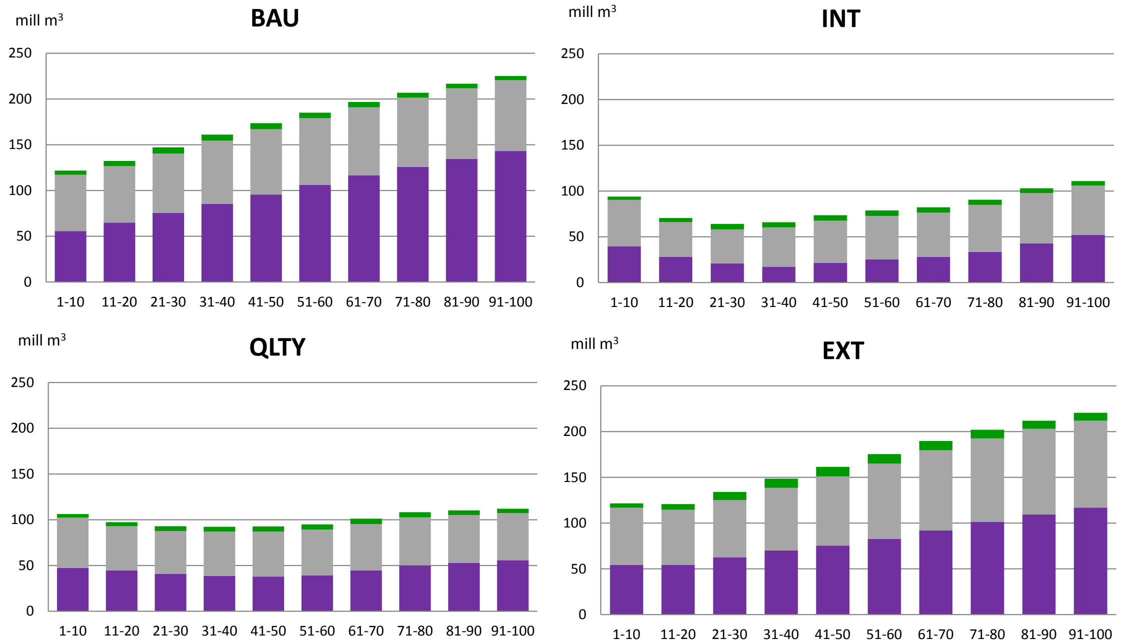
Year	BAU	INT	QLTY	EXT
1-10	129	271	203	164
11-20	130	239	219	147
21-30	119	184	203	112
31-40	115	174	192	112
41-50	117	184	201	113
51-60	114	178	195	110
61-70	115	183	194	109
71-80	113	184	207	108
81-90	114	189	227	108
91-100	115	235	230	108
Average	*124*	*212*	*218*	*124*

Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	1.90	1.52	0.19	3.88	3.08	1.24	2.97	2.50	0.79	2.46	1.38	0.70
11-20	1.20	0.88	0.12	1.91	1.51	0.51	2.09	1.39	0.42	1.26	0.76	0.30
21-30	2.00	1.20	0.22	3.51	2.37	1.01	3.42	1.84	0.80	2.20	1.23	0.45
31-40	1.89	1.11	0.20	2.88	2.07	0.80	3.25	1.82	0.75	1.89	1.09	0.38
41-50	1.82	1.12	0.21	2.64	2.00	0.74	3.11	1.84	0.70	1.66	1.01	0.35
51-60	1.82	1.17	0.20	2.42	2.02	0.69	2.86	1.90	0.65	1.58	0.99	0.36
61-70	1.71	1.22	0.19	2.33	2.31	0.68	2.80	2.14	0.63	1.64	1.03	0.39
71-80	1.72	1.24	0.19	2.02	2.08	0.60	2.91	2.07	0.64	1.75	1.07	0.40
81-90	1.74	1.18	0.18	2.51	2.13	0.90	3.05	1.90	0.62	1.67	0.99	0.34
91-100	1.74	1.22	0.17	2.79	2.39	0.95	3.23	2.08	0.62	1.60	0.99	0.28
Average	*1.75*	*1.17*	*0.17*	*2.85*	*2.10*	*0.79*	*3.12*	*1.90*	*0.63*	*1.73*	*1.05*	*0.34*
Scots pine												
1-10	0.63	0.59		1.29	1.27		0.94	0.96		0.77	0.49	
11-20	0.59	0.56		1.23	1.10		1.01	0.82		0.68	0.53	
21-30	0.70	0.53		1.13	0.97		1.18	0.84		0.70	0.49	
31-40	0.72	0.51		1.02	0.79		1.19	0.72		0.72	0.48	
41-50	0.79	0.51		0.62	0.49		1.43	0.72		0.79	0.48	
51-60	0.54	0.43		0.36	0.42		1.00	0.53		0.68	0.44	
61-70	0.42	0.40		0.46	0.49		0.63	0.41		0.49	0.36	
71-80	0.38	0.48		0.37	0.51		0.56	0.42		0.36	0.33	
81-90	0.36	0.45		0.32	0.40		0.50	0.41		0.21	0.25	
91-100	0.39	0.46		0.27	0.31		0.52	0.40		0.29	0.32	
Average	*0.53*	*0.48*		*0.68*	*0.65*		*0.86*	*0.60*		*0.55*	*0.40*	
Norway spruce												
1-10	1.18	0.45		2.42	0.88		1.87	0.72		1.59	0.41	
11-20	1.33	0.34		2.10	0.67		2.29	0.54		1.43	0.38	
21-30	1.03	0.30		1.35	0.54		1.80	0.55		0.86	0.25	
31-40	0.90	0.46		1.19	1.13		1.45	0.93		0.84	0.29	
41-50	0.87	0.41		1.81	1.34		1.48	0.82		0.80	0.27	
51-60	1.08	0.56		2.09	1.48		1.82	1.14		0.86	0.32	
61-70	1.29	0.54		2.16	1.36		2.33	1.20		1.02	0.35	
71-80	1.30	0.52		2.34	1.29		2.61	1.17		1.17	0.40	
81-90	1.40	0.49		2.62	1.18		3.07	1.26		1.31	0.46	
91-100	1.38	0.46		3.23	1.76		3.12	1.14		1.26	0.38	
Average	*1.15*	*0.44*		*2.08*	*1.12*		*2.14*	*0.92*		*1.09*	*0.34*	
Birch												
1-10	0.09	0.49		0.18	0.93		0.16	0.82		0.10	0.47	
11-20	0.08	0.30		0.18	0.59		0.13	0.47		0.10	0.32	
21-30	0.09	0.29		0.15	0.49		0.13	0.45		0.09	0.27	
31-40	0.08	0.26		0.12	0.40		0.16	0.49		0.08	0.25	
41-50	0.09	0.27		0.08	0.30		0.14	0.36		0.08	0.25	
51-60	0.08	0.23		0.08	0.22		0.13	0.33		0.09	0.28	
61-70	0.07	0.21		0.05	0.13		0.10	0.27		0.11	0.33	
71-80	0.06	0.19		0.03	0.11		0.11	0.27		0.10	0.31	
81-90	0.05	0.19		0.03	0.09		0.09	0.24		0.10	0.35	
91-100	0.05	0.19		0.04	0.13		0.11	0.27		0.09	0.32	
Average	*0.07*	*0.25*		*0.09*	*0.32*		*0.12*	*0.38*		*0.09*	*0.30*	

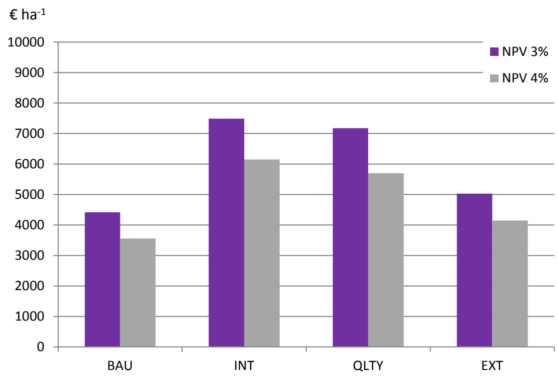
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3

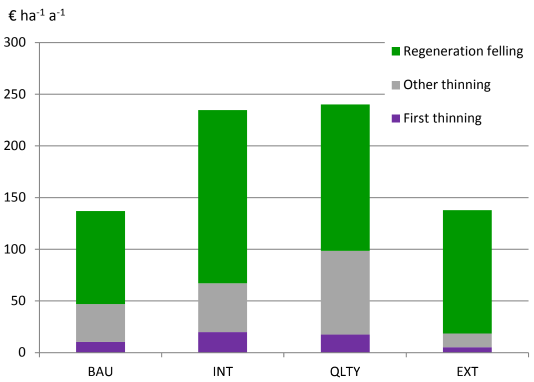


PROFITABILITY

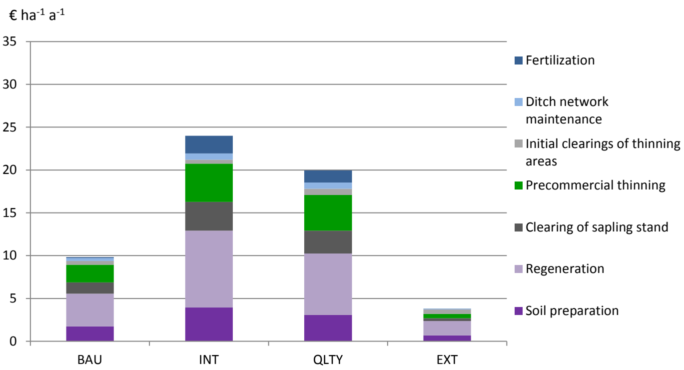
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



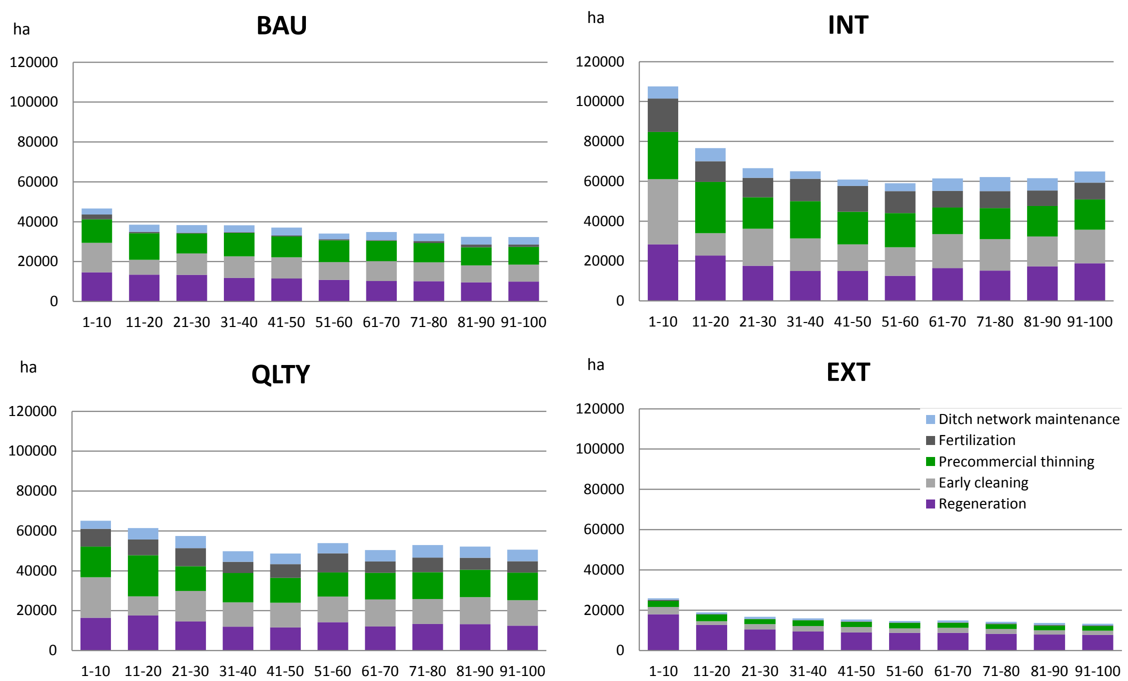
Appendix 7: Forestry centre Etelä-Savo

FOREST MANAGEMENT PRACTICES

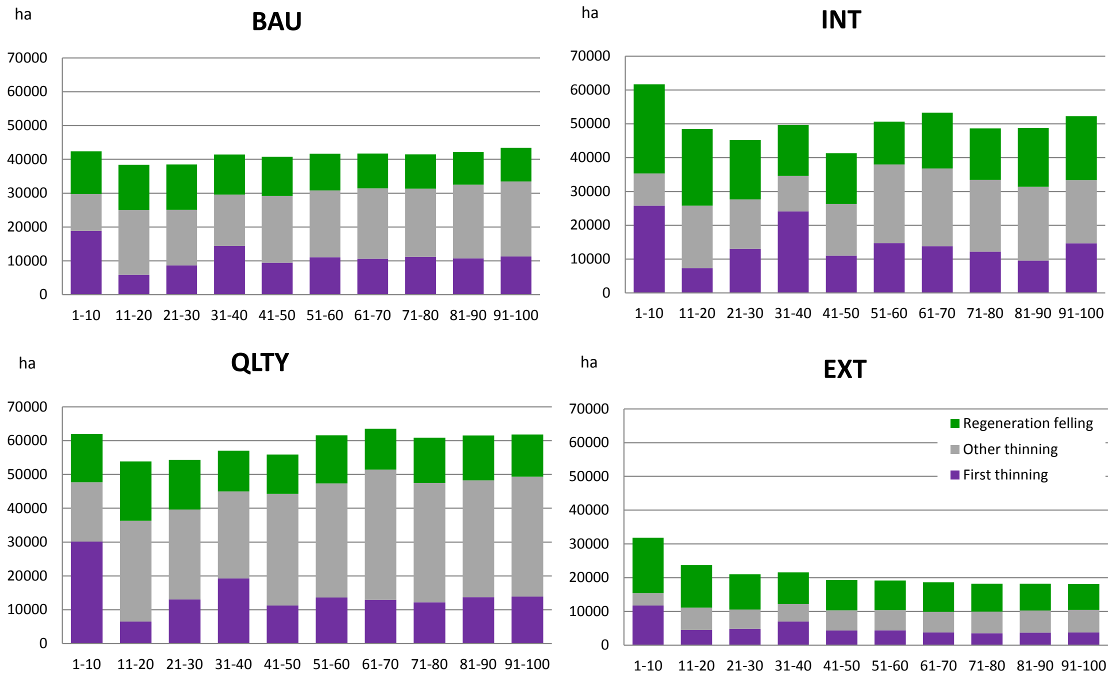
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	10487	17073	13124	3661
Natural regeneration	536	3	3	5955
Total regeneration	*11024*	*17076*	*13127*	*9617*
Early cleaning	9594	16490	13004	2399
Precommercial thinning	10239	17221	13773	2560
Fertilization	838	9998	6938	210
Ditch network maintenance	3495	5146	5303	876
First thinning	10867	14093	14164	4991
Other thinning	17995	16961	30031	5695
Regeneration fellings	11052	17179	13230	9606
Total fellings	*39914*	*48233*	*57425*	*20291*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

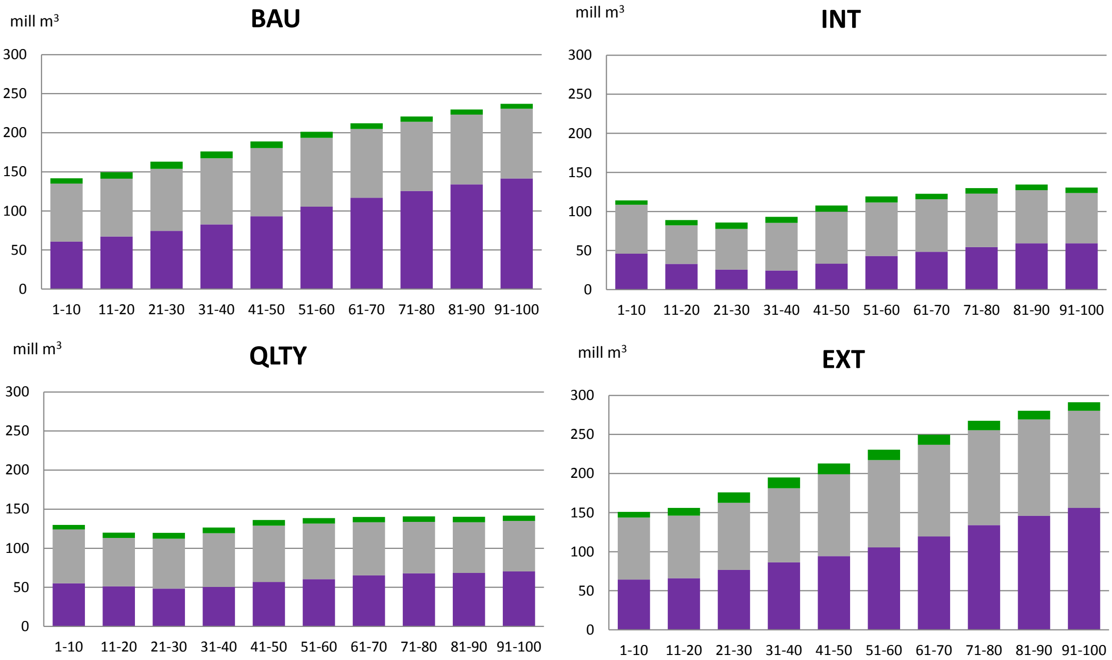
Year	BAU	INT	QLTY	EXT
1-10	205	353	268	210
11-20	209	304	294	180
21-30	200	234	250	157
31-40	193	217	241	156
41-50	193	237	246	156
51-60	192	229	295	152
61-70	196	289	295	153
71-80	197	286	301	151
81-90	197	330	302	152
91-100	205	361	298	154
Average	*209*	*295*	*296*	*170*

Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	2.93	2.60	0.34	4.91	4.24	1.65	3.79	3.52	1.10	3.07	1.90	0.94
11-20	1.93	1.61	0.21	2.30	2.16	0.66	2.74	2.19	0.63	1.38	0.96	0.46
21-30	3.14	2.14	0.37	4.38	3.12	1.38	4.49	2.70	1.12	2.65	1.62	0.64
31-40	2.79	1.97	0.32	3.65	2.76	1.12	3.98	2.56	0.96	2.44	1.52	0.57
41-50	2.98	2.04	0.37	3.26	2.75	0.99	3.72	2.58	0.90	2.30	1.42	0.54
51-60	2.81	2.16	0.35	3.09	2.86	0.98	3.45	2.74	0.81	2.21	1.41	0.56
61-70	2.80	2.23	0.35	2.81	3.19	0.90	3.49	2.81	0.80	2.26	1.47	0.60
71-80	2.78	2.10	0.33	2.61	2.75	0.84	3.57	2.58	0.79	2.33	1.45	0.59
81-90	2.81	2.22	0.28	3.28	2.73	1.10	3.68	2.62	0.70	2.29	1.43	0.48
91-100	2.73	2.24	0.25	3.59	3.13	1.12	4.27	2.97	0.80	2.29	1.56	0.41
Average	*2.90*	*2.08*	*0.31*	*4.00*	*2.86*	*1.15*	*4.17*	*2.65*	*0.88*	*2.32*	*1.47*	*0.25*
Scots pine												
1-10	1.31	1.12		2.16	1.90		1.64	1.50		1.31	0.76	
11-20	1.20	1.00		1.72	1.43		1.62	1.18		0.97	0.69	
21-30	1.25	0.93		1.47	1.21		1.65	1.16		1.09	0.69	
31-40	1.28	0.94		1.25	1.01		1.47	0.91		1.07	0.69	
41-50	1.11	0.89		0.80	0.58		1.62	0.85		1.00	0.63	
51-60	0.72	0.76		0.67	0.56		1.56	0.74		0.82	0.57	
61-70	0.68	0.77		0.70	0.55		0.94	0.53		0.64	0.53	
71-80	0.84	0.85		0.55	0.51		0.92	0.49		0.48	0.42	
81-90	0.80	0.81		0.58	0.47		0.71	0.44		0.45	0.41	
91-100	0.97	0.83		0.54	0.49		0.65	0.43		0.55	0.46	
Average	*0.98*	*0.86*		*1.01*	*0.84*		*1.23*	*0.79*		*0.81*	*0.56*	
Norway spruce												
1-10	1.47	0.64		2.49	1.03		1.95	0.89		1.61	0.47	
11-20	1.82	0.60		2.49	0.95		2.70	0.79		1.57	0.49	
21-30	1.61	0.59		1.61	0.85		1.90	0.77		1.12	0.39	
31-40	1.38	0.84		1.33	1.57		1.83	1.35		1.07	0.45	
41-50	1.51	0.83		2.31	1.71		1.88	1.27		1.14	0.43	
51-60	1.98	1.01		2.51	1.80		2.73	1.62		1.21	0.49	
61-70	2.17	0.91		3.50	2.04		3.53	1.70		1.47	0.53	
71-80	2.08	0.83		3.76	1.74		3.63	1.59		1.61	0.63	
81-90	2.11	0.84		4.48	1.90		3.90	1.64		1.66	0.60	
91-100	2.09	0.86		4.82	2.46		3.93	1.63		1.66	0.55	
Average	*1.78*	*0.77*		*2.85*	*1.56*		*2.75*	*1.29*		*1.38*	*0.49*	
Birch												
1-10	0.15	0.84		0.26	1.31		0.20	1.13		0.15	0.68	
11-20	0.12	0.55		0.16	0.73		0.17	0.73		0.11	0.44	
21-30	0.13	0.52		0.17	0.68		0.17	0.65		0.09	0.35	
31-40	0.15	0.45		0.23	0.61		0.19	0.54		0.11	0.33	
41-50	0.20	0.50		0.18	0.44		0.18	0.50		0.15	0.37	
51-60	0.15	0.40		0.13	0.33		0.21	0.48		0.18	0.44	
61-70	0.14	0.35		0.10	0.23		0.20	0.45		0.16	0.39	
71-80	0.11	0.33		0.08	0.18		0.24	0.47		0.15	0.44	
81-90	0.12	0.35		0.07	0.19		0.22	0.43		0.14	0.45	
91-100	0.11	0.34		0.06	0.19		0.21	0.50		0.13	0.41	
Average	*0.13*	*0.44*		*0.14*	*0.47*		*0.19*	*0.57*		*0.13*	*0.42*	

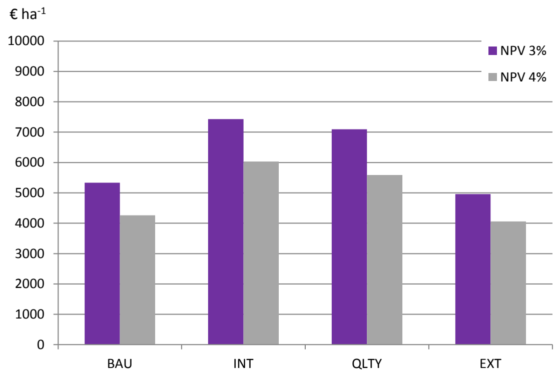
GROWING STOCK

Growing stock during the years 2010-2110, mill m³

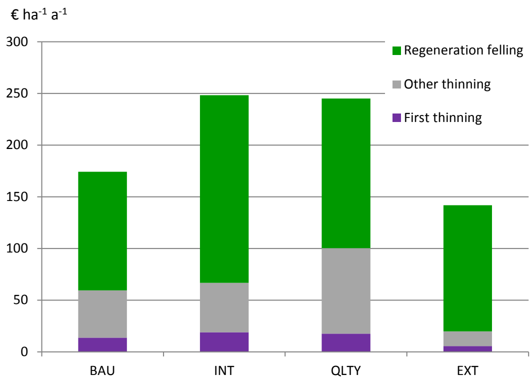


PROFITABILITY

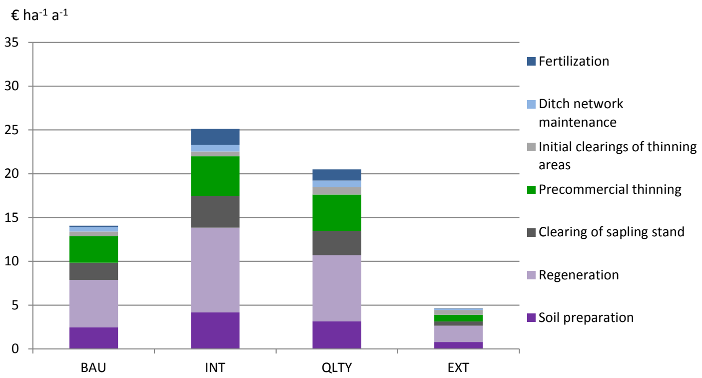
Net present value at 3% and 4% discount rates



Mean annual incomes € ha⁻¹ a⁻¹, undiscounted



Mean annual management costs € ha⁻¹ a⁻¹, undiscounted



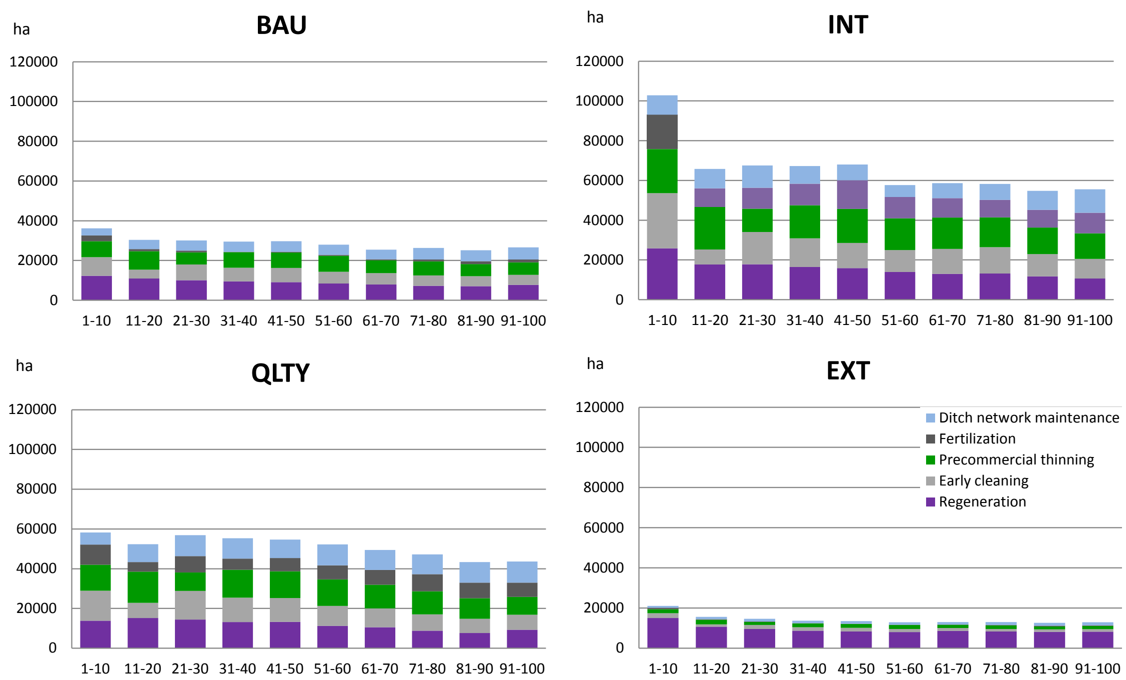
Appendix 8: Forestry centre Etelä-Pohjanmaa

FOREST MANAGEMENT PRACTICES

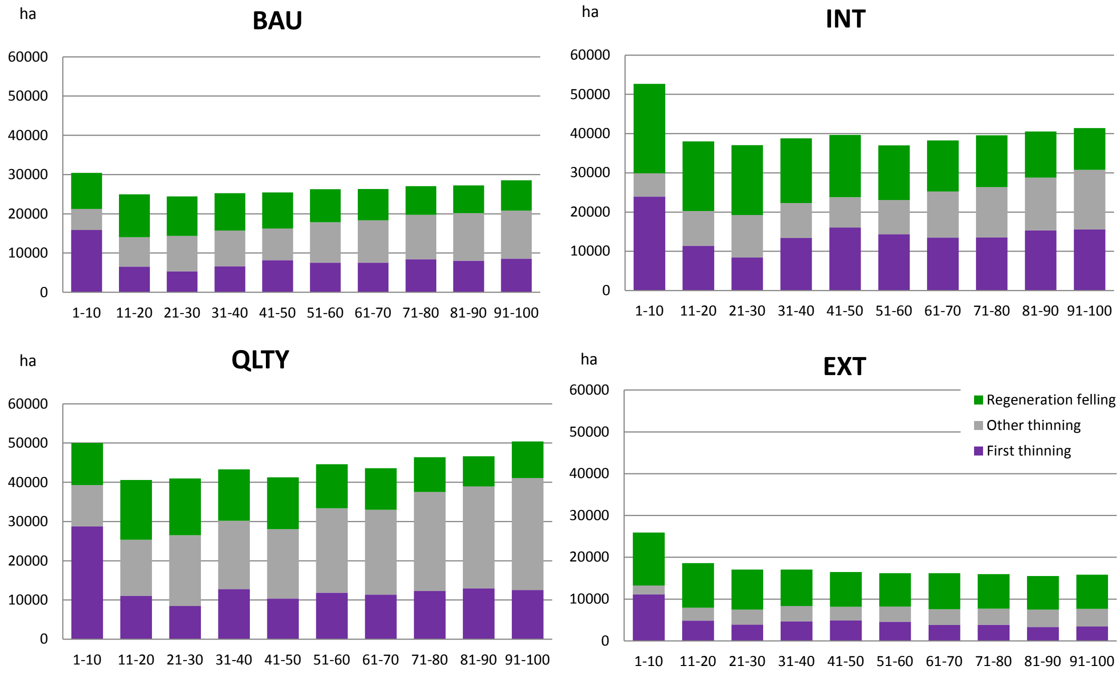
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	7726	14882	11195	3082
Natural regeneration	896	7	7	5821
Total regeneration	*8622*	*14889*	*11202*	*8903*
Early cleaning	6234	13461	10362	1558
Precommercial thinning	7424	16265	12326	1856
Fertilization	977	10584	7011	244
Ditch network maintenance	5299	9492	9989	1328
First thinning	8729	15638	13683	5026
Other thinning	10204	10999	20923	3729
Regeneration fellings	9027	15657	11882	9394
Total fellings	*27960*	*42294*	*46488*	*18150*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

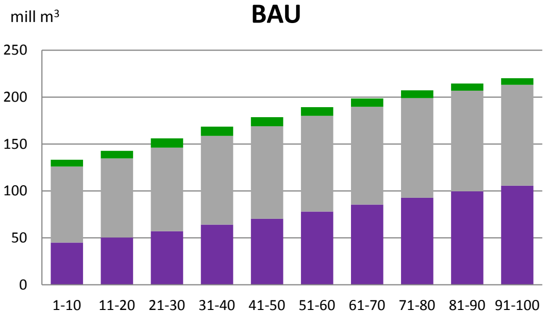
Year	BAU	INT	QLTY	EXT
1-10	103	218	146	111
11-20	110	164	170	104
21-30	107	161	167	95
31-40	104	159	162	96
41-50	104	154	166	96
51-60	104	161	163	96
61-70	105	169	167	107
71-80	105	168	167	106
81-90	107	170	169	106
91-100	115	169	194	107
Average	*111*	*177*	*177*	*107*

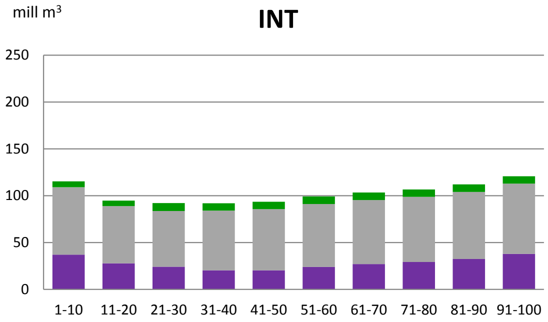
Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

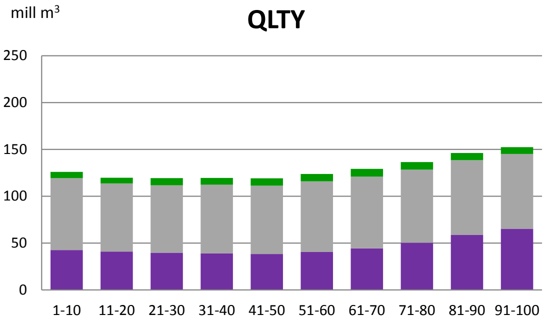
All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	1.32	1.76	0.20	2.76	3.41	1.06	1.87	2.59	0.63	1.45	1.45	0.65
11-20	0.86	0.99	0.12	1.07	1.48	0.35	1.40	1.56	0.41	0.79	0.73	0.30
21-30	1.50	1.43	0.22	2.12	2.34	0.71	2.36	2.10	0.70	1.43	1.19	0.38
31-40	1.57	1.49	0.21	2.20	2.40	0.70	2.46	2.19	0.68	1.43	1.22	0.35
41-50	1.45	1.42	0.21	2.05	2.41	0.64	2.30	2.16	0.62	1.28	1.17	0.33
51-60	1.33	1.36	0.19	1.94	2.33	0.58	2.18	2.13	0.57	1.23	1.12	0.35
61-70	1.39	1.48	0.18	1.99	2.48	0.60	2.14	2.32	0.56	1.28	1.17	0.37
71-80	1.40	1.59	0.18	1.81	2.58	0.51	2.26	2.47	0.56	1.26	1.19	0.38
81-90	1.36	1.51	0.17	1.88	2.58	0.47	2.26	2.21	0.51	1.28	1.17	0.37
91-100	1.31	1.44	0.14	1.73	2.30	0.43	2.15	2.07	0.47	1.26	1.13	0.34
Average	*1.53*	*1.53*	*0.18*	*2.34*	*2.50*	*0.67*	*2.52*	*2.21*	*0.53*	*1.46*	*1.30*	*0.36*
Scots pine												
1-10	0.77	1.03		1.59	2.02		1.08	1.52		0.86	0.80	
11-20	0.90	0.95		1.41	1.62		1.43	1.40		0.82	0.73	
21-30	0.94	0.98		1.55	1.73		1.47	1.45		0.85	0.75	
31-40	1.03	1.02		1.61	1.70		1.57	1.49		0.90	0.77	
41-50	1.07	1.01		1.54	1.65		1.75	1.39		0.96	0.79	
51-60	1.06	1.02		1.12	1.20		1.71	1.31		1.04	0.85	
61-70	0.88	0.91		0.89	1.02		1.52	1.09		1.11	0.89	
71-80	0.81	0.92		0.85	1.02		1.30	1.01		0.99	0.87	
81-90	0.75	0.89		0.69	0.98		1.00	0.88		0.81	0.76	
91-100	0.81	0.97		0.68	0.99		1.06	0.93		0.72	0.76	
Average	*0.94*	*1.01*		*1.20*	*1.43*		*1.43*	*1.28*		*0.93*	*0.83*	
Norway spruce												
1-10	0.49	0.24		1.06	0.51		0.70	0.35		0.53	0.20	
11-20	0.55	0.17		0.64	0.23		0.86	0.24		0.56	0.17	
21-30	0.46	0.14		0.42	0.18		0.74	0.23		0.39	0.13	
31-40	0.31	0.17		0.30	0.39		0.49	0.37		0.34	0.14	
41-50	0.24	0.25		0.28	0.62		0.43	0.44		0.27	0.13	
51-60	0.29	0.29		0.86	1.04		0.45	0.65		0.21	0.13	
61-70	0.55	0.35		1.39	1.03		0.80	0.77		0.33	0.15	
71-80	0.63	0.37		1.44	1.06		1.10	0.86		0.43	0.19	
81-90	0.76	0.36		1.71	0.99		1.51	0.89		0.60	0.26	
91-100	0.81	0.34		1.74	0.98		1.90	0.93		0.69	0.29	
Average	*0.55*	*0.29*		*1.09*	*0.76*		*1.03*	*0.60*		*0.48*	*0.20*	
Birch												
1-10	0.06	0.49		0.11	0.89		0.09	0.73		0.06	0.44	
11-20	0.05	0.31		0.08	0.48		0.07	0.45		0.05	0.29	
21-30	0.05	0.30		0.08	0.49		0.09	0.48		0.05	0.29	
31-40	0.05	0.29		0.08	0.39		0.08	0.45		0.05	0.26	
41-50	0.05	0.26		0.05	0.30		0.07	0.38		0.04	0.25	
51-60	0.03	0.18		0.03	0.22		0.06	0.27		0.03	0.19	
61-70	0.03	0.16		0.02	0.12		0.05	0.23		0.03	0.19	
71-80	0.02	0.13		0.01	0.09		0.04	0.15		0.03	0.20	
81-90	0.02	0.12		0.01	0.07		0.03	0.14		0.05	0.23	
91-100	0.02	0.13		0.01	0.06		0.02	0.13		0.04	0.29	
Average	*0.04*	*0.24*		*0.05*	*0.30*		*0.06*	*0.34*		*0.05*	*0.28*	

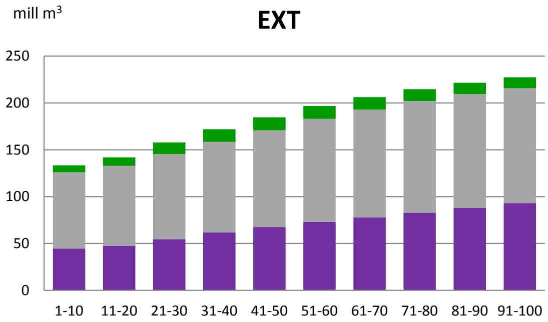
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3



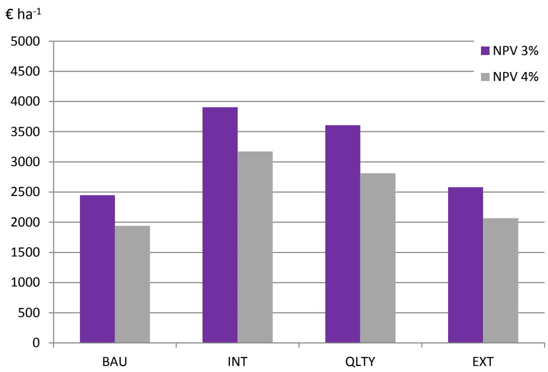




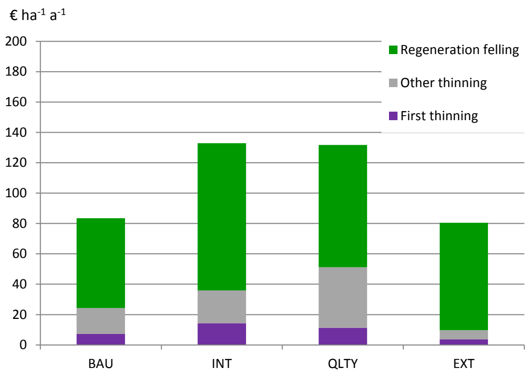


PROFITABILITY

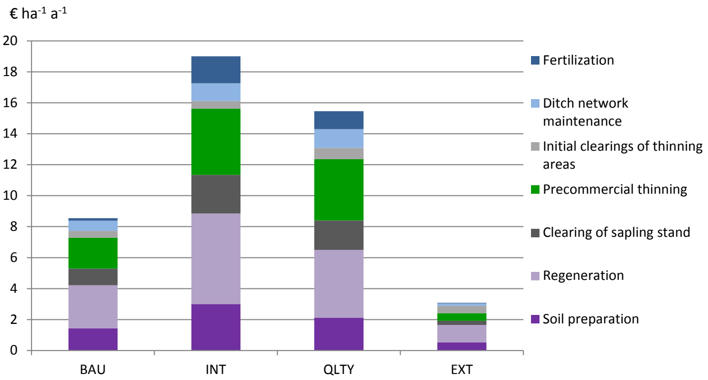
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



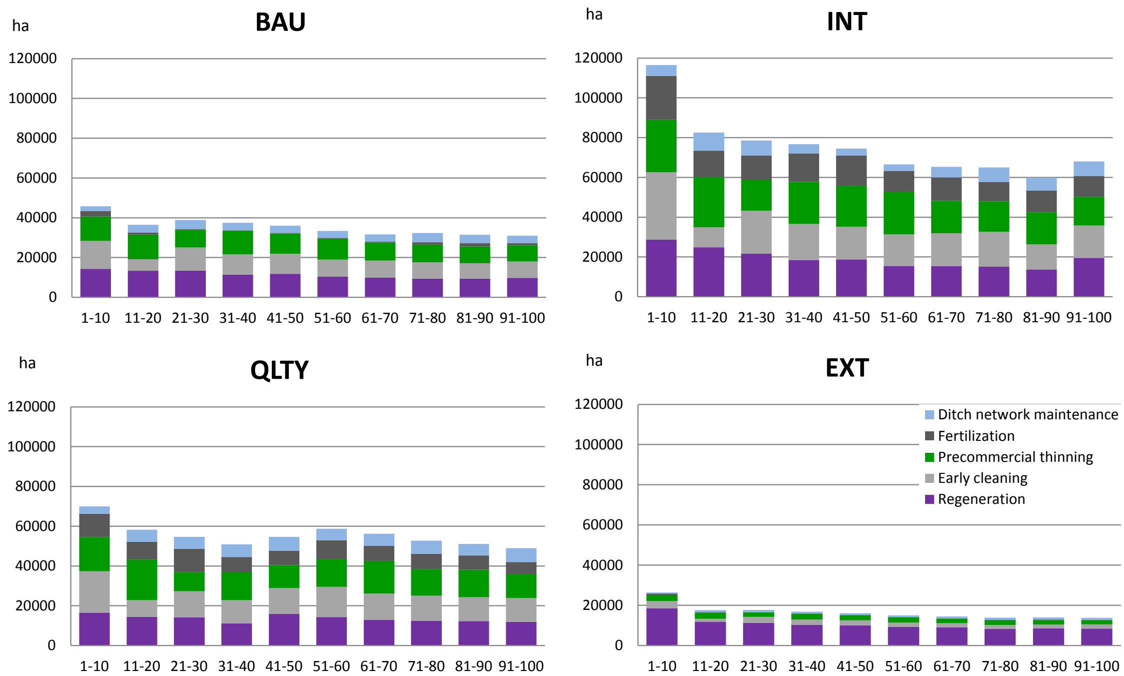
Appendix 9: Forestry centre Keski-Suomi

FOREST MANAGEMENT PRACTICES

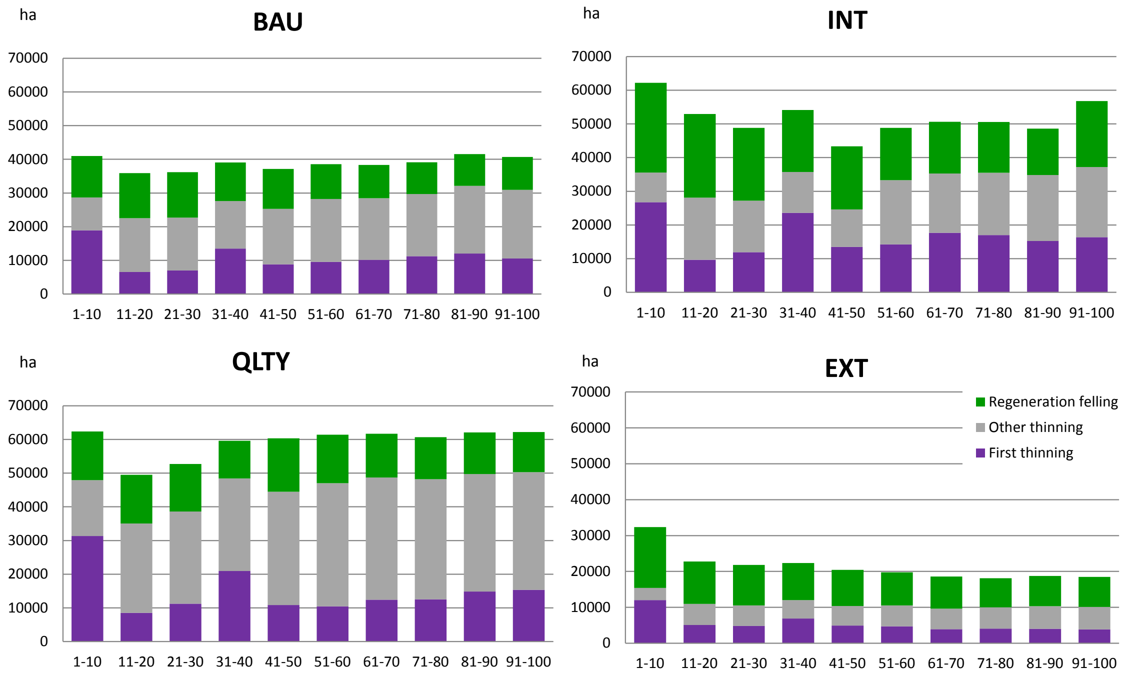
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	10100	18263	12981	3743
Natural regeneration	698	0	0	6281
Total regeneration	*10798*	*18263*	*12981*	*10024*
Early cleaning	9314	17981	13291	2329
Precommercial thinning	10558	19749	14811	2639
Fertilization	895	12483	8107	224
Ditch network maintenance	3754	6161	6070	942
First thinning	10884	17225	15069	5495
Other thinning	17341	16582	31758	5722
Regeneration fellings	11643	19636	13967	10611
Total fellings	*39869*	*53443*	*60794*	*21828*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

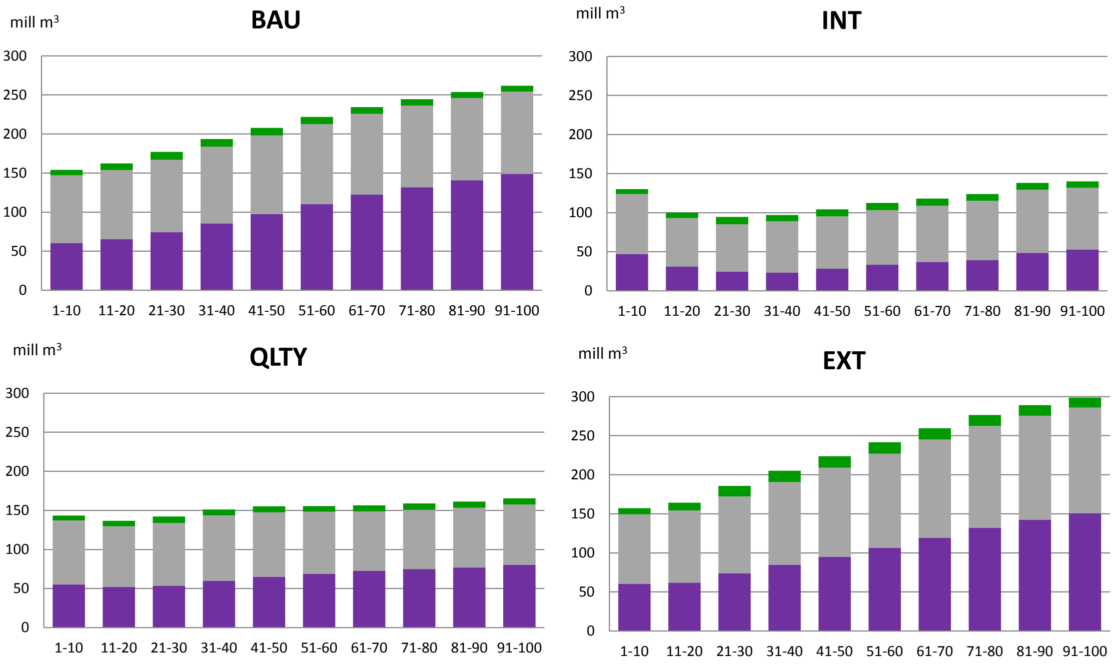
Year	BAU	INT	QLTY	EXT
1-10	181	329	241	200
11-20	182	276	231	145
21-30	170	230	225	140
31-40	162	215	211	138
41-50	169	236	264	141
51-60	167	236	271	139
61-70	170	239	274	140
71-80	173	241	278	141
81-90	177	244	273	151
91-100	184	335	273	153
Average	*183*	*270*	*266*	*155*

Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	2.59	2.27	0.33	4.60	3.89	1.59	3.43	3.14	1.01	2.94	1.77	0.89
11-20	1.56	1.40	0.18	1.88	2.08	0.58	2.29	1.94	0.54	1.22	0.94	0.42
21-30	2.68	1.94	0.36	3.81	3.32	1.23	3.47	2.30	0.86	2.08	1.44	0.51
31-40	2.54	1.98	0.33	3.30	3.05	1.05	3.27	2.38	0.79	2.00	1.44	0.49
41-50	2.42	1.96	0.31	3.07	3.04	0.97	3.29	2.48	0.81	1.98	1.46	0.50
51-60	2.20	1.96	0.27	2.80	3.12	0.90	3.04	2.61	0.75	1.95	1.47	0.49
61-70	2.24	2.14	0.26	2.64	3.46	0.87	2.94	2.83	0.69	1.92	1.51	0.52
71-80	2.33	2.10	0.27	2.53	3.15	0.83	3.41	2.75	0.74	1.94	1.48	0.52
81-90	2.42	1.97	0.28	3.13	2.98	1.12	3.91	2.79	0.78	1.99	1.45	0.48
91-100	2.38	1.95	0.26	3.16	2.91	1.07	4.12	2.91	0.79	1.97	1.44	0.44
Average	*2.71*	*2.01*	*0.30*	*3.77*	*3.16*	*1.14*	*4.05*	*2.64*	*0.84*	*2.26*	*1.52*	*0.48*
Scots pine												
1-10	1.00	1.06		1.78	1.88		1.25	1.45		1.08	0.74	
11-20	1.00	1.01		1.71	1.85		1.31	1.19		0.79	0.70	
21-30	1.23	1.12		1.77	1.76		1.45	1.25		1.01	0.83	
31-40	1.22	1.05		1.49	1.47		1.51	1.17		1.10	0.84	
41-50	1.27	0.95		1.02	0.98		2.15	1.24		1.12	0.79	
51-60	0.89	0.81		0.69	0.70		1.85	0.98		1.00	0.72	
61-70	0.71	0.76		0.70	0.77		1.40	0.78		0.85	0.65	
71-80	0.74	0.84		0.60	0.79		1.08	0.65		0.58	0.51	
81-90	0.81	0.93		0.56	0.72		1.06	0.70		0.57	0.51	
91-100	0.83	0.88		0.60	0.77		0.96	0.67		0.59	0.54	
Average	*0.99*	*0.96*		*1.10*	*1.19*		*1.42*	*1.02*		*0.88*	*0.70*	
Norway spruce												
1-10	1.48	0.54		2.63	0.93		2.02	0.73		1.74	0.46	
11-20	1.57	0.48		1.93	0.75		2.05	0.59		1.21	0.39	
21-30	1.10	0.44		1.14	0.67		1.68	0.63		0.90	0.33	
31-40	0.92	0.69		1.01	1.45		1.29	1.17		0.74	0.36	
41-50	1.04	0.67		1.99	1.56		1.60	1.05		0.78	0.35	
51-60	1.44	0.85		2.53	1.87		2.14	1.28		0.88	0.41	
61-70	1.77	0.78		2.69	1.77		2.78	1.36		1.12	0.43	
71-80	1.82	0.71		2.88	1.68		3.23	1.39		1.38	0.51	
81-90	1.81	0.74		3.02	1.69		3.08	1.42		1.57	0.57	
91-100	1.91	0.74		4.27	2.38		3.25	1.46		1.60	0.53	
Average	*1.63*	*0.68*		*2.58*	*1.56*		*2.50*	*1.13*		*1.29*	*0.45*	
Birch												
1-10	0.11	0.68		0.19	1.08		0.16	0.95		0.11	0.57	
11-20	0.10	0.45		0.17	0.73		0.12	0.52		0.08	0.35	
21-30	0.10	0.41		0.16	0.61		0.16	0.59		0.08	0.30	
31-40	0.11	0.40		0.15	0.54		0.13	0.49		0.09	0.31	
41-50	0.10	0.35		0.12	0.44		0.15	0.50		0.10	0.30	
51-60	0.09	0.31		0.05	0.26		0.13	0.41		0.10	0.32	
61-70	0.08	0.28		0.03	0.14		0.12	0.35		0.09	0.31	
71-80	0.07	0.26		0.03	0.13		0.11	0.32		0.11	0.36	
81-90	0.07	0.25		0.02	0.11		0.15	0.39		0.11	0.38	
91-100	0.07	0.27		0.02	0.15		0.11	0.34		0.09	0.38	
Average	*0.09*	*0.36*		*0.09*	*0.41*		*0.13*	*0.48*		*0.10*	*0.37*	

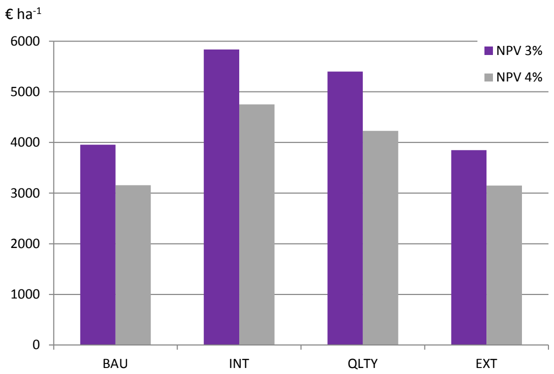
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3

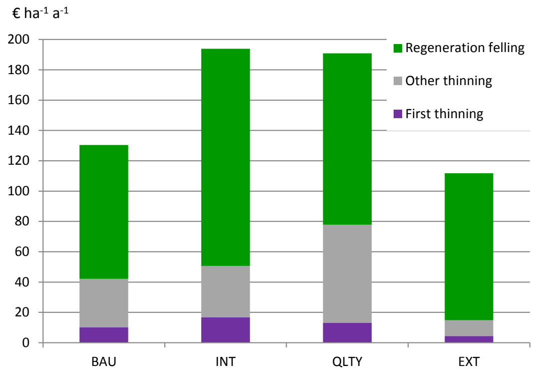


PROFITABILITY

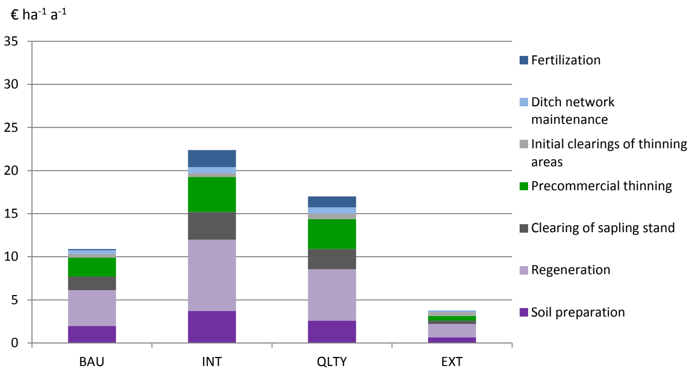
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



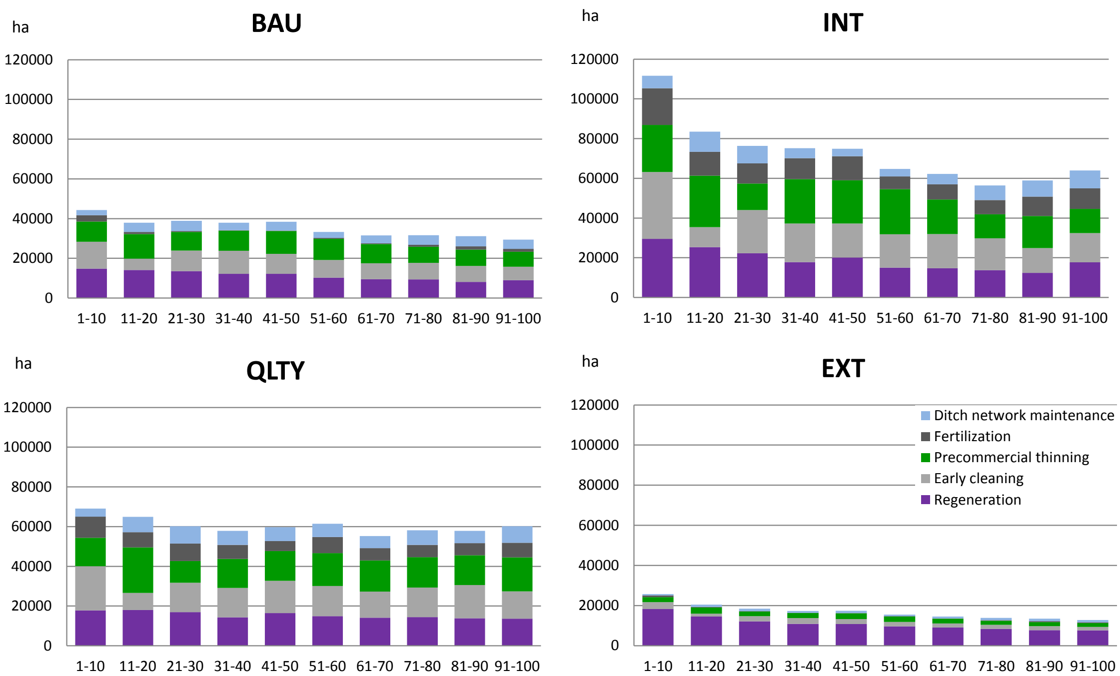
Appendix 10: Forestry centre Pohjois-Savo

FOREST MANAGEMENT PRACTICES

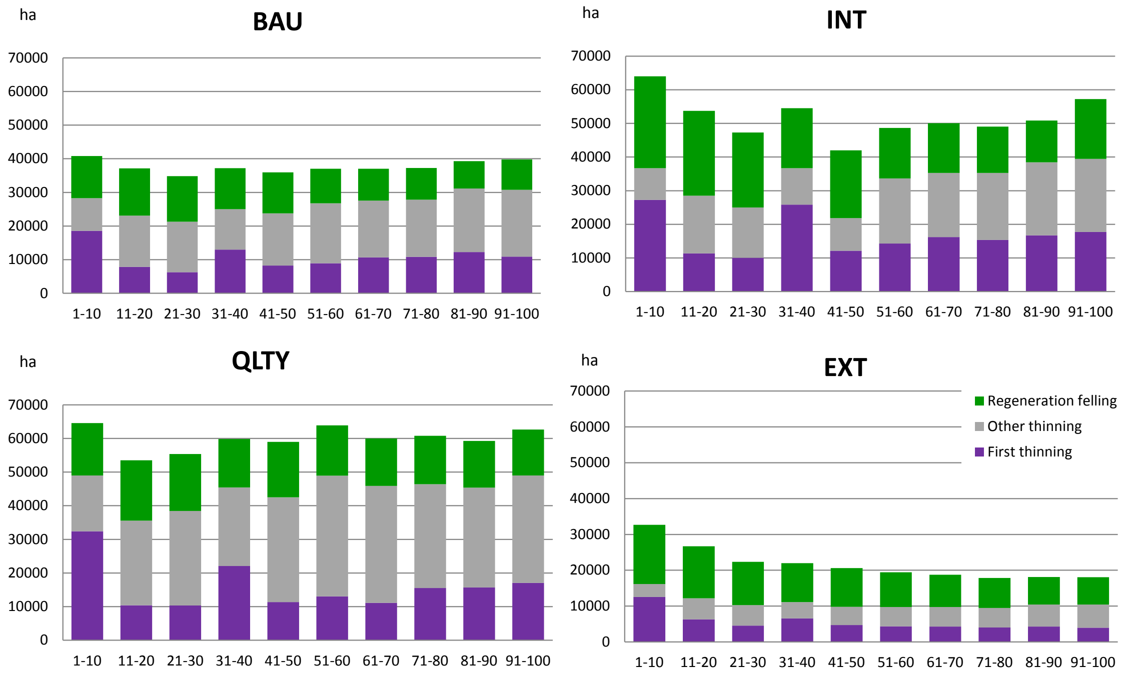
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	9992	17983	14735	3803
Natural regeneration	784	0	0	6577
Total regeneration	*10776*	*17983*	*14735*	*10380*
Early cleaning	9224	18160	14840	2306
Precommercial thinning	10036	19342	16343	2509
Fertilization	959	9946	6950	240
Ditch network maintenance	4266	6852	7026	1072
First thinning	10917	17669	16490	5628
Other thinning	16445	16988	29991	5570
Regeneration fellings	11548	19437	16117	10938
Total fellings	*38910*	*54093*	*62599*	*22136*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

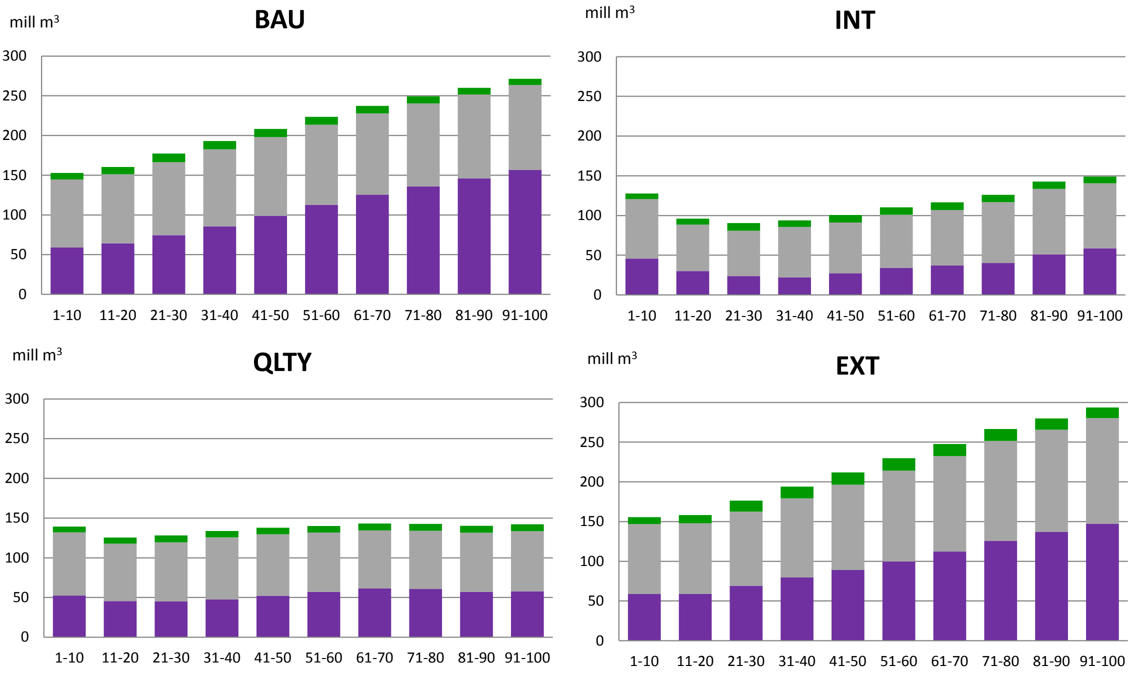
Year	BAU	INT	QLTY	EXT
1-10	180	332	254	196
11-20	184	277	263	176
21-30	171	234	239	145
31-40	162	216	228	142
41-50	166	242	254	143
51-60	168	239	277	142
61-70	170	248	289	143
71-80	170	249	286	143
81-90	168	246	288	144
91-100	176	328	278	147
Average	*181*	*278*	*281*	*159*

Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	2.53	2.41	0.33	4.54	4.22	1.79	3.52	3.52	1.20	2.84	1.91	0.96
11-20	1.44	1.38	0.18	1.82	2.18	0.62	2.15	1.99	0.60	1.21	0.96	0.45
21-30	2.68	2.04	0.36	3.76	3.45	1.37	3.92	2.61	1.17	2.51	1.77	0.67
31-40	2.35	1.91	0.33	3.27	3.09	1.18	3.31	2.49	0.95	2.24	1.69	0.61
41-50	2.44	1.97	0.36	3.12	3.07	1.13	3.40	2.79	0.99	2.02	1.60	0.55
51-60	2.43	2.05	0.37	2.90	3.19	1.06	3.17	2.92	0.92	2.00	1.59	0.55
61-70	2.21	2.16	0.31	2.60	3.58	0.98	3.10	3.09	0.89	1.96	1.59	0.56
71-80	2.17	2.12	0.29	2.59	3.35	0.98	3.47	3.01	0.94	1.96	1.62	0.57
81-90	2.35	2.01	0.32	3.22	2.96	1.24	3.66	2.91	0.89	1.98	1.57	0.53
91-100	2.37	1.95	0.30	3.20	2.87	1.14	3.89	3.10	0.87	2.00	1.54	0.44
Average	*2.67*	*2.02*	*0.33*	*3.88*	*3.24*	*1.26*	*4.16*	*2.96*	*1.04*	*2.30*	*1.62*	*0.53*
Scots pine												
1-10	0.73	0.81		1.30	1.51		0.98	1.20		0.75	0.54	
11-20	0.79	0.86		1.37	1.58		1.01	0.98		0.77	0.70	
21-30	0.94	0.87		1.32	1.38		1.36	1.17		0.84	0.72	
31-40	0.98	0.84		1.10	1.02		1.28	0.94		0.86	0.70	
41-50	0.98	0.76		0.92	0.85		1.65	1.02		0.95	0.71	
51-60	0.55	0.50		0.38	0.38		1.33	0.75		0.78	0.61	
61-70	0.44	0.52		0.36	0.43		0.70	0.48		0.54	0.45	
71-80	0.44	0.57		0.33	0.48		0.76	0.46		0.32	0.33	
81-90	0.38	0.61		0.28	0.52		0.50	0.38		0.20	0.27	
91-100	0.54	0.69		0.37	0.52		0.60	0.53		0.29	0.34	
Average	*0.71*	*0.73*		*0.77*	*0.88*		*1.08*	*0.82*		*0.63*	*0.54*	
Norway spruce												
1-10	1.65	0.66		3.00	1.19		2.33	0.98		1.93	0.55	
11-20	1.77	0.59		2.19	0.91		2.75	0.83		1.63	0.56	
21-30	1.37	0.55		1.61	0.85		1.85	0.84		1.07	0.43	
31-40	1.10	0.84		1.34	1.93		1.66	1.51		0.98	0.49	
41-50	1.23	0.78		2.15	1.56		1.82	1.28		0.90	0.43	
51-60	1.81	1.03		2.84	2.19		2.64	1.74		1.12	0.51	
61-70	2.03	0.96		3.22	2.00		3.69	1.72		1.38	0.58	
71-80	2.07	0.86		3.32	1.91		3.46	1.77		1.66	0.67	
81-90	2.09	0.93		3.35	1.89		3.80	1.77		1.81	0.73	
91-100	2.09	0.87		4.43	2.54		3.43	1.78		1.82	0.65	
Average	*1.85*	*0.83*		*3.00*	*1.83*		*2.91*	*1.49*		*1.54*	*0.59*	
Birch												
1-10	0.15	0.93		0.24	1.52		0.21	1.34		0.15	0.82	
11-20	0.11	0.59		0.20	0.96		0.15	0.80		0.11	0.51	
21-30	0.12	0.56		0.20	0.84		0.20	0.79		0.11	0.46	
31-40	0.13	0.48		0.17	0.64		0.16	0.64		0.11	0.40	
41-50	0.14	0.47		0.16	0.55		0.19	0.61		0.13	0.43	
51-60	0.10	0.37		0.07	0.33		0.12	0.45		0.12	0.42	
61-70	0.10	0.32		0.03	0.15		0.10	0.36		0.15	0.46	
71-80	0.10	0.33		0.02	0.12		0.15	0.45		0.13	0.45	
81-90	0.08	0.29		0.02	0.11		0.17	0.42		0.12	0.44	
91-100	0.06	0.29		0.03	0.16		0.19	0.51		0.10	0.40	
Average	*0.11*	*0.46*		*0.11*	*0.53*		*0.17*	*0.65*		*0.13*	*0.49*	

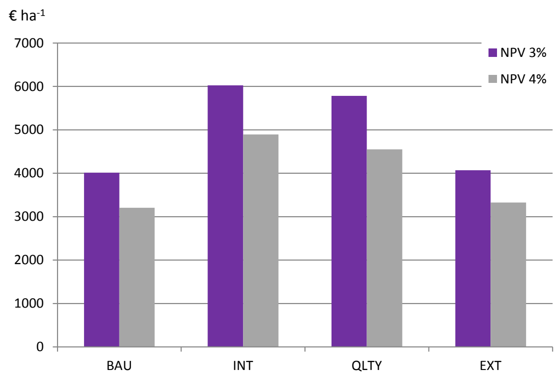
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3

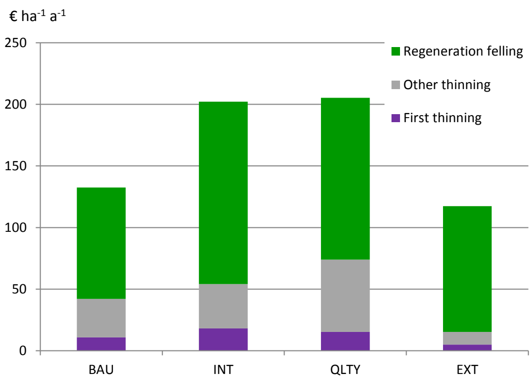


PROFITABILITY

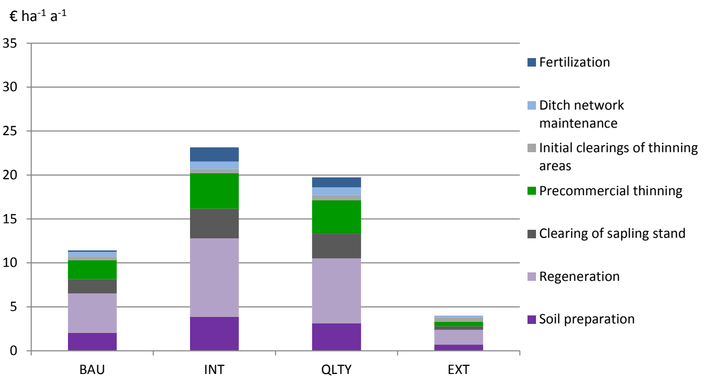
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



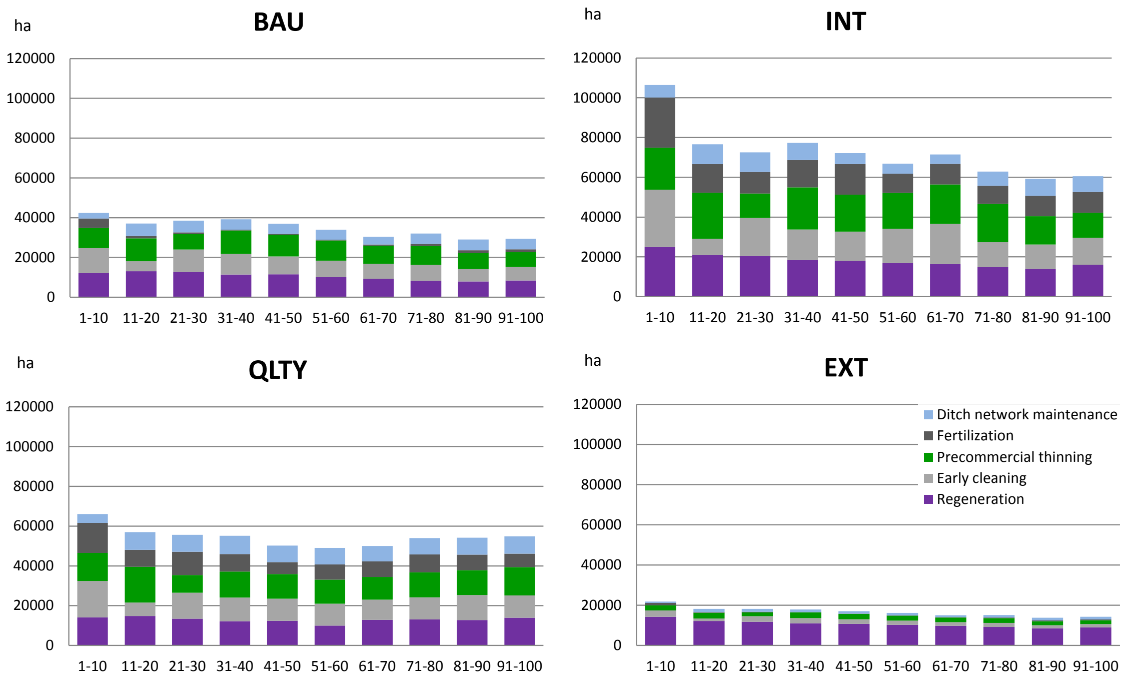
Appendix 11: Forestry centre Pohjois-Karjala

FOREST MANAGEMENT PRACTICES

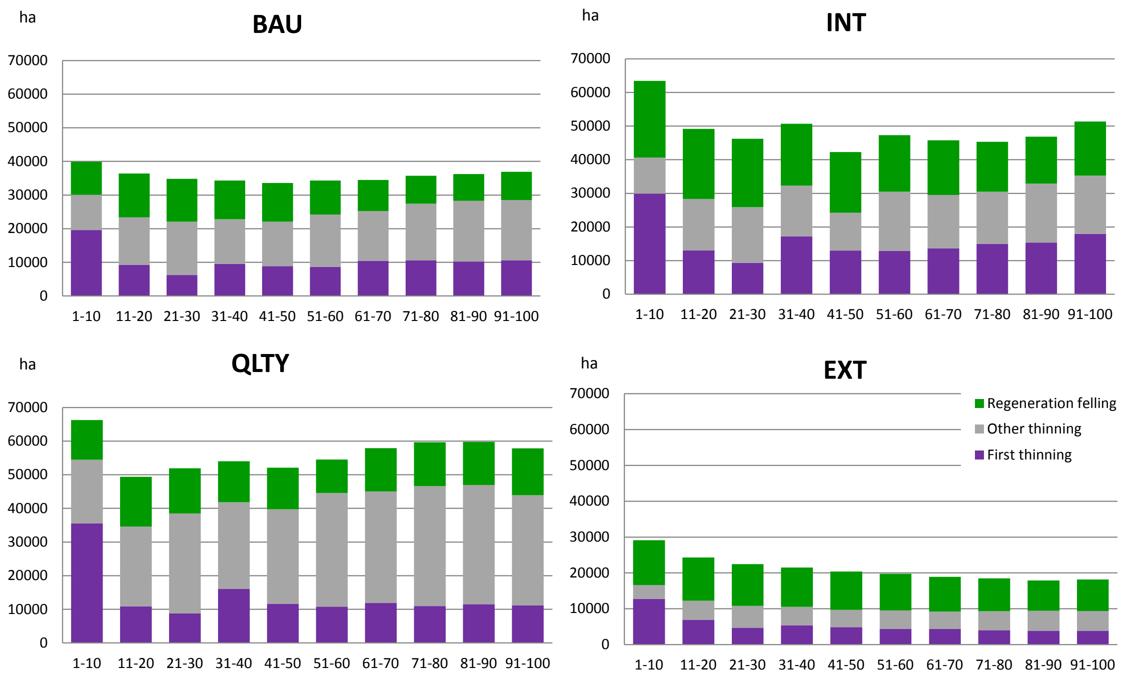
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	9481	17215	12332	3596
Natural regeneration	521	6	6	6524
Total regeneration	*10002*	*17222*	*12338*	*10119*
Early cleaning	8527	16141	11938	2132
Precommercial thinning	9852	18732	13566	2463
Fertilization	1194	12313	8495	298
Ditch network maintenance	5162	8027	8040	1291
First thinning	10784	17219	14128	5694
Other thinning	15883	15721	30613	5387
Regeneration fellings	10632	18341	13194	10673
Total fellings	*37299*	*51281*	*57935*	*21754*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

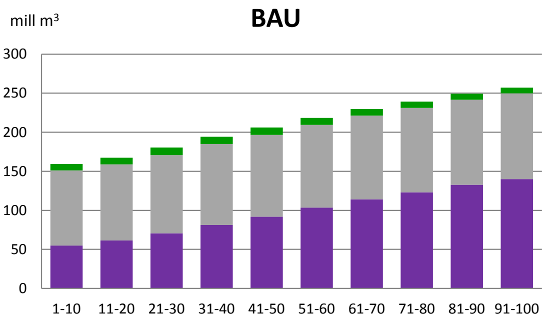
Year	BAU	INT	QLTY	EXT
1-10	152	293	215	150
11-20	160	222	204	145
21-30	151	209	200	137
31-40	141	204	196	133
41-50	142	211	200	134
51-60	141	219	200	135
61-70	145	219	243	139
71-80	145	224	262	138
81-90	145	224	263	138
91-100	151	259	268	137
Average	*155*	*239*	*236*	*146*

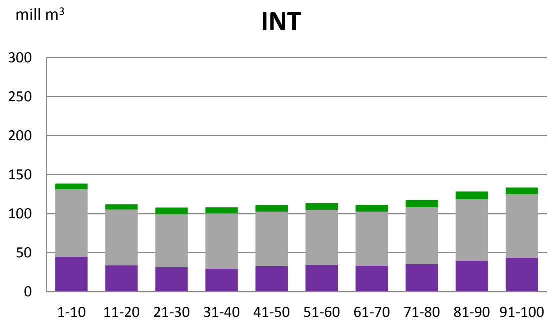
Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

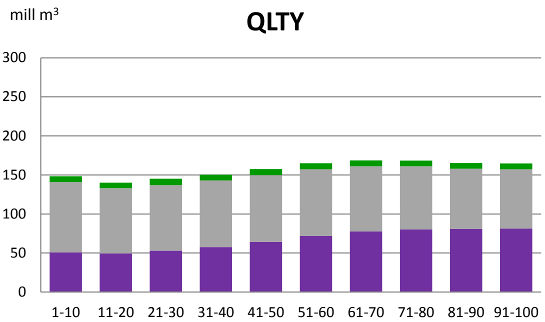
All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	2.04	2.36	0.25	3.87	4.22	1.37	2.83	3.58	0.86	2.09	1.66	0.79
11-20	1.11	1.35	0.14	1.41	2.14	0.45	1.67	2.01	0.44	1.00	0.87	0.41
21-30	2.22	2.05	0.29	2.92	3.09	0.92	2.93	2.42	0.75	2.05	1.51	0.54
31-40	2.23	2.03	0.26	2.85	2.92	0.87	2.89	2.42	0.69	2.04	1.55	0.51
41-50	2.11	1.94	0.24	2.75	2.92	0.85	2.85	2.48	0.67	1.90	1.53	0.47
51-60	1.99	1.83	0.23	2.61	2.84	0.77	2.79	2.54	0.63	1.83	1.49	0.46
61-70	1.92	1.91	0.23	2.62	3.06	0.78	2.72	2.62	0.65	1.83	1.53	0.47
71-80	1.95	1.96	0.23	2.44	3.01	0.73	2.69	2.52	0.63	1.76	1.50	0.44
81-90	1.96	1.87	0.21	2.68	2.99	0.96	2.88	2.47	0.58	1.84	1.52	0.45
91-100	1.88	1.80	0.20	2.95	2.97	1.01	3.08	2.50	0.57	1.82	1.46	0.43
Average	*2.22*	*1.92*	*0.24*	*3.22*	*3.08*	*1.00*	*3.52*	*2.59*	*0.71*	*2.06*	*1.56*	*0.46*
Scots pine												
1-10	0.93	1.15		1.74	2.09		1.27	1.74		0.93	0.72	
11-20	1.15	1.14		1.66	1.78		1.40	1.30		0.99	0.80	
21-30	1.19	1.11		1.62	1.64		1.50	1.38		1.06	0.84	
31-40	1.12	1.04		1.70	1.55		1.45	1.21		1.05	0.86	
41-50	1.21	0.99		1.29	1.15		1.64	1.17		1.17	0.87	
51-60	0.96	0.87		1.41	1.02		1.58	1.04		1.12	0.86	
61-70	0.77	0.77		0.84	0.78		1.82	0.96		1.09	0.79	
71-80	0.61	0.78		0.78	0.73		1.60	0.93		0.87	0.71	
81-90	0.63	0.81		0.76	0.83		1.28	0.81		0.49	0.51	
91-100	0.74	0.89		0.62	0.72		1.33	0.84		0.74	0.73	
Average	*0.97*	*0.99*		*1.26*	*1.27*		*1.51*	*1.15*		*0.96*	*0.78*	
Norway spruce												
1-10	1.02	0.50		1.94	0.90		1.40	0.75		1.07	0.37	
11-20	0.99	0.38		1.13	0.58		1.41	0.46		0.98	0.34	
21-30	0.81	0.34		0.95	0.53		1.21	0.46		0.74	0.28	
31-40	0.68	0.45		0.76	0.92		1.11	0.82		0.67	0.30	
41-50	0.62	0.46		1.23	1.34		1.06	0.74		0.54	0.25	
51-60	0.90	0.59		1.50	1.15		1.23	0.92		0.67	0.29	
61-70	1.25	0.65		2.07	1.67		1.68	1.04		0.79	0.31	
71-80	1.47	0.63		2.35	1.56		2.30	1.06		1.00	0.35	
81-90	1.48	0.59		2.43	1.51		2.70	1.10		1.39	0.55	
91-100	1.45	0.55		2.86	2.33		2.83	1.03		1.13	0.38	
Average	*1.15*	*0.53*		*1.85*	*1.33*		*1.85*	*0.87*		*1.00*	*0.36*	
Birch												
1-10	0.10	0.72		0.18	1.23		0.16	1.09		0.09	0.57	
11-20	0.08	0.52		0.13	0.73		0.12	0.65		0.07	0.37	
21-30	0.11	0.49		0.18	0.75		0.14	0.64		0.10	0.42	
31-40	0.12	0.42		0.16	0.60		0.16	0.59		0.11	0.37	
41-50	0.13	0.41		0.16	0.51		0.17	0.56		0.13	0.40	
51-60	0.12	0.38		0.15	0.45		0.13	0.44		0.10	0.32	
61-70	0.09	0.31		0.06	0.25		0.19	0.50		0.10	0.35	
71-80	0.07	0.26		0.05	0.20		0.17	0.46		0.12	0.40	
81-90	0.07	0.25		0.03	0.12		0.17	0.45		0.10	0.40	
91-100	0.08	0.27		0.02	0.14		0.11	0.36		0.10	0.40	
Average	*0.09*	*0.40*		*0.11*	*0.48*		*0.16*	*0.58*		*0.10*	*0.41*	

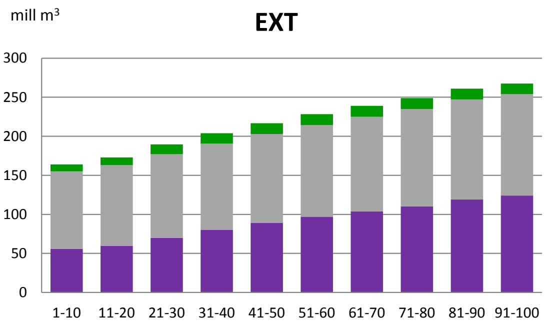
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3



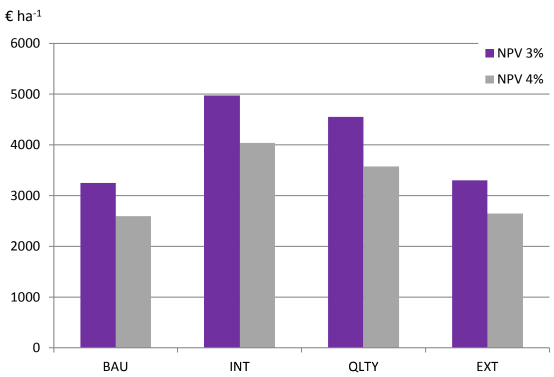




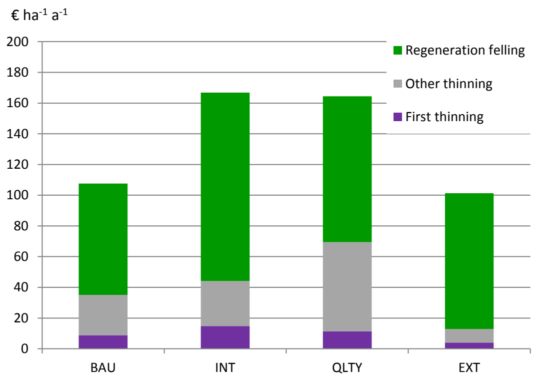


PROFITABILITY

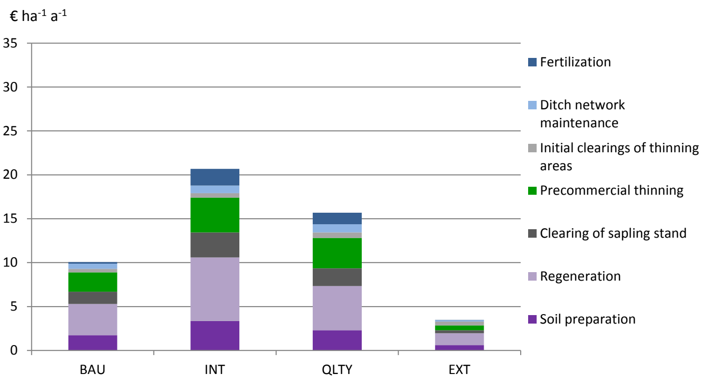
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



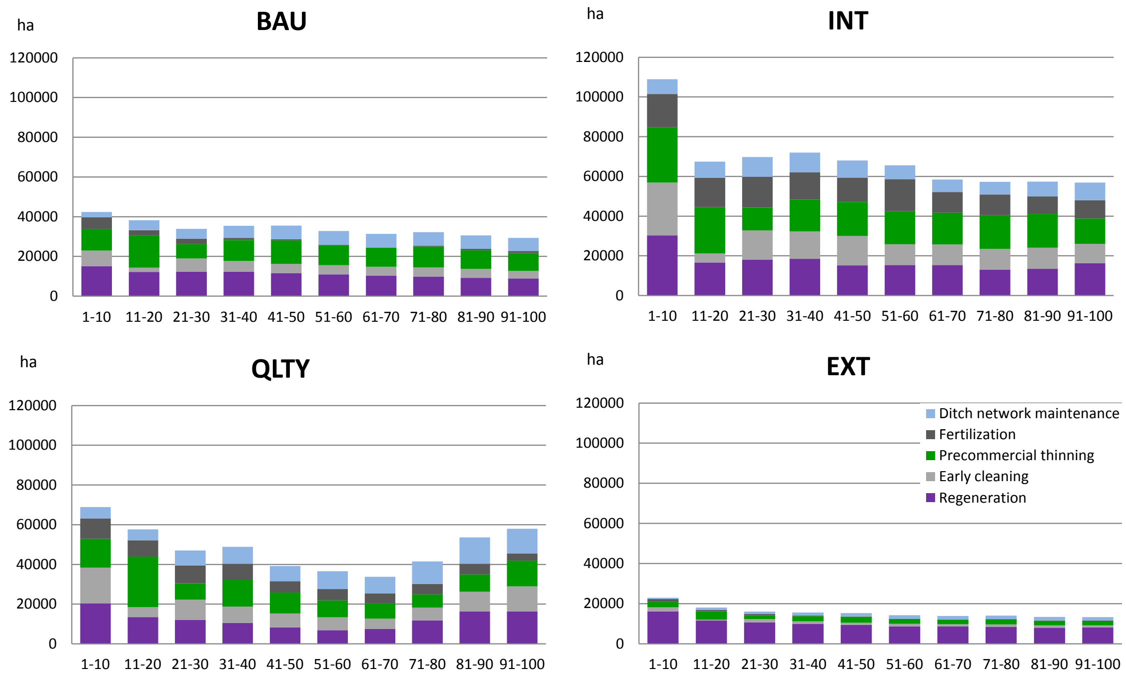
Appendix 12: Forestry centre Kainuu

FOREST MANAGEMENT PRACTICES

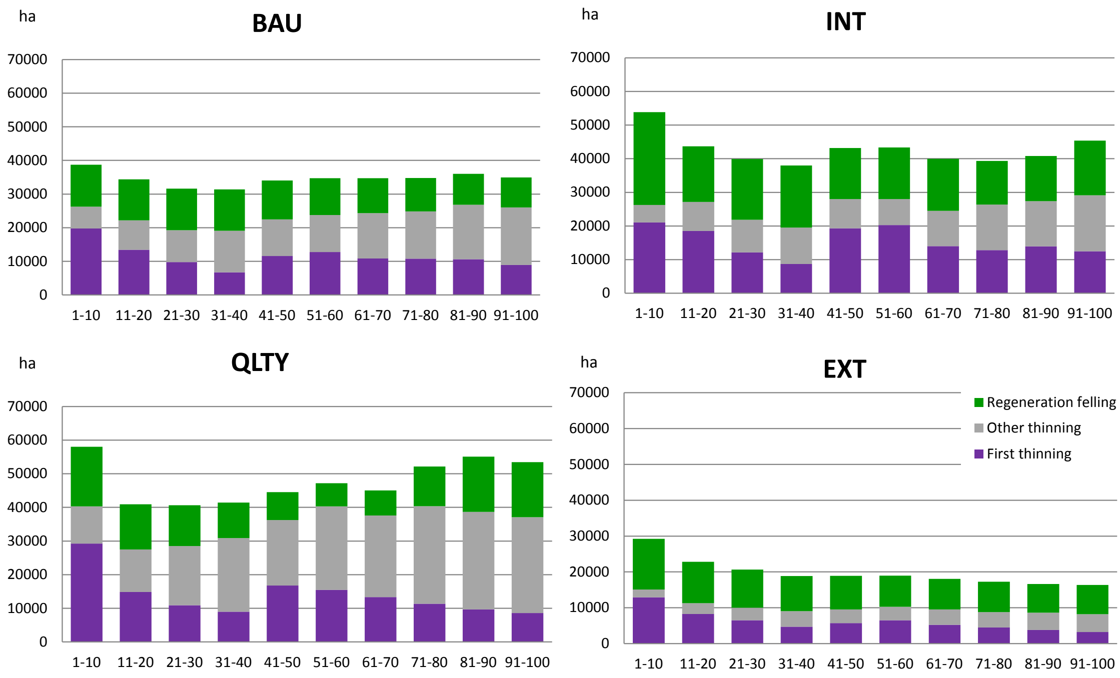
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	10057	16385	9503	4305
Natural regeneration	699	15	2288	5172
Total regeneration	*10757*	*16400*	*11791*	*9476*
Early cleaning	4779	12575	9041	1195
Precommercial thinning	10725	18141	13048	2681
Fertilization	1461	12212	6313	365
Ditch network maintenance	6017	8002	8716	1509
First thinning	12259	16164	14186	6296
Other thinning	12771	11872	22595	4170
Regeneration fellings	11305	17036	12807	9951
Total fellings	*36335*	*45072*	*49589*	*20417*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

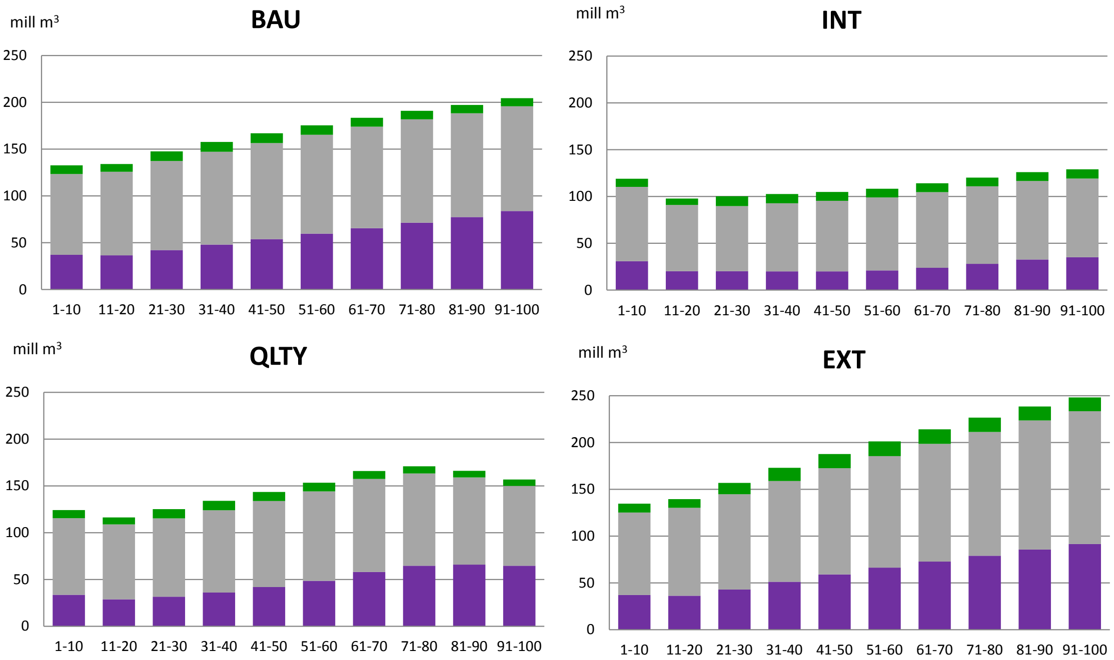
Year	BAU	INT	QLTY	EXT
1-10	133	235	180	129
11-20	102	130	122	86
21-30	101	130	119	84
31-40	101	132	117	79
41-50	98	125	113	79
51-60	99	130	113	80
61-70	100	136	117	80
71-80	102	141	163	80
81-90	100	150	205	80
91-100	105	180	207	91
Average	*109*	*155*	*155*	*90*

Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	1.72	2.02	0.35	2.95	3.35	1.45	2.26	2.89	0.94	1.71	1.52	0.70
11-20	0.64	1.03	0.12	0.73	1.44	0.35	0.92	1.40	0.36	0.54	0.69	0.29
21-30	1.27	1.72	0.24	1.49	2.39	0.71	1.54	1.87	0.56	1.06	1.28	0.43
31-40	1.18	1.66	0.25	1.46	2.47	0.78	1.52	1.98	0.58	1.05	1.29	0.45
41-50	1.22	1.73	0.28	1.46	2.42	0.78	1.49	1.93	0.55	1.03	1.25	0.42
51-60	1.20	1.72	0.26	1.42	2.27	0.75	1.43	1.88	0.48	0.94	1.20	0.39
61-70	1.24	1.72	0.25	1.49	2.39	0.83	1.46	1.95	0.48	0.96	1.22	0.39
71-80	1.18	1.73	0.23	1.47	2.54	0.80	1.36	2.01	0.46	0.95	1.20	0.37
81-90	1.15	1.81	0.23	1.33	2.55	0.64	1.35	2.07	0.44	0.96	1.23	0.37
91-100	1.18	1.81	0.24	1.40	2.50	0.61	1.46	2.16	0.42	0.99	1.23	0.40
Average	*1.36*	*1.83*	*0.24*	*1.90*	*2.50*	*0.79*	*2.08*	*2.18*	*0.61*	*1.14*	*1.29*	*0.39*
Scots pine												
1-10	0.95	1.06		1.59	1.73		1.21	1.52		0.92	0.75	
11-20	0.80	1.03		1.08	1.58		0.95	1.10		0.66	0.68	
21-30	0.85	1.09		1.15	1.64		1.00	1.18		0.72	0.75	
31-40	0.95	1.15		1.18	1.62		1.13	1.23		0.71	0.76	
41-50	0.89	1.17		1.00	1.45		1.02	1.13		0.73	0.80	
51-60	0.86	1.20		1.11	1.47		1.08	1.15		0.74	0.82	
61-70	0.75	1.05		1.01	1.24		1.05	1.01		0.71	0.79	
71-80	0.77	1.13		0.58	0.82		1.35	1.07		0.70	0.80	
81-90	0.69	1.12		0.57	0.88		1.70	1.27		0.62	0.74	
91-100	0.68	1.05		0.70	0.93		1.48	1.11		0.65	0.72	
Average	*0.85*	*1.17*		*0.99*	*1.34*		*1.24*	*1.20*		*0.74*	*0.79*	
Norway spruce												
1-10	0.73	0.48		1.29	0.84		0.98	0.66		0.76	0.43	
11-20	0.42	0.26		0.34	0.25		0.54	0.31		0.35	0.22	
21-30	0.31	0.21		0.25	0.22		0.43	0.26		0.26	0.17	
31-40	0.23	0.17		0.24	0.28		0.27	0.26		0.20	0.14	
41-50	0.21	0.30		0.27	0.70		0.28	0.60		0.18	0.15	
51-60	0.27	0.36		0.32	0.68		0.28	0.63		0.21	0.17	
61-70	0.43	0.49		0.60	0.80		0.43	0.69		0.26	0.20	
71-80	0.48	0.41		1.19	1.15		0.86	0.84		0.28	0.18	
81-90	0.55	0.46		1.37	1.12		1.21	0.75		0.38	0.23	
91-100	0.70	0.45		1.70	1.24		1.52	0.87		0.53	0.29	
Average	*0.47*	*0.38*		*0.86*	*0.82*		*0.79*	*0.63*		*0.36*	*0.23*	
Birch												
1-10	0.04	0.47		0.08	0.78		0.07	0.70		0.03	0.34	
11-20	0.05	0.42		0.07	0.55		0.05	0.46		0.05	0.38	
21-30	0.06	0.44		0.07	0.55		0.06	0.50		0.05	0.33	
31-40	0.07	0.40		0.07	0.49		0.06	0.46		0.05	0.33	
41-50	0.05	0.33		0.06	0.40		0.05	0.34		0.04	0.28	
51-60	0.04	0.23		0.04	0.26		0.04	0.23		0.03	0.22	
61-70	0.03	0.21		0.03	0.21		0.03	0.20		0.03	0.20	
71-80	0.02	0.14		0.01	0.12		0.04	0.27		0.02	0.20	
81-90	0.02	0.12		0.01	0.08		0.04	0.26		0.02	0.20	
91-100	0.01	0.10		0.01	0.10		0.03	0.22		0.02	0.21	
Average	*0.04*	*0.28*		*0.04*	*0.34*		*0.05*	*0.36*		*0.04*	*0.28*	

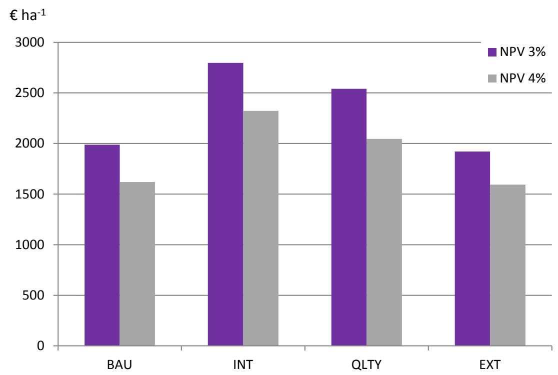
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3

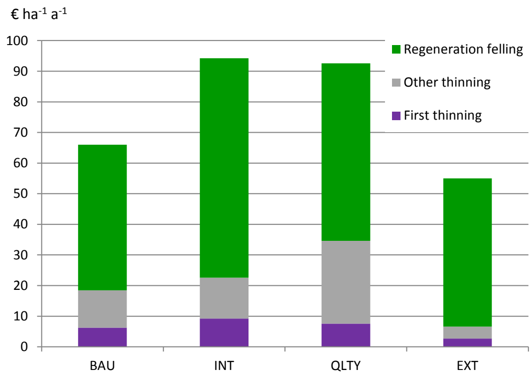


PROFITABILITY

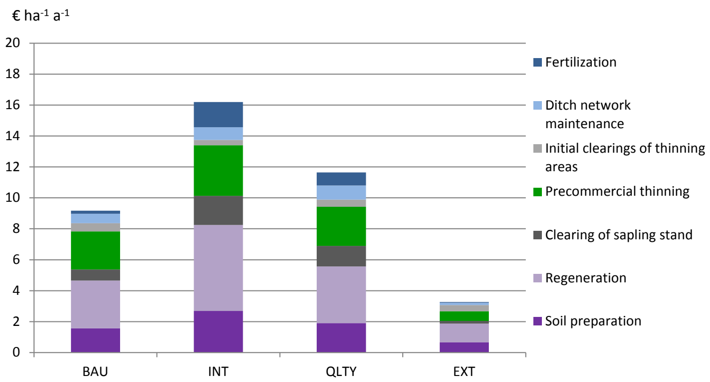
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



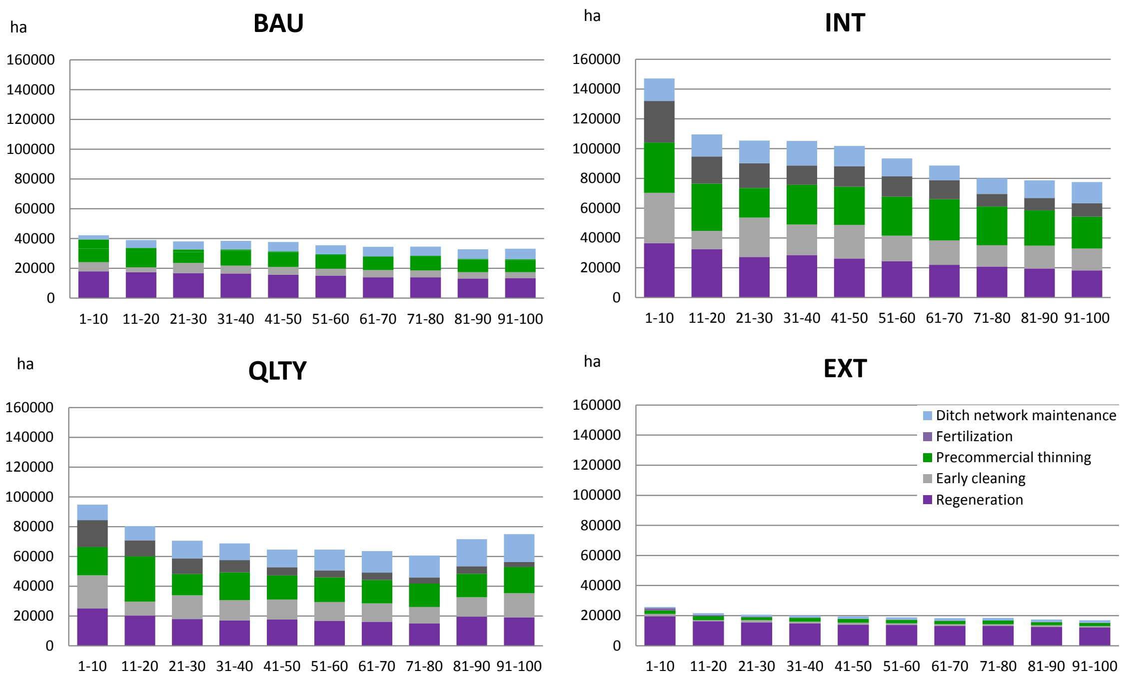
Appendix 13: Forestry centre Pohjois-Pohjanmaa

FOREST MANAGEMENT PRACTICES

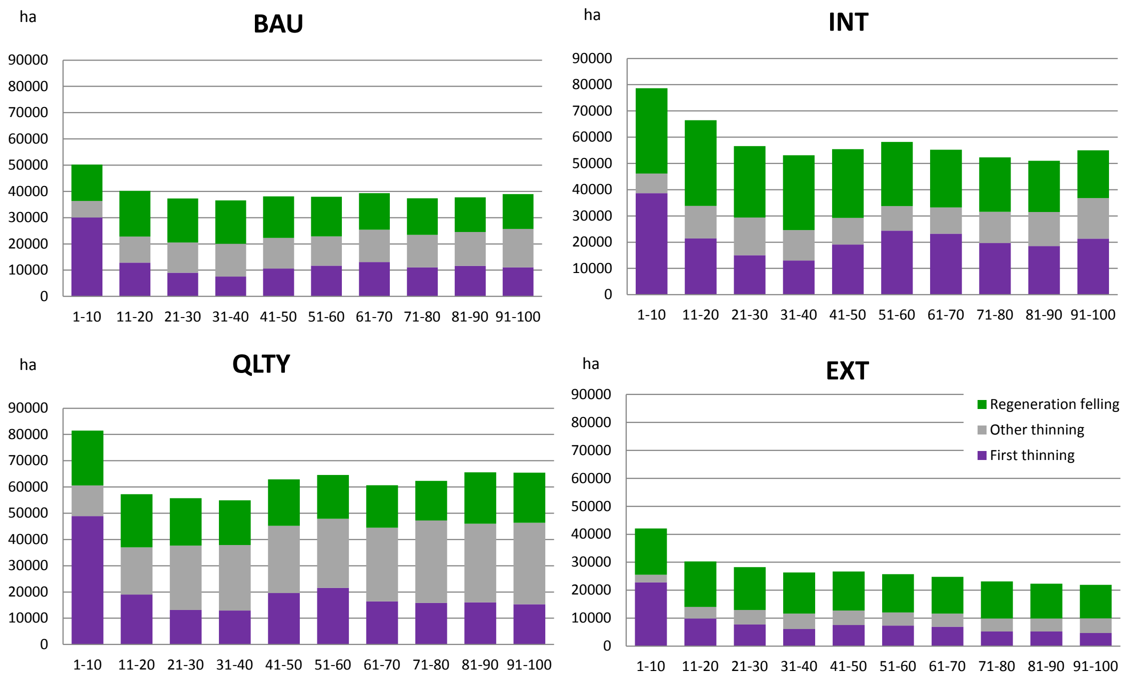
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	11502	24321	14408	6037
Natural regeneration	3157	37	3180	7737
Total regeneration	*14659*	*24358*	*17588*	*13773*
Early cleaning	4935	19336	14181	1234
Precommercial thinning	9477	26353	19243	2369
Fertilization	1264	13455	7151	316
Ditch network maintenance	5777	13248	13442	1450
First thinning	13503	22342	20168	8581
Other thinning	12334	12473	27023	4914
Regeneration fellings	15324	25818	18882	14428
Total fellings	*41161*	*60633*	*66072*	*27924*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

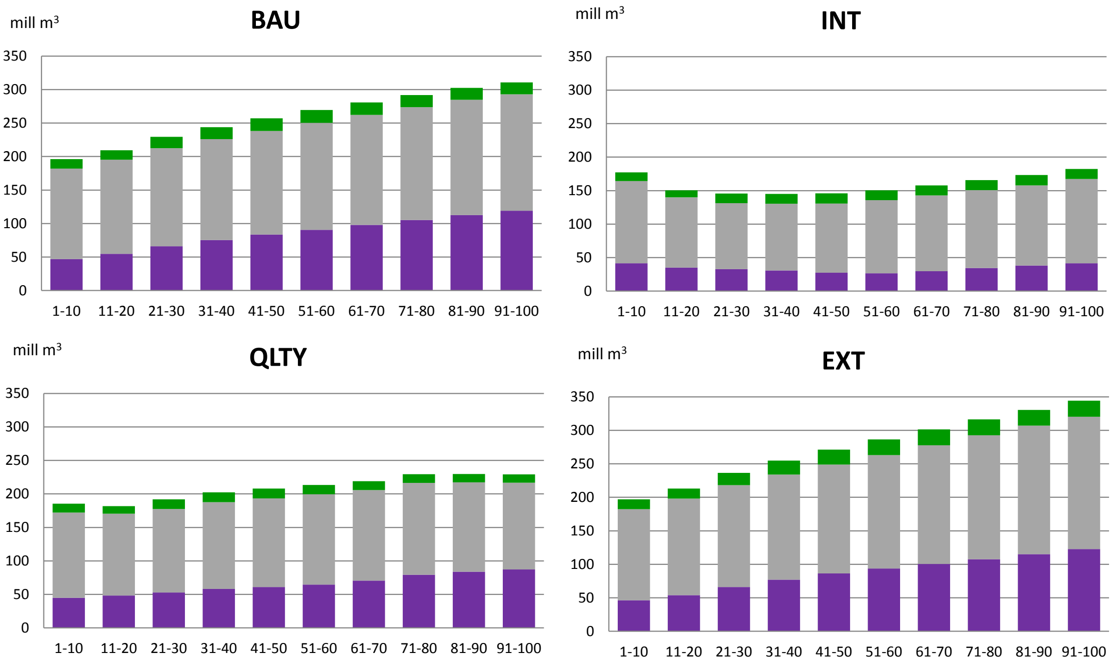
Year	BAU	INT	QLTY	EXT
1-10	122	224	170	120
11-20	137	240	180	123
21-30	139	201	181	122
31-40	140	202	179	123
41-50	140	201	202	126
51-60	140	202	200	125
61-70	138	207	207	124
71-80	142	215	212	125
81-90	144	224	263	126
91-100	150	221	265	128
Average	*147*	*225*	*220*	*131*

Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

	BAU			INT			QLTY			EXT		
All tree species	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	1.38	2.62	0.35	2.36	4.80	1.68	1.74	4.14	1.10	1.39	1.98	1.08
11-20	0.92	1.60	0.21	1.29	2.66	0.76	1.19	2.28	0.57	0.84	1.20	0.48
21-30	1.66	2.35	0.36	2.81	4.13	1.50	2.26	2.85	0.93	1.50	1.87	0.62
31-40	1.66	2.39	0.34	2.69	3.95	1.40	2.49	2.91	0.94	1.50	1.93	0.63
41-50	1.71	2.29	0.34	2.34	3.53	1.16	2.34	2.78	0.84	1.50	1.87	0.60
51-60	1.75	2.23	0.32	2.16	3.32	1.12	2.17	2.66	0.75	1.56	1.84	0.56
61-70	1.74	2.27	0.32	2.33	3.54	1.25	2.27	2.84	0.78	1.53	1.84	0.56
71-80	1.69	2.22	0.33	2.33	3.55	1.17	2.41	3.01	0.81	1.52	1.79	0.62
81-90	1.74	2.26	0.34	2.32	3.56	0.97	2.55	3.20	0.84	1.57	1.80	0.63
91-100	1.77	2.26	0.32	2.34	3.56	0.98	2.54	3.14	0.79	1.59	1.81	0.60
Average	*1.84*	*2.38*	*0.34*	*2.72*	*3.66*	*1.21*	*2.91*	*3.21*	*0.92*	*1.64*	*1.89*	*0.60*
Scots pine												
1-10	0.73	1.31		1.25	2.32		0.92	1.97		0.71	0.87	
11-20	0.96	1.28		1.84	2.66		1.25	1.64		0.85	0.92	
21-30	1.06	1.31		1.72	2.41		1.50	1.73		0.92	0.99	
31-40	1.24	1.41		1.78	2.44		1.60	1.75		1.08	1.11	
41-50	1.34	1.49		1.84	2.27		1.92	1.86		1.19	1.19	
51-60	1.31	1.45		1.62	1.97		1.94	1.75		1.22	1.20	
61-70	1.16	1.38		1.15	1.55		1.87	1.57		1.15	1.17	
71-80	1.13	1.35		0.81	1.24		1.62	1.39		1.14	1.18	
81-90	1.01	1.28		0.62	0.98		1.77	1.44		1.00	1.07	
91-100	1.02	1.33		0.52	1.01		1.65	1.38		0.89	1.01	
Average	*1.11*	*1.39*		*1.32*	*1.90*		*1.67*	*1.68*		*1.03*	*1.09*	
Norway spruce												
1-10	0.59	0.47		0.98	0.82		0.70	0.64		0.61	0.42	
11-20	0.61	0.34		0.86	0.51		0.93	0.45		0.56	0.30	
21-30	0.55	0.30		0.51	0.33		0.74	0.36		0.48	0.27	
31-40	0.41	0.26		0.44	0.32		0.58	0.40		0.38	0.21	
41-50	0.33	0.31		0.41	0.75		0.55	0.78		0.32	0.20	
51-60	0.37	0.43		0.64	1.20		0.48	1.05		0.29	0.22	
61-70	0.49	0.56		1.28	1.63		0.79	1.14		0.36	0.27	
71-80	0.65	0.56		1.84	1.82		1.23	1.21		0.41	0.26	
81-90	0.84	0.61		2.29	1.86		1.92	1.38		0.59	0.35	
91-100	0.94	0.61		2.39	1.84		2.10	1.39		0.75	0.40	
Average	*0.67*	*0.49*		*1.33*	*1.21*		*1.17*	*0.96*		*0.55*	*0.33*	
Birch												
1-10	0.07	0.85		0.13	1.67		0.12	1.53		0.06	0.69	
11-20	0.09	0.73		0.12	0.97		0.08	0.77		0.08	0.64	
21-30	0.10	0.69		0.11	0.79		0.10	0.68		0.09	0.62	
31-40	0.09	0.60		0.11	0.78		0.09	0.68		0.08	0.52	
41-50	0.07	0.46		0.07	0.54		0.08	0.56		0.06	0.41	
51-60	0.05	0.39		0.05	0.40		0.06	0.46		0.05	0.38	
61-70	0.04	0.37		0.03	0.24		0.05	0.34		0.04	0.38	
71-80	0.03	0.29		0.02	0.14		0.04	0.25		0.04	0.34	
81-90	0.03	0.29		0.02	0.11		0.04	0.26		0.03	0.33	
91-100	0.03	0.27		0.02	0.10		0.04	0.25		0.04	0.33	
Average	*0.06*	*0.50*		*0.07*	*0.55*		*0.07*	*0.57*		*0.06*	*0.47*	

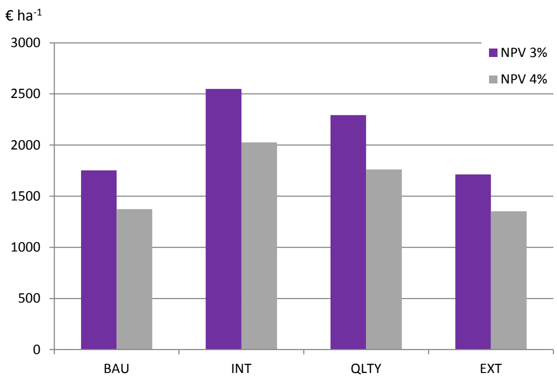
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3

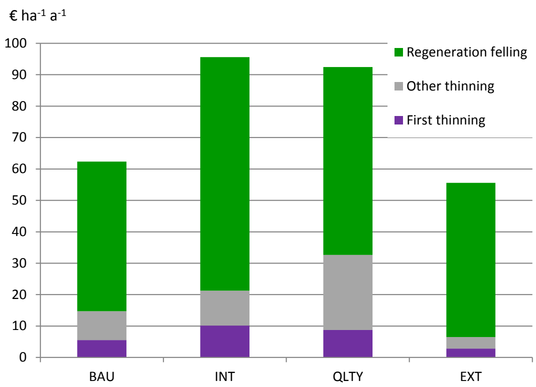


PROFITABILITY

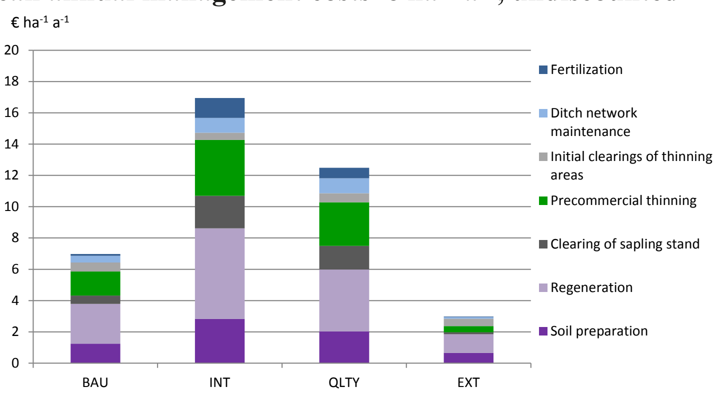
Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted



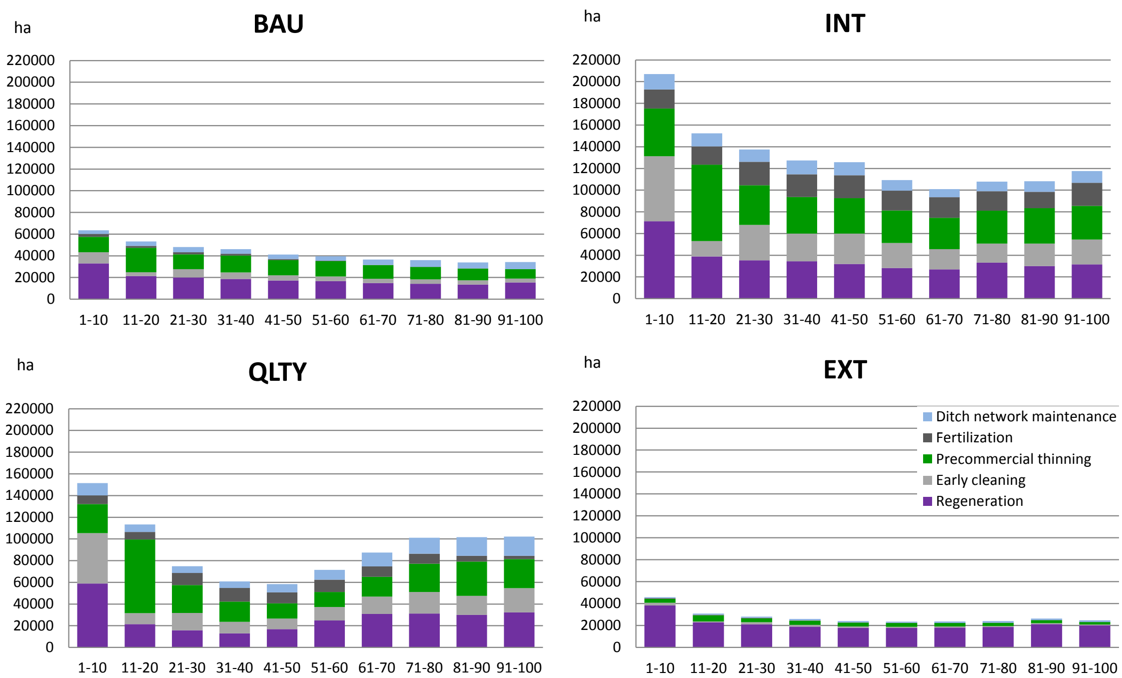
Appendix 14: Forestry centre Lappi

FOREST MANAGEMENT PRACTICES

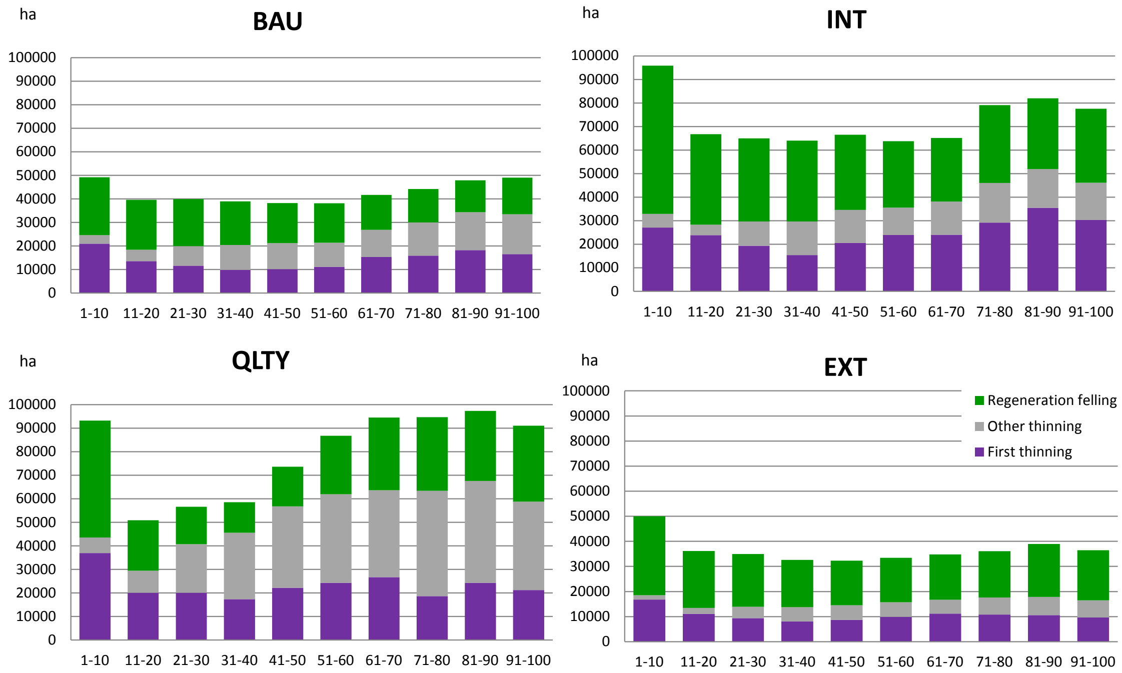
Annual areas of forest management practices, ha

	BAU	INT	QLTY	EXT
Artificial regeneration	14611	34424	18790	7817
Natural regeneration	3034	66	7437	12587
Total regeneration	*17645*	*34490*	*26226*	*20404*
Early cleaning	5167	26057	18405	1292
Precommercial thinning	13720	38715	28330	3430
Fertilization	920	18057	8320	230
Ditch network maintenance	4819	10601	10677	1230
First thinning	16215	27269	24236	11445
Other thinning	11738	13522	31532	5562
Regeneration fellings	17816	35279	26762	20921
Total fellings	*45769*	*76069*	*82529*	*37929*

Annual areas of silvicultural practices during the years 2010-2110, ha



Annual area of cuttings during the years 2010-2110, ha



HARVESTING REMOVALS

Temporal variation and mean of gross stumpage earnings during the years 2010-2110, mill €, undiscounted

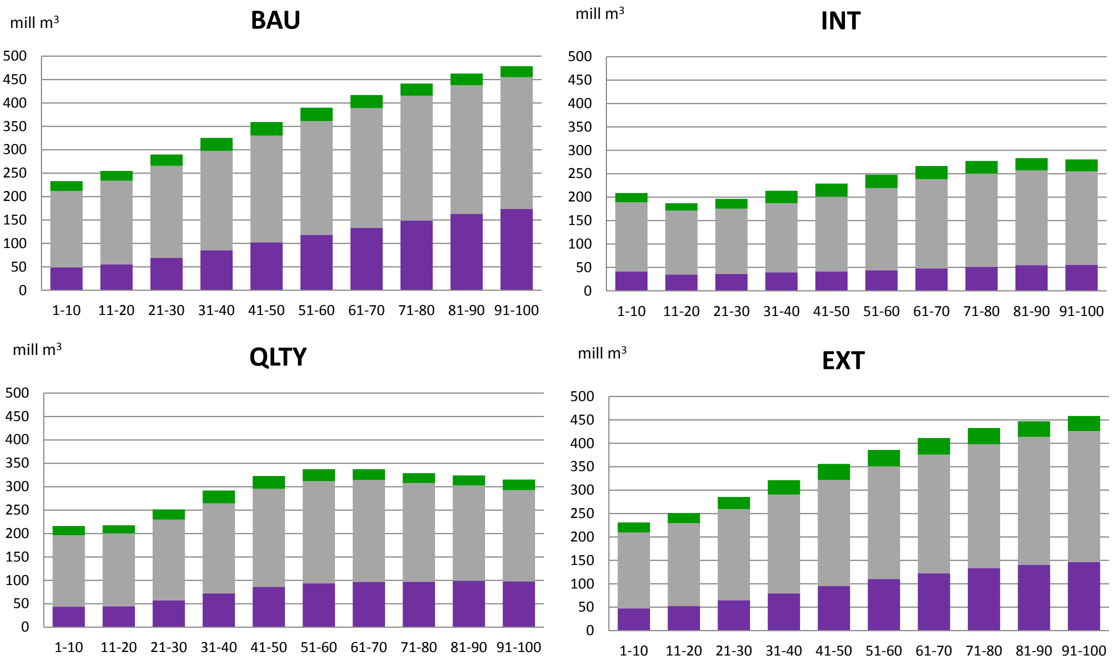
Year	BAU	INT	QLTY	EXT
1-10	102	240	196	117
11-20	107	177	116	108
21-30	100	176	106	105
31-40	102	177	118	107
41-50	102	172	159	107
51-60	105	174	220	112
61-70	109	176	268	130
71-80	114	240	283	138
81-90	120	255	284	163
91-100	140	266	292	165
Average	*116*	*213*	*213*	*130*

Temporal variation and mean of annual harvesting removals during the years 2010-2110, mill m^3 a^{-1}

All tree species	BAU			INT			QLTY			EXT		
	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood	Logs	Pulp-wood	Energy wood
1-10	1.10	2.21	0.37	2.47	4.92	2.13	1.99	4.26	1.66	1.30	2.15	0.86
11-20	0.71	1.26	0.23	1.02	2.43	0.88	0.90	1.85	0.64	0.70	1.09	0.46
21-30	1.22	1.94	0.37	1.82	3.60	1.51	1.29	2.16	0.83	1.23	1.83	0.65
31-40	1.10	1.99	0.34	1.87	3.60	1.47	1.20	2.26	0.78	1.22	1.92	0.65
41-50	1.07	2.08	0.33	1.81	3.62	1.35	1.13	2.32	0.67	1.17	1.89	0.59
51-60	1.04	1.99	0.28	1.67	3.38	1.19	1.18	2.27	0.57	1.14	1.78	0.54
61-70	1.12	2.03	0.29	1.85	3.57	1.26	1.37	2.34	0.58	1.22	1.84	0.59
71-80	1.09	1.97	0.29	1.88	3.79	1.29	1.52	2.56	0.60	1.16	1.79	0.61
81-90	1.13	2.03	0.28	1.77	3.65	1.13	1.88	3.03	0.66	1.21	1.85	0.58
91-100	1.19	2.08	0.29	1.77	3.49	1.04	2.34	3.51	0.77	1.29	1.96	0.63
Average	*1.30*	*2.27*	*0.31*	*2.33*	*4.07*	*1.34*	*2.61*	*3.57*	*1.01*	*1.51*	*2.17*	*0.70*
Scots pine												
1-10	0.67	1.04		1.48	2.26		1.20	1.90		0.78	0.97	
11-20	0.77	1.02		1.24	2.18		0.74	1.08		0.75	0.85	
21-30	0.72	1.20		1.41	2.38		0.78	1.36		0.79	0.99	
31-40	0.83	1.39		1.41	2.52		0.93	1.50		0.81	1.08	
41-50	0.91	1.48		1.37	2.58		1.35	1.92		0.93	1.28	
51-60	0.92	1.39		1.54	2.46		2.12	2.48		1.00	1.31	
61-70	0.94	1.55		1.52	2.36		2.52	2.73		1.17	1.48	
71-80	0.96	1.48		1.99	2.70		2.80	2.75		1.24	1.55	
81-90	0.95	1.52		1.63	2.34		2.53	2.37		1.51	1.79	
91-100	1.00	1.58		1.45	1.85		2.51	2.19		1.40	1.65	
Average	*0.88*	*1.44*		*1.49*	*2.36*		*1.81*	*2.06*		*1.06*	*1.34*	
Norway spruce												
1-10	0.41	0.49		0.92	1.14		0.73	0.94		0.50	0.52	
11-20	0.41	0.36		0.52	0.55		0.51	0.42		0.44	0.38	
21-30	0.30	0.31		0.34	0.42		0.32	0.32		0.33	0.32	
31-40	0.27	0.25		0.39	0.40		0.40	0.34		0.37	0.31	
41-50	0.19	0.25		0.35	0.54		0.49	0.65		0.25	0.24	
51-60	0.22	0.36		0.26	0.74		0.50	0.88		0.24	0.26	
61-70	0.24	0.38		0.36	0.83		0.70	1.13		0.33	0.28	
71-80	0.32	0.44		0.70	1.34		0.79	0.99		0.37	0.31	
81-90	0.41	0.57		1.27	1.86		1.07	1.37		0.42	0.34	
91-100	0.69	0.61		1.70	2.15		1.28	1.41		0.61	0.41	
Average	*0.40*	*0.45*		*0.80*	*1.13*		*0.76*	*0.91*		*0.41*	*0.36*	
Birch												
1-10	0.03	0.68		0.08	1.53		0.07	1.42		0.03	0.66	
11-20	0.04	0.56		0.05	0.87		0.03	0.66		0.04	0.61	
21-30	0.05	0.57		0.05	0.82		0.03	0.64		0.05	0.59	
31-40	0.03	0.39		0.06	0.65		0.04	0.50		0.04	0.44	
41-50	0.03	0.30		0.05	0.52		0.04	0.46		0.03	0.34	
51-60	0.03	0.30		0.04	0.39		0.04	0.45		0.03	0.38	
61-70	0.02	0.24		0.03	0.32		0.06	0.50		0.03	0.36	
71-80	0.03	0.28		0.03	0.30		0.05	0.50		0.03	0.39	
81-90	0.02	0.24		0.02	0.25		0.05	0.50		0.03	0.46	
91-100	0.02	0.24		0.02	0.23		0.05	0.45		0.03	0.42	
Average	*0.03*	*0.38*		*0.04*	*0.58*		*0.05*	*0.60*		*0.03*	*0.48*	

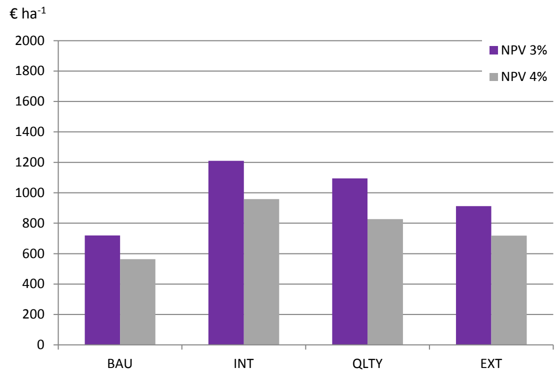
GROWING STOCK

Growing stock during the years 2010-2110, mill m^3

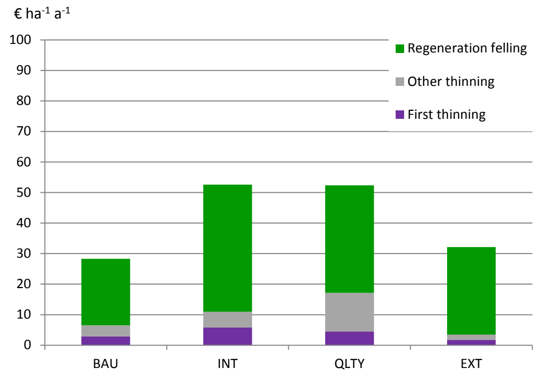


PROFITABILITY

Net present value at 3% and 4% discount rates



Mean annual incomes € ha^{-1} a^{-1}, undiscounted



Mean annual management costs € ha^{-1} a^{-1}, undiscounted