Validation of the European Forest Information Scenario Model (EFISCEN) and a Projection of Finnish Forests

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Large-scale forest scenario models are intensively used to make projections of forest areas of up to hundreds of millions of hectares. Within Europe, such projections have been done for 11 countries at the individual national scale, most often to foresee the long-term implications of the ongoing forest management. However, the validity of the models has rarely been tested.

The aim of this study was 1. to validate the European Forest Information SCENario model (EFISCEN) by running it on historic Finnish forest inventory data, 2. to improve the model based on the validation, and 3. to project the Finnish forest development till 2050 with the improved model under alternative scenarios.

The results of the validation showed that EFISCEN is capable of making reliable large-scale projections of forest resources for periods up to 50–60 years. Based on the validation, the model was improved concerning simulation of age development, thinning regimes and regrowth after thinning. The projection of the Finnish forests till 2050 with the improved model presented a maximum sustainable felling level of around 70 million m^3 per year. That provides an average growing stock of 106 m^3 ha^{-1} in 2050 and a net annual increment of 3.6 m^3 ha^{-1} y^{-1}. If the current trend towards more nature oriented forest management continues and 1.39 million ha of forests have been set aside additionally for nature reserves by 2050, the felling level could meet a realistic demand of 57 million m^3 per year in 2050. Under the latter regime the average growing stock will have grown to 160 m^3 ha^{-1} in 2050.

Keywords European forests, EFISCEN, historic forest inventory data, Finland
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1 Introduction

Planning and decision making have always been at the core of forestry research due to the long rotations, long-term impact of management, and the wide range of goals in forestry (Davis and Johnson 1987, von Gadow and Bredenkamp 1992). Now that environmental, biodiversity and recreational concerns have become equally as, or even more important than timber production, the planning problem has become both more complicated as well as interesting. The planning tools have developed accordingly, taking into account these other values of the forest (Lohmander 1987, Holland et al. 1994, Kangas et al. 1996, Szaro et al. 1998, Arthaud and Rose 1996, Naesset 1997, Riitters et al. 1997, Martell et al. 1998, Nabuurs et al. 1998b, Päivinen et al. 1999). However, despite massive forest inventories and a fast development of computerised models, the controversy over future forest development seems to have increased only (Nilsson et al. 1999).

European scale forest scenario studies have been carried out rarely. One exception is a study by Nilsson et al. (1992). Another one is the European Timber Trend Studies of which the fifth one has been completed in the early nineties (Pajuoja 1995, UN-ECE/FAO 1996). However, the latter used a rather simple and static approach for the forest resource projection. Also, the methods differed greatly between the countries. A lack of dynamic long-term predictions is surprising because European forests are the most intensively used forests in the world. They cover only 4 % of the world's forests but provide 13 % of the current global harvest of wood products (Pajuoja 1995). Apart from wood production, Europe's forests are a refuge for nature and are of high importance as a recreational area for the urbanised European population (Konijnendijk 1999). Also, the long-term impacts of climate change and the future role of European forests in the global carbon cycle are uncertain.

Complicating for harmonised projections of European forests is that they are scattered over 30 countries of which only 11 (Austria, Belgium, Czech Republic, Finland, France, Germany, Hungary, Ireland, The Netherlands, Norway, and Sweden) have their own national forest scenario model (Nabuurs and Päivinen 1996). These national scale studies cannot be compared because data, methods and reporting formats differ greatly between the countries. Therefore, European scale projections would benefit from one dynamic and harmonised projection method.

The above outline on issues in European forests shows that there is a need for harmonised European scale forest resource projections. In order to use and further develop the model that was selected for a new European scale projection (Sallnäs 1990, Nilsson et al. 1992), it is important to understand the accuracy of the predictions. The aim of this study was therefore to 1. validate the European Forest Information SCENario model (EFISCEN) by running it on historic Finnish forest inventory data, 2. improve the model based on the validation, and 3. project the Finnish forest development till 2050 with the improved model under alternative scenarios and to compare those results to other projections made for Finnish forests.

2 Methods

2.1 Approach

The reason to choose Finland for this study was that both inventory data of the 1920's and several projections based on different methods were available. The validation of the EFISCEN model was carried out using those historical forest inventory data of Finland. The First National Forest Inventory (NFI I) was carried out in 1921–1924 (Ilvessalo 1927). The results of that inventory were used as input for the model. The outcome of the simulation was compared with the results of the seven following NFI's. Based on the comparison, improvements were made in the model. The improved EFISCEN model was then parameterised again, but now based on 1990 inventory data. Simulations were done for three alternative scenarios till 2050.

The following scenarios were run for the period 1990–2050:

1 Business as usual: The input data cover 19.92 million ha out of 20.1 million ha of forest land (Finnish Statistical Yearbook of Forestry 1998).

The scenario consists of a continuation harvesting at the 1990 level. Although fellings fluctuated in the 1990's, we used an annual total felling of 55.1 million m^3. Fellings were set at 42.4 million m^3 y^{-1} for conifers and 11.6 million m^3 y^{-1} for broadleaves. A proportion of thinnings out of total fellings of 40 % was assumed. No forest expansion was assumed.

2 Maximum sustainable production: Maximum sustainable felling levels under which the average standing volume did not decrease were found through a trial and error approach.

3 In the multi-functional scenario we assume that the fellings in conifers will increase by 0.5 % per year during the first 20 years. After that the felling level stabilises; fellings of the deciduous species is kept constant at the ETTS (European Timber Trend Studies) level of 1990 (Pajuoja 1995). This assumption of a gradual increase in fellings reflects: 1. A reduced interest of owners in wood production because many of them do not depend on the forest for their income anymore; 2. A higher interest of owners in the nature values of the forest; and 3. On the other hand, a higher demand for wood because of large-scale use of wood for bioenergy. All together we assume that this leads to an increasing demand as mentioned above.

In the scenario 3, new management regimes were adopted in order to pay more attention to current trends in forest management towards more nature oriented management, i.e. all forests of more than 170 years old are taken out of production. This is initially an area of 582 000 ha but, during the simulated period, this area may increase because the forest may get older. Also the rotation length of all species is elongated by 20 years and the share of thinnings out of total fellings is increased to 50 %. The species distribution is kept as it was in 1990. This is done through regenerating a final cut area with the same species as there was before the final cut. Some forest area expansion is part of this scenario because of marginal agricultural land being available; 96 000 ha is afforested in 2000 and another 96 000 ha in 2010, equally distributed over all species.

2.2 The EFISCEN Model

EFISCEN is an area-based matrix model (Sallnäs 1990, Nilsson et al. 1992). The model is especially suitable for analyses of large areas, e.g. for a region or a country. The minimum area unit is 10 ha. EFISCEN uses time steps of five years. In a country, forest types can be distinguished by region, owner, site class and tree species, depending on how detailed the input data are.

The forest state is depicted as an area distribution over age and volume classes in a matrix. For each forest type that can be distinguished, a separate matrix is set up. This matrix consists of age and volume classes (10 for the volume dimension and 30 for the age dimension).

To calculate the volume distribution, three variables are used: (a) the mean volume per hectare, (b) the coefficient of variation in volume per hectare, and (c) the correlation between volume per hectare and age or transformations of age. The calculation is performed in four steps.

1. Calculate the variance in volume per hectare, using mean volume per hectare and the coefficient of variation:

$$s_v^2 = (\overline{V} * Cv)^2 \quad (1)$$

where Cv is the coefficient of variation, $\overline{V}$ is the mean volume per hectare, and s_v^2 is the variance in volume per hectare.

2. Calculate the conditional variance with a given mean age:

$$s_{v(T)}^2 = (1 - r^2) S_v^2 \quad (2)$$

where $s_{v(T)}^2$ is the variance in volume per hectare with a given mean age and r^2 is the coefficient of correlation between age and volume per hectare.

3. Calculate the ratio of volume variance and mean age ($\overline{T}$):

$$k = S_{v(\overline{T})}^2 / \overline{T} \quad (3)$$

Use this ratio to calculate the variance in each age class. The variance of volume in age class i is then

$$s_{Ti}^2 = k\overline{Ti} \quad (4)$$

where $\overline{T}_i$ is the mid point of each age class.

The class limits for the volume classes are calculated using the largest volume per hectare plus three times the largest standard deviation as the class limit for the largest volume class. This range is then divided into a sequence of volume classes. The growth dynamics are simulated as the five-year net increment as a percentage of the standing volume. The negative exponential growth models are depicted by the following function:

$$I_{vf} = a_0 + \frac{a_1}{T} + \frac{a_2}{T^2} \quad (5)$$

where I_{vf} is the five-year volume increment in percent of the standing volume, T is the stand age in years, and a_0, a_1, a_2 are coefficients. These coefficients were obtained by a regression of the five-year net increment on the standing volume.

The mean volume in an age-volume cell will deviate from the mean volume series. Accordingly, the percent volume increment will also deviate from the value given by the function, which means that some corrections must be made. The correction is made according to

$$I_{va} = I_{vf}\left(\frac{V_m}{V_a}\right)^{\beta} \quad (6)$$

where I_{va} is the five-year percent volume increment for actual standing volume, I_{vf} is the five-year percent volume increment given by the function, V_a is the actual standing volume (cubic meters per hectare), and V_m is the mean standing volume in the input data volume series. The relationship between the relative standing volume and the relative volume increment is described by parameter β. The function of this β is that high stocked cells do not start to grow exponentially fast. β is estimated at 0.4 (Sallnäs 1990).

Ageing is incorporated as a function of time up to the point of clearcutting. Management is controlled at two levels in the model. First, a basic management for each forest type, like thinning and final felling regimes, are incorporated. These regimes are seen as constraints of cutting levels. The thinning regimes are incorporated as the range of age classes at which a thinning can be carried out. Final felling regimes for each age class are incorporated as a probability that a final felling can in principle be carried out. Second, the required total volume of harvest from the thinnings and the final fellings are specified for the whole country for each species group for each time period. Thinnings are carried out in the matrix of each forest type by preventing part of the area in a cell from moving to a higher volume class. The prevented transition is the thinned volume. Areas in the top volume class cannot grow to a higher volume class, indirectly representing a balance between increment and mortality (i.e. fully stocked stands). The fact that these areas cannot move to a higher volume class also means that they cannot be thinned.

2.3 Data

The results of the first National Forest Inventory (NFI I) of Finland (Ilvessalo 1927) were used as input data for the model (see Annex I for the way in which forest types were distinguished). The results of the seven following NFI's were used to validate the model projections. The latter forest inventory results were obtained from Ilvessalo (1943) for NFI II, Tiihonen (1968) for NFI's III & IV and the Finnish Statistical Yearbook of Forestry (1997) for NFI's V to VIII. The Finnish Forest Research Institute (Metla) provided the detailed forest inventory data of NFI VIII (1986–1992) that were used to make the projections till 2050 (see Annex I for forest types).

The Finnish forests largely consisting of Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.), birch (*Betula pendula* Roth and *B. pubescens* Ehrh.), and aspen (*Populus tremula* L.), have changed considerably since the 1920's. The management has evolved from a selective cutting regime (resulting in understocked, over-mature forests) into a clear felling type of management with thinning from below. Drainage and fertilisation during the 1960's and 1970's had an impact on the increment level. The general development of the Finnish forest resource from 1923 to 1993 is characterised by a real decline in area and growing stock from 1923 till approximately 1960. Since 1960 the trends have been an expansion of area and a considera-

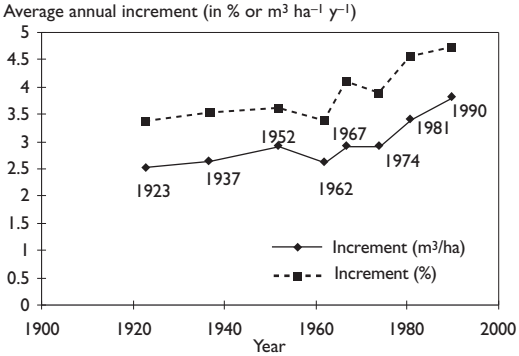

Fig. 1. Development of average net annual increment per hectare in Finland from 1923 to 1990 on productive forest land (Ilvessalo, 1927, 1940, 1955, Tiihonen 1968, Yearbook of forest statistics 1989, Finnish statistical yearbook of forestry 1997).

ble build-up of growing stock due to both an increase in increment and undercutting of this increment (Kuusela and Salminen 1991, Finnish Statistical Yearbook of Forestry 1997, Schelhaas et al. 1999). The average increment per hectare has increased especially since 1967 (Fig. 1). Mielikäinen and Sennov (1996) and Mielikäinen and Timonen (1996) conclude that it is very likely that the increase can partly be explained by changes in the stand structure and the adoption of new silvicultural practices such as fertilisation and drainage.

3 Results

3.1 Model Validity

For the simulation over time, the assessment of the initial distribution of areas over the matrix is essential. To check the accuracy of these initial matrices as assessed by the model's matrix generator, the growing stock per age class over the volume classes was recalculated from the simulated matrices (Fig. 2).

According to the NFI results, the average growing stock in each age class has increased between 1923 and 1990, especially in the medium aged forests (Fig. 2). So, forests of the same age contain more volume now. The results of the simulation for 1963 show a different picture. For

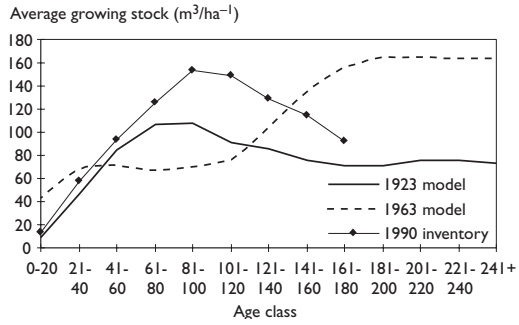

Fig. 2. Growing stock per age class as assessed by the matrix generator and as recalculated for 1923, simulated for 1963 and inventoried in 1990.

Fig. 3. Age class distributions from the validation part of the study.

1923 the initial matrices do show a decrease in growing stock in age classes older than 70 years, representing the understocked, over-mature forests that had developed by that time. In 1963 the simulated average growing stock has risen above the results of NFI VIII for 1990 for the first two age classes. In the middle age classes the average growing stock is lower than the values in NFI's I and VIII. Then, in the oldest age classes the simulated volume increases. This trend in volume per age class is partly a consequence of this type of matrix simulation where the lower cells represent sites of lower fertility. Thus after a thinning the area moves to a cell with a lower growth rate and consequently has a decreased growth rate. The thinning in the model takes place in age classes of 21–40 years to 121–140 years. The difference in the accuracy between the age classes with thinning (21–140 years) and without thinning (< 20 years and > 140 years) is clearly discernible in Fig. 2. The special type of

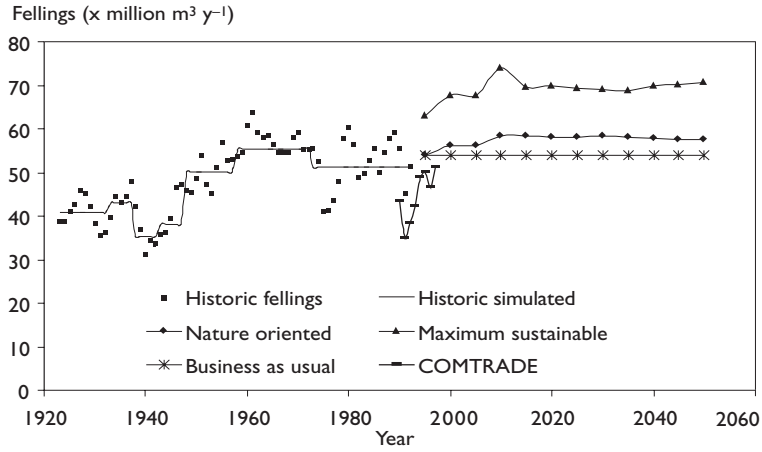

Fig. 4. Historic (statistics and simulated) and projected felling levels (Ilvessalo, 1927, 1940, 1955, Tiihonen 1968, Yearbook of forest statistics 1989, Finnish statistical yearbook of forestry 1997).

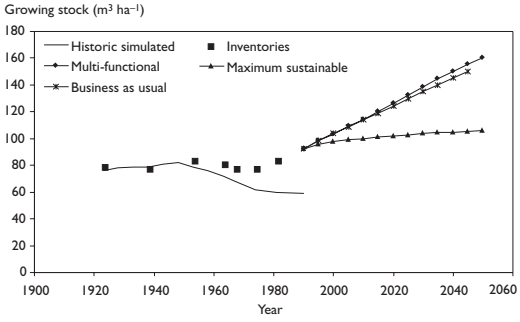

Fig. 5. Development of average growing stock of forests of both the validation part of the study and the projection part.

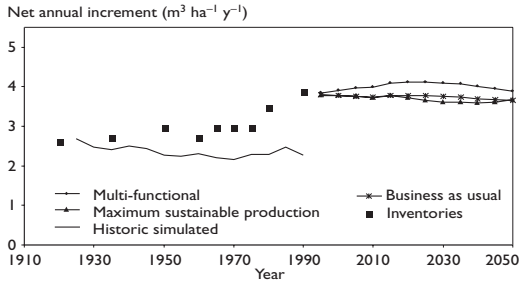

Fig. 6. Development of mean net annual increment of forests of both the validation part of the study and the projection part.

management of selective cutting early this century is thus not accurately represented in the simulations.

Partly due to the previously mentioned deviations in the volume distribution and its consequences on the annually regenerated area, the age class distribution simulated for 1963 deviates from the inventory data (Fig. 3). The simulated area for the bare-forest-land class (0–10 years) and the age class of 11–20 years are too large. The area in age classes of 41–50 and 71–80 years is too small. In the older age classes the simulated area is larger than in the NFI's. Especially towards the end of the simulation period, the clear felled area appeared to be too large. This is caused by the fact that the final felling regimes were defined by age class, irrespective of the volume classes. Thus, areas with low volumes are being harvested at the same frequency as areas with high volumes. This creates a large area with regeneration fellings because the amount of felled volume is used as input in the EFISCEN (Fig. 4). Also, the fact that the model works with strict felling regimes creates the gradual decrease in area per age class as given in Fig. 3. Deviations are also caused by the fact that EFISCEN calculates with 5-year time steps while the inventory data are given by 20-year age classes.

In the historic simulation the development of total standing volume of all tree species is close to reality (maximum 8 % overestimated till 1953, Fig. 5) although deviations for the tree species

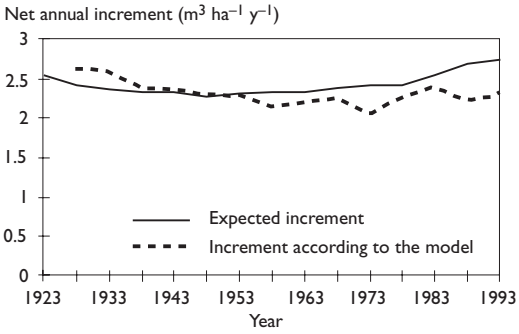

Fig. 7. Average annual increment of Scots pine as simulated by the model and as recalculated from the age class distribution as simulated by the model. The expected increment is calculated with the current increment per age class in NFI I and the age class distribution as simulated by the model.

differed. After 1953 the simulated total volume tends to decrease. This is caused by the decreasing increment in the model overall and the transient change in the increment of spruce that could not be followed by the model.

The increment as simulated by the model for 1925 is 2.52 m^3 ha^{-1} y^{-1} (Fig. 6). Calculated from the forest inventory input file, the average annual increment was also 2.52 m^3 ha^{-1} y^{-1}. However, after 1963 the increment level as reported by the NFI's starts to increase. This was not simulated and results in an underestimation of 21 % in 1963. Since the growth functions were based on the 1920's increment and do not take into account any transient change of growth, the model is not capable of simulating the transient increasing growth rate.

Another explanation of a simulated decrease in the total increment can be the development of the age class distribution. When the age class distribution deviates from reality also the increment will deviate. To determine this latter fraction, the average annual increment simulated by the model and the expected increment level for pine (recalculated based on the simulated age class distribution but with raw increment data per age class) was assessed (Fig. 7). The increment calculated by the model underestimated the expected increment for Scots pine. This was caused by the lack of regrowth dynamics after thinning in the model. The same underestimation was shown for Norway spruce. For birch the simulated and expected increment fitted very well. This is due to the fact that in the case of birch the proportion of thinnings in total fellings was small (Schelhaas et al. 1999).

3.2 Improvements Made in EFISCEN

In addition to the inability of the model to follow transient growth changes, the following shortcomings were found in the historic simulations. The underestimated growth after thinning caused the total increment to be underestimated. This resulted in a volume class distribution which is not very realistic and, thus, in too large clearcut areas. The clearcut areas also differed because the final felling regimes were defined according to age only, not according to volume class, and because the historic management of selective cutting was not represented accurately. All of these had implications for the development of age class distribution. Deviations in the age class distributions, in turn, affect the total increment level.

Regular thinnings increase the total growth in the long term (Jonsson et al. 1993). Therefore a re-growth boost after each thinning was introduced in EFISCEN. Normally after a thinning, an area was prevented from moving one volume class up with its accompanying lower growth rate. This was changed by introducing a 'thinned status' to areas thinned in that time step. This area receives a fixed and higher chance to move one volume class up in the next time step. The thinning boost was quantified from yield tables at 0.4 (Koivisto 1959). It means that of all thinned areas, a fraction of 0.4 will move one volume class up. As soon as the forest area has moved to the next volume class, it will no longer be counted as a thinned area. The area that is in the thinned status cannot be subject to thinning. If the area of thinned status reaches an age at which thinnings are not carried out normally, it will no longer keep the thinned status. To initialize the model we set the area in the thinned status at 30 % of all forest area in Finland (Koivisto 1959, Yearbook of Forest Statistics 1989, Finnish Statistical Yearbook of forestry 1997).

Another reason for the failure to simulate age class distributions correctly was that age classes of 20 years were used in the original EFISCEN model. Their use meant that 25 % of the area in an age class received an age of the next age class during the five years simulation step. This resulted in rapid ageing for part of the area and slow ageing for some areas. For example, if there is 100 ha of 10-year-old forest, after a 20 years simulation 31.6 ha is still 10 years old $(1 - 0.25)^4$ and after 40 years 10 ha is still 10 years old $(1–0.25)^8$. On the contrary, after 10 years 6 ha is already 50 years old (0.25^2). The model was changed to use 5-year age classes which resulted in logical ageing of the forests in the model.

Another shortcoming of the model was the calculation of growth in the cells above an average standing volume. The growth in the old EFISCEN is expressed as a percentage of the growing stock, i.e. higher standing volumes mean higher increment (i.e. the distribution over the volume classes represents a kind of distribution over the sites). This caused the fast growing areas to grow faster and faster, i.e. the matrix spreads out during the simulation, even though function (6) is meant to curb this. This shortcoming of the model was resolved by making the increment of the volume classes above average volume independent from the standing volume. The volumes above the average standing volume are considered fully stocked and an absolute increment is set at the increment of the average volume class.

3.3 Projective Simulations until 2050 with the Improved EFISCEN Model

The simulation of the development of Finnish forests till 2050 shows that a maximum sustainable felling level of 70.6 million m^3 y^{-1} can be reached. Under that felling level the increment remains stable at 3.7 m^3 ha^{-1} y^{-1} and the average growing stock increases only slightly to 106 m^3 ha^{-1}. The age class distribution shifts strongly towards younger forests under this scenario. In 1990, 10.3 million ha is younger than 60 years and in 2050 under the maximum sustainable scenario this is 14.9 million ha (Fig. 8).

Under the multifunctional forest management regime, the area of strict reserves has gradually increased through time to an area of 1.4 million ha (or 7 % of the exploitable forest). This has taken place because not all ageing forests are harvested and thus attain an age over the reserves limit of 170 years (Fig. 8). Despite this, a rather realistic total felling level of 57.4 million m^3 y^{-1} can still be found, while the growing stock increases to 160.5 m^3 ha^{-1} (Fig. 5). It is unclear whether this high average growing stock can be reached in Finland without running into large-scale mortality problems. Individual stands can in any case reach far higher volumes without problems (Yearbook of forest statistics 1989). In the age class distribution the area of reserves is not clearly discernible, because under the business as usual scenario the forests age rather fast as well. This results in comparable forest areas in old age classes.

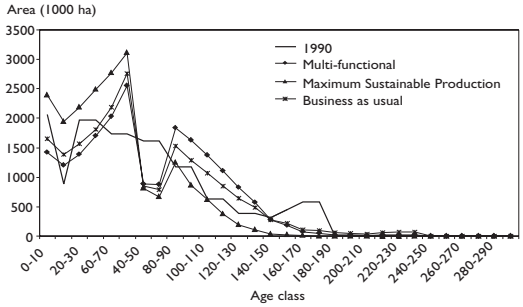

Fig. 8. Age class distribution of Finnish forests in 1990 and in 2050 under alternative management regimes.

Under the business as usual scenario the increment is rather stable at 3.8 m^3 ha^{-1} y^{-1} in 1990 to 3.6 m^3 ha^{-1} y^{-1} in 2050 (Fig. 6). However, the growing stock quickly increases to 155 m^3 ha^{-1}. The age class distributions (Fig. 8) show that EFISCEN predicts very small areas in the age classes of 60–70 and 70–80 years. This may be an underestimation of those areas and is a result of the way the matrices are initialised. Inventory data usually give very small standing volumes for the first age class. When distributing those areas over bare land class and the class of 0–10 years, EFISCEN assesses relatively large areas in the bare land class to obtain the right average standing volume; leading to a relatively small area in the class 0–10 years.

4 Discussion

4.1 Validation of Large-scale Models

Attempts to validate forest projection models in order to gain insight in the accuracy of the assessments can be carried out through various approaches. These are:

1 validating the growth functions against other growth functions or data sets,
2 comparing the projections against other projections carried out for the same forests,
3 running the model on historic data and comparing the output to the present state of the forests, and
4 propagation of variance assessments (e.g. Monte Carlo simulation) to gain insight in accuracy.

Approach 1 has been applied to the previous version of EFISCEN by Sallnäs (1990). He compared the growth as assessed in the area matrix approach of EFISCEN with the growth function of the EKÖ model at the forest type level. The growth in the EKÖ model showed some differences with the growth in the EFISCEN model, but these were explained by the fact that the site classes of the EKÖ model represented often extremes within these site classes.

Approach 2 has been applied by Nilsson et al. (1992) for European forests, by Päivinen et al. (1998) for Leningrad Region forests and by Nabuurs et al. (1998a) for a selected number of European countries. The latter compared the output of EFISCEN with the European Timber Trend Studies (ETTS V) scenario results for seven European countries for 1990–2040. EFISCEN was able to reproduce the ETTS scenarios. Where differences in output occurred they were explained from differences in input data or by the fact that a more dynamic approach was incorporated in EFISCEN.

Approaches 3 and 4 can be seen as a way of validating the whole model with all its module interactions. Approach 3 had never been tried for EFISCEN before and in general for very few other large-scale forest projection models. The only exceptions are by Manley (1998) for New Zealand's projections of supply and by Clawson (1979) for US forests' net increment. Clawson concluded that the projections have consistently underestimated the actual growth. Manley concluded that most projections were realistic till about 1990, but thereafter consistently underestimated the actual harvest. He states that the projections are not predictions, but merely scenarios of what could happen under specific assumptions.

Errors in projections have four main sources (Kangas 1997, 1998): 1. Stochastic character of the estimated model coefficients (i.e. growth variation and management irregularity are not incorporated); 2. Measurement and sampling errors in the data used for model construction; 3. Accuracy of fit of the utilised models; and 4. Assumptions in the model.

From the run until 1993 it becomes clear that EFISCEN is not able to predict the situation of the forests in 1993 with the data from 1923. The reason for this is the transient increase in the increment after the 1960's. The transient increase is to some degree comparable to what Kangas (1997) mentions as uncertainty in growth projections due to annual variation of growth. She states that the uncertainty of volume growth due to annual variation in e.g. weather circumstances was about 5–6 %.

In the present study there are two types of uncertainties related to data preparation and setting up an accurate scenario. The first one is the reliability of the individual inventory results. The latest forest inventory in Finland is very accurate: standard errors (s.e.) of some characteristics at the country level are for forest land area 0.4 %, growing stock 0.7 %, and total increment 1.1 % (Tomppo 1996). Ilvessalo (1927) also reports very accurate results of the first NFI. The result for mean volume was: 64.3 ± 0.96 m^3 ha^{-1} (s.e. 1.49 %) and for mean growth was 1.77 ± 0.029 m^3 ha^{-1} y^{-1} (s.e. 1.64 %). This is however only the uncertainty in initial data quality. Mowrer and Frayer (1986) project the coefficient of variation as a result of input measurement and regression errors. They state that when the input CV is 5 to 10 %, the maximum projection period would be 20 years when desiring an output CV of less than 20 %. Also Kangas (1998) states that when the data set contains measurement errors, the coefficients will contain a bias that cannot be ignored.

The second source of uncertainty is the limited comparability between the different inventories

Table 1. Comparison of different projections made for Finnish forests.

Origin or model	Scenario	Year	Increment (m^3 ha^{-1} y^{-1})	Total fellings (million m^3 y^{-1})	Growing stock (m^3 ha^{-1})	References
MELA	ETTS-V	1990	4.18	55	91.8	Pajuoja 1995
		2020	6.26	52.6	144.2	
		2040	5.62	52	209.3	
IIASA	Basic Forest Study	1980	3.4	59	86	Nilsson et al. 1992
		2080	3.4	62.6	125	
MELA: Finland´s National Forest Programme 2010	MELA 70	2020	3.95	71	87	Ministry of Agriculture and Forestry 1999
		2030	4.72	73	89	
	MELA 80	2020	3.59	65	72	
		2030	4.31	65	71	

because of the use of different definitions. Yearbook of Forest Statistics (1989) reports that when using a new method to determine the volume in NFI VI, it resulted in 3 % higher volumes than for all previous inventories. Also the definitions for e.g. forest land in the different NFI's have changed.

The main assumption underlying EFISCEN is that the growth and management of a forest can be represented by areas moving across a volume-age area matrix. Recalculating the increment (Fig. 7) showed that the model yielded an underestimation of increment. Through the improvements made in the model concerning the growth-boost after thinning this underestimation was counteracted. Furthermore, in EFISCEN it is assumed that we can set management regimes as constraints per forest type and age class. Those constraints determine whether a certain demand can be met in the existing forest resource.

4.2 Comparison of Projective Simulations with other Projections

Several other projections have been made for Finnish forests (Table 1). The MELA model (Siitonen and Nuutinen 1996) has been used for the projections for the European Timber Trend Studies V (Pajuoja 1995) and for the projections for the Ministry of Agriculture in Finland. The IIASA model has been applied to Finland by Nilsson et al. (1992).

The MELA model (Table 1) projects in all cases a rather strong increase in the increment. This was not found in our simulations. The IIASA study projected a decreasing increment for Finland (Nilsson et al. 1992). This is reflected in the felling potential that Nilsson et al. (1992) foresee. The simulations with MELA show that fellings of 80 million m^3 y^{-1} cannot be sustained (in 2020 and 2030 only 65 million m^3 can be harvested according to MELA). At a felling level of 70 million m^3 y^{-1} MELA shows that the growing stock declines slightly to 89 m^3 ha^{-1} (Ministry of Agriculture and Forestry 1999). At that felling level we found a growing stock still increasing to 106 m^3 ha^{-1} in 2050. The most obvious difference between MELA and EFISCEN is that in EFISCEN higher fellings stimulate the net increment, because the forest does not reach the maximum growing stocks. In MELA the opposite seems to occur, i.e. the higher the stock, the higher the increment.

5 Conclusion

For the period 1923–1963 the old EFISCEN is able to reproduce the historic forest development in terms of increment, growing stock, average thinning level and total harvest level. However, the increment level tends to be underestimated at simulation periods longer than 50 years because of the decreased growth after thinning. EFISCEN was improved concerning the simulation of age development, thinning regimes and regrowth after thinning.

The projection of the Finnish forests till 2050 with the improved model presented a maximum sustainable felling level of around 70 million m^3 per year. That provides an average growing stock of 106 m^3 ha^{-1} in 2050 and a net annual increment of 3.6 m^3 ha^{-1} y^{-1}. If the current trend towards more nature oriented forest management continues and 1.39 million ha of forests have additionally been set aside (currently 517 000 ha) for nature reserves by 2050, the felling level could easily meet a realistic demand of 57 million m^3 per year in 2050. Under the latter regime the average growing stock will have grown to 160.5 m^3 ha^{-1} in 2050.

Although we cannot speak of other models that are in use for large-scale projections, the sometimes large deviations between the reality and the simulations by the old EFISCEN indicate that long-term large-scale forest resource projections should be interpreted with caution. Given the fact that the same type of data as were used in this study are available for most European countries, we can conclude that EFISCEN may be used for European scale forest scenario studies. However, every country will show its own specific problems like we have seen in the present validation.

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Total of 42 references

Annex I. Forest types distinguished in the historic run and in the projection.

Type of run	Region	Owner	Site	Species
Historic run	North South	All	Grass herb forests Forest resembling grass herb forests Myrtillus type Hylocomium-Myrtillus type Vaccinium type Empetrum-Myrtillus type Calluna type Cladina type Spruce swamps Pine swamps Reafforested cultivated lands	Norway spruce Scots pine Broadleaves
Projection till 2050	North South	All	Mineral soil, class 1 &2 Mineral soil, class 3 Mineral soil, class 4 Mineral soil, class 5 to 8 Peat soil, class 1 & 2 Peat soil, class 3 Peat soil, class 4 Peat soil, class 5 to 8	Norway spruce Scots pine Birch Other deciduous