Testing a Large-Scale Forestry Scenario Model by Means of Successive Inventories on a Forest Property

Tron Eid

Eid, T. 2004. Testing a large-scale forestry scenario model by means of successive inventories on a forest property. Silva Fennica 38(3): 305–317.

Modellers of large-scale forestry scenario models face numerous challenges. Information and sub-models from different disciplines within forestry, along with statistical and mathematical methodology, have to be considered. The individual biological sub-models (i.e. models for recruitment, growth and mortality) applied in large-scale forestry scenario models are in general well documented and extensively evaluated. However, evaluations by means of full-scale comparisons of observed and predicted values for continuous forest areas, where the totality of the large-scale forestry scenario model including interactions between sub-models and other parts of the model, are considered, have rarely been seen.

The aim of the present work was to test the totality of the Norwegian large-scale forestry scenario model AVVIRK-2000, and thereby evaluate the applicability of the model for use in management planning. The test was done by means of successive inventories and accurate recordings of treatments over a period of 30 years for a property comprising 78.5 ha forest-land. Seen in the perspective of management planning, the differences between observed and predicted values for potential harvest level, growing stock and growth were small, e.g. a difference between observed growing stock in year 2000 and growing stock in the same year predicted from 1970 of 2.6%. The model may therefore be applied for practical purposes without any fundamental changes or calibrations of the biological model basis. However, the present test should be seen as an example that failed to falsify the model, rather than a final validation. As long as the model is in practical use, further evaluations should continue and subsequent possible calibrations should be performed.

Keywords forest planning, growth, large-scale scenario analyses, validation

Author´s address Agricultural University of Norway, Dept of Ecology and Natural Resource Management, P.O. Box 5003 NO-1432 Ås, Norway
Fax +47 64948890 **E-mail** tron.eid@ina.nlh.no

Received 21 November 2003 **Revised** 5 May 2004 **Accepted** 28 May 2004

1 Introduction

The strategic level of the forest planning process, i.e. long-term planning at the property-, landscape- or regional level, is complex, and there is an obvious need for tools and analyses in order to provide adequate information to decisions-makers. Such tools and analyses are often referred to as ”large-scale forestry scenario models and analyses” (e.g. Nabuurs and Päivinen 1996).

There are large variations in large-scale forestry scenario models with respect to applied biological sub-models for predictions of forest dynamics (i.e. models for recruitment, growth and mortality), methodology, complexity, resolution and use. Two large-scale forestry scenario models have recently been developed in Norway; i.e. AVVIRK-2000 (Eid and Hobbelstad 2000) and GAYA-JLP (Hoen and Eid 1990, Hoen and Gobakken 1997, Lappi 1992). Similar models exist in other countries; e.g. Hugin in Sweden (Lundström and Söderberg 1996), MELA in Finland (Lappi 1992, Siitonen 1993, Hynynen et al. 2002), FORPLAN (Johnson et al. 1986) and the successor SPECTRUM (Camenson et al. 1996) in the USA and IFS/FOLPI (Manley 1996) in New Zealand. Also a model designed for applications covering large parts of Europe (EFISCEN) has been developed and applied (Sallnäs 1990, Nilsson et al. 1992, Nabuurs et al. 2000). Review articles describing such models from different perspectives have been provided by Nabuurs and Päivinen (1996), Weintraub and Bare (1996) and Martell et al. (1998).

Large-scale forestry scenario models are in general complex, and the modellers face numerous challenges. A first challenge is to choose appropriate biological sub-models, and to consider interactions between such models with respect to logical biological behaviour. There is also a constant focus on knowledge gaps, which in general, are easy to identify. Quite often there is a choice between ignoring the gaps knowing that this will lead to biases or errors, on one side, or filling in the gaps applying poorly documented ad-hoc solutions that provide uncertain results, on the other side. The balance with respect to accuracy and reliability between different parts of a large-scale forestry scenario model is therefore a major challenge. Since it is very unlikely that the users of large-scale forestry scenario models will pay any attention to such problems, it is usually the modeller’s responsibility to consider possible implications of applying the poorly documented ad-hoc solutions in a model. Another challenge is related to the robustness of the biological sub-models. The users of large-scale forestry scenario models tend to simulate “extreme” treatments. It is for example quite obvious, considering the diversity of the thousands of decisions-makers participating in non-industrial farm forestry, that the silvicultural treatments frequently violate the basic assumptions of the biological sub-models developed from experimental sample plots. Hence, an important part of the modelling should focus on the model’s performance under “extreme” conditions. Another possible approach to this problem would be to develop sub-models based on a wider range of forest conditions and treatments than the experimental sample plots are able to provide, e.g. National Forest Inventory (NFI) data.

There is a lot of literature on development and evaluation of biological sub-models for recruitment, growth and mortality. Review articles with focus on the evaluation phase in model development have been written by e.g. Vanclay and Skovsgaard (1997) and Huang et al. (2003). Usually the evaluations of the sub-models stop when potential biases and random error levels of the individual sub-models are quantified from independent data. Since a large-scale forestry scenario model is more than just a systematically built up composition of individual sub-models, such tests are not sufficient when it comes to a large-scale forestry scenario model’s applicability in management planning. Questions related to e.g. the robustness of and to the interactions between sub-models, to the appropriateness of the applied ad-hoc solutions and to the balance between different parts with respect to accuracy and reliability, should also be considered in order to evaluate the totality of such models.

Important evaluation work with focus on the totality of a large-scale forestry scenario model is, of course, quite often done by means of sensitivity analyses or other subjectively founded approaches. However, empirical evaluations that include the traditional concept of validation, i.e.

comparing observed and predicted values based on independent data from larger forest areas, are much more complex and demanding with respect to data- and research design. For such evaluations, not only the changes in forest conditions over a longer period, preferably for continuous forest area, but also a detailed description of the silvicultural treatment history that should be used to mimic the treatments in the analyses, are required. There are very few examples of evaluations of this kind. Exceptions, where at a least part of all these requirements are taken care of, have been provided by Nabuurs et al. (2000), who evaluated EFISCEN by means of historical Finnish NFI sample plot data covering the whole country and by Manley (1998), who did a similar evaluation of IPS/FOLPY based sample plots from the plantation forest of New Zealand.

A discussion on the reliability of large-scale forestry scenario models has taken place in Norway over the past few years. The background for this discussion was a decrease of potential harvest levels, instead of the expected increase, for quite a large number of properties, when new management plans were produced. The immediate response to these results was that the growth models had overestimated growth in the past. The subsequent discussions (e.g. Hobbelstad 1998, Hofstad 1998, Myrbakken 1998, Eid 2002), however, pointed at three main factors that possibly could explain the unexpected results; i) systematic errors in present or in previous inventories, ii) lack of consistency between assumptions made for treatments in previous analyses and the subsequent actual treatments carried out in the forest, and iii) systematic errors in the biological model basis of the applied scenario models.

Systematic errors in inventories or particular growth/mortality conditions may in some cases explain the unexpected results. However, the most apparent explanation is a lack of consistency between treatment assumptions made in analyses, and the actual subsequent treatments carried out in the field. The thinning practices are one example of such inconsistency. Analyses made 20–30 years ago in general assumed intensive thinning programmes in the determination of potential harvests, while most timber quantities cut since then have in practice been done as final harvests. Such deviations between “model” and “reality” over several years will obviously lead to discrepancies, and do explain the decreased potential harvest levels in many of the new plans.

Large-scale forestry scenario models have extensively been used for analyses in practical management planning at the property level as well as for larger areas in Norway. AVVIRK-2000 is a recently developed model (Eid and Hobbelstad 2000) that in a near future will be an integrated part of the software used in practical management planning. The totality of the model was during the development phase extensively evaluated by means of sensitivity analyses and other subjective approaches. Although these evaluations did not reveal any fundamental discrepancies with respect to the performance of the model, there are still uncertainties, and accordingly a need for further assessments, preferably empirical assessments based on historical data.

A perfect situation for an empirical evaluation of the totality would be to apply a wide range of forest conditions over a large area where forest developments and treatments were described continuously and in details over a long period. Such data do not exist, however. An evaluation could possibly be performed on a large set of NFI sample plots (see e.g. Nabuurs et al 2000, Manley 1998). There are two main problems connected to such an approach, however. The Norwegian NFI permanent sample plots only cover a period of 15 years, which is too short a period. One may also apply temporary sample plots from the NFI, and in that way be able to consider a longer period. The problem of this, however, would be to identify and keep track of all the previously performed treatments, which are supposed to be mimicked in the analyses. An alternative to NFI sample plots would be to apply data from a smaller forest area, e.g. property. A more limited range of forest conditions would then be included, but the historical forest conditions and treatments could be described more in detail.

The aim of the present study was to test and evaluate AVVIRK-2000 with respect to applicability in management planning by comparing predicted and observed values from a forest property over period of 30 years. The evaluation was based on a typical non-industrial farm property managed in combination with agricultural production comprising 78.5 ha forest-land. Since the property has been intensively inventoried over 30-year period, i.e. all trees callipered and a large number of sample trees selected for height measurements, and since all treatments have been quite accurately described in all stands over the same period, two out of the three sources of uncertainty discussed above can be ruled out, i.e. potential systematic errors in inventories and lack of consistency between assumed and actual treatments.

2 Material and Methods

2.1 Model Description

AVVIRK-2000 is a deterministic simulation model. There are no elements of stochasticity or optimisation built in. The model should be operated heuristically, i.e. the user should calculate different alternatives through «intelligent» manipulation of the assumptions, and search for a few, but satisfactory solutions. The model does biological projections, i.e. describes the forest conditions, treatments and potential harvests, and calculates the corresponding gross values, harvesting costs and silvicultural costs, for a period of 100 years. The simulations are divided into ten 10-year periods, and all treatments are assumed to take place in the middle of each 10-year period. Net present values at the stand and forest level are also calculated. The economic parts of the model are not considered in the present work. Eid and Hobbelstad (2000) provided a description of these features. Fig. 1 shows the main features and the data flow of the biological part of the model.

The model can be operated using sample plots, stands or aggregates of sample plots or stands as basic calculation units (from now on referred to as a stand). The most important variables used to describe the initial state of a stand are mean diameter weighted by basal area (D_{ba}), mean height weighted by basal area (H_L), number of stems ha^{-1} (N), site quality (H_{40}, i.e. dominant height in meters at breast height age 40 years) and total age (TT).

The computations comprise two phases: i) simulation of silvicultural regimes for all stands, and ii) scheduling the potential harvests at the forest level. The user may choose between the following harvest strategies: i) a non-declining harvest level for the period of 100 years; ii) a user given harvest level for any number of 10-year periods up to 10; iii) a harvest level according to user given final harvest and thinning instructions for all stands.

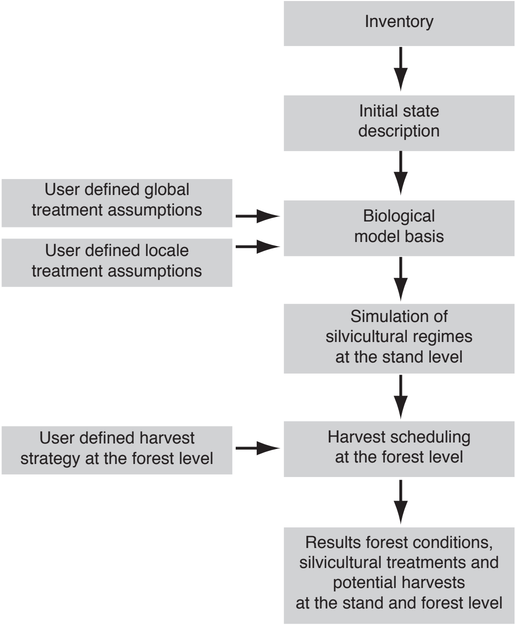

Fig. 1. Main features and data flow of AVVIRK-2000.

The simulations of silvicultural regimes at the stand level are based on the initial description of each stand, globally (forest level) and/or locally (stand level) user defined silvicultural treatment assumptions and the biological model basis, i.e. a set of biological sub-models for Norway spruce (*Picea abies* (L.) Karst.), Scots pine (*Pinus sylvestris* L.) and Birch (*Betula* spp.) projecting state and dynamics of the stands (Table 1). The biological sub-models are mainly based on data from experimental permanent sample plots administrated by Norwegian Forest Research Institute. All the biological sub-models are area-based, and the projections are based on D_{ba}, H_L and N.

The most important biological sub-models are diameter growth models (Blingsmo, 1984), height development models (Braastad 1977, Strand 1967, Tveite 1967, 1976, 1977) and a mortality model (Braastad 1982). Diameter growth (I_d) is

Table 1. Biological model basis. [a]

Task	Tree species	Reference	Dependent variable	Independent variables
Diameter growth	Norway spruce	Blingsmo (1984)	I_d	$T_{1.3}$, H_{dom}, H_{40}, N, D_{ba}
	Scots pine	Blingsmo (1984)	I_d	$T_{1.3}$, H_{dom}, H_{40}, N, D_{ba}
	Birch	Blingsmo (1984)	I_d	$T_{1.3}$, H_{dom}, H_{40}, N, D_{ba}
Height development	Norway spruce	Tveite (1967, 1977)	H_L	$T_{1.3}$, H_{dom}, H_{40}, N, D_{ba}, BA
	Scots pine	Tveite (1967, 1976)	H_L	$T_{1.3}$, H_{dom}, H_{40}, N, D_{ba}, BA
	Birch	Strand (1967), Braastad (1977)	H_L	$T_{1.3}$, H_{dom}, H_{40}, N, D_{ba}
Mortality	Norway spruce	Braastad (1982)	N_{mort}	N
	Scots pine	Braastad (1982)	N_{mort}	N
	Birch	Braastad (1982)	N_{mort}	N
Volume of "average tree"	Norway spruce	Vestjordet (1967), Braastad (1974)	v	D_{ba}, H_L
	Scots pine	Brantseg (1967), Braastad (1980)	v	D_{ba}, H_L
	Birch	Braastad (1966), Braastad (1980)	v	D_{ba}, H_L
Initiation basal area	Norway spruce	Braastad (1975)	BA_{init}	H_{dom}, H_{40}, N
	Scots pine	Braastad (1980)	BA_{init}	H_L, H_{40}, N
	Birch	Braastad (1977)	BA_{init}	H_L, N

[a] I_d = diameter growth yr^{-1}, $T_{1.3}$ = age at breast height, H_{dom} = dominant height, H_{40} = site quality, N = number of trees ha^{-1}, D_{ba} = mean diameter weighted by basal area, H_L = mean height weighted by basal area, BA = basal area ha^{-1}, N_{mort} = number of trees dying yr^{-1}, v = volume of the average tree, BA_{init} = initial basal area ha^{-1} at H_0 = 9 meter

calculated for periods of five years, and a new D_{ba} is settled by adding this growth to the old diameter. Dominant height (H_{dom}) at a certain breast height age ($T_{1.3}$) is determined by means of height development curves, and H_L is estimated by means of functions determining the difference between H_{dom} and H_L. The mortality (N_{mort}) is calculated according to a simple function, based on Norway spruce data, but applied also for Scots pine and Birch, using N as the only independent variable. All broad-leaved species are treated according to the sub-models applied for Birch. The volume of the "average tree" under bark (v), i.e. the volume of a tree determined from D_{ba} and H_L, is estimated with functions of Braastad (1966, 1974, 1980), Brantseg (1967) and Vestjordet (1967). The volume ha^{-1} under bark of the stand (V) is established by multiplying v and N. For stands in the young growth phase, i.e. H_{dom} lower than 8–10 m, diameter growth models are not used. Instead, an initial basal area (BA_{init}) is estimated when H_{dom} reach 8–10 m (Braastad 1975, 1977, 1980). For present young stands, the initiation is based on N from the inventory. For "new forest", i.e. forest established after final harvests, the initiation is based on the number of trees ha^{-1} derived from treatment assumptions made by the user.

2.2 Test Site, Data and Calculations

A forest property in the municipality of Gjøvik (60º5´N, 10º4´E, 350 m a.s.l.) was used as test site. The property, comprising 78.5 ha of productive forest-land, represents a typical Norwegian non-industrial farm forest managed in combination with agricultural production. The whole property has been intensively inventoried four times; in 1970 (Nersten 1973), 1980 (Gisnås 1981), 1990 (Aasland 1992) and 2000 (Eid 2003). In the same period (1971–2000), treatments (final harvests, thinnings and regeneration efforts) with respect to location (stand), time and amounts have been recorded. The stand delineation has basically been kept constant over the period. Some adjustments due to vitality problems and windfall have been necessary, however.

The four successive inventories were mostly performed according to the same instructions. For development class II (i.e. young forest stands with ages lower than or equal to 15, 20, 25, 30 and 35 years, respectively, for site quality classes H_{40} = 23 m, H_{40} = 20 m, H_{40} = 17 m, H_{40} = 14 m and H_{40} = 11 m), the measurements were based on systematic sample plots within each stand. N by tree species was determined from the mean of the sample plots. For development class III (i.e. young thinning stands with ages higher than

Table 2. Observed growing stock and development classes in year 1970, 1980, 1990 and 2000, and observed annual harvests and growth from 1971 to 2000.

Year	Growing stock (m^3)	Proportion development class (% of total area) I	II	III	IV	V	Period	Annual harvest (m^3) Thinning	Final harvest	Total	Annual growth (m^3)
1970	7765	0	42	13	24	21	1971–1980	0	376	376	394
1980	7586	3	43	18	27	9	1981–1990	30	373	403	425
1990	7367	1	48	28	14	9	1990–2000	35	182	217	444
2000	9640	2	38	37	17	6					

Table 3. Summary of stand data in year 2000.

Variable	Development class III–V (50 stands) Mean	Range	Development class II (18 stands) Mean	Range
Area (ha)	0.96	0.13–4.59	1.69	0.20–4.99
Total age – TT (years)	57	25–107	14	1–24
Site quality – H_{40} (m)	16.8	11.0–23.0	17.2	14.0–20.0
Mean diameter weighted by basal area – D_{ba} (cm)	15.9	7.8–25.4	–	–
Mean height weighted by basal area – H_L (m)	17.0	8.0–26.5	–	–
Number of trees – N (ha^{-1})	1521	500–3800	1522	860–2000
Volume – V (m^3 ha^{-1})	221	36–527	–	–
Proportion Norway spruce (%) *)	91	33–100	94	80–100
Proportion Scots pine (%) *)	2	0–37	0	0–2
Proportion Birch (%) *)	7	0–67	6	0–19

*) Proportion according to volume in old forest, proportion according to number of trees in young forest

defined for development class II and ages lower than or equal to 35, 45, 55, 60 and 70 years, respectively, for site quality classes H_{40} = 23 m, H_{40} = 20 m, H_{40} = 17 m, H_{40} = 14 m and H_{40} = 11 m), for development class IV (i.e. advanced thinning stands with ages higher than those defined for development class III and ages lower than or equal to 60, 70, 80, 90 and 100 years, respectively, for site quality classes H_{40} = 23 m, H_{40} = 20 m, H_{40} = 17 m, H_{40} = 14 m and H_{40} = 11 m), and for development class V (i.e. mature stands with ages higher than those defined for development class IV), all trees were callipered and recorded according to species, and a high number of sample trees for height measurements were selected by means of relascope. D_{ba}, H_L, N and V of each stand were calculated from these measurements.

Age- and site quality measurements were carried out in 1970, 1980 and 1990, but not in 2000. Since the measurements of these parameters in 1970 and 1980 to some extent relied on subjective judgements, while the measurements in 1990 were based on an intensive systematic sample plot inventory within each stand (Aasland 1992), all records for stand age (TT) and stand site quality (H_{40}) were established from the 1990 measurements. For development class I (i.e. forest under regeneration), stand site quality only was measured. Table 2 shows total growing stock and the distribution of development classes in year 1970, 1980, 1990 and 2000. Table 3 shows arithmetic means and ranges for several variables of the stand data in year 2000.

Final harvests and thinnings carried out in the period from 1971 to 2000 have been recorded with respect time and location (stand). The respective amounts of most of the thinnings and all final harvests were based on official wood scaling data. A part of the thinnings has been done for fuel wood purposes, and these amounts have been estimated. The annual amounts of thinnings were 0 m^3, 30 m^3 and 35 m^3 in the periods 1971–1980, 1981–1990 and 1991–2000, while the total amounts of harvest were 376 m^3, 403 m^3 and 217 m^3, respectively, in the same periods (Table 2). The annual growth was calculated as the net change per year in growing stock over a period, plus mean annual harvests in the same period.

The state of the stands in 1970, 1980, 1990 and 2000, respectively, was used to predict the growing stock, growth and harvests for the period 1971–2070. For the projections based on data from 1970, 1980 and 1990, the actual (observed) harvests in the period from 1971–2000 with respect to amounts and locations (stand) were carried out for all stands. Since AVVIRK-2000 work with 10-year periods and all treatments are assumed to take place in the middle of a period, the harvest in a particular stand could not be distributed to the actual year, but was consequently carried out in the middle of the 10-year period. For thinnings, the amount only could be mimicked. The actual appliance of a thinning with respect to number of trees taken out and mean diameter before and after the thinning cannot be handled by the user in AVIRK-2000. The actual (observed) regeneration efforts with respect to method (planting or natural regeneration) were carried out for all stands.

For the period 2001–2070, general treatment assumptions were done for all predictions (also those based on 2000 data), i.e. final harvests were carried out when the age of the stands reached certain limits differentiated over site quality classes, thinnings were varied according to density (number of trees ha^{-1}) and regeneration were varied according to site quality class.

Table 4. Observed and predicted annual harvests according to different data origins.

Data origin	Annual harvests (m^3) 1971–80	1981–90	1991–2000	2001–10
Observed	376	403	217	–
Predicted 1970	376	403	217	534
Predicted 1980	–	403	217	537
Predicted 1990	–	–	217	541
Predicted 2000	–	–	–	554

Table 5. Observed and predicted growing stock according to different data origins.

Data origin	Growing stock (m^3) 1970	1980	1990	2000	2010
Observed	7765	7586	7367	9640	–
Predicted 1970	–	7776	7350	9388	8942
Predicted 1980	–	–	7298	9235	8650
Predicted 1990	–	–	–	9373	8839
Predicted 2000	–	–	–	–	9336

Table 6. Observed and predicted annual growth according to different data origins.

Data origin	Annual growth (m^3) 1971–80	1981–90	1991–2000	2001–10
Observed	394	425	444	–
Predicted 1970	377	446	421	579
Predicted 1980	–	432	411	596
Predicted 1990	–	–	415	594
Predicted 2000	–	–	–	584

3 Results

The annual harvest potential for the period 2001–2010 was 554 m^3 when the prediction was based on 2000 data (Table 4). The corresponding harvest potentials were 534 m^3 based on data from 1970, 537 m^3 based on data from 1980 and 541 m^3 based on data from 1990, i.e. 3.6%, 3.1% and 2.3%, respectively, lower than the harvest potential predicted from the 2000 data.

The observed growing stock in 2000 was 9640 m^3, while it was 9388 m^3 predicted in 1970, 9235 m^3 predicted in 1980 and 9373 m^3 predicted in 1990 (Table 5). These figures correspond to, respectively, 2.6%, 4.2% and 2.8% lower predicted growing stock than the observed. Also in 1990, the predicted growing stock was slightly lower than the observed. The only example where predicted growing stock was higher than observed growing stock was seen in 1980.

The observed annual growth was 444 m^3 in the period 1991–2000 (Table 6). The annual growth for the same period, predicted in 1970, was 421 m^3 (i.e. 5.2% lower than observed), while it was 411 m^3 (i.e. 7.4% lower than observed) predicted in 1980 and 415 m^3 (i.e. 6.5% lower than observed) predicted in 1990. The potential annual growth in the period 2001–2010 was varying between 579 m^3 and 596 m^3, i.e. a range of less than 3% between the lowest and highest value.

Fig. 2. Predicted long-term annual harvest potentials according to different data origins.

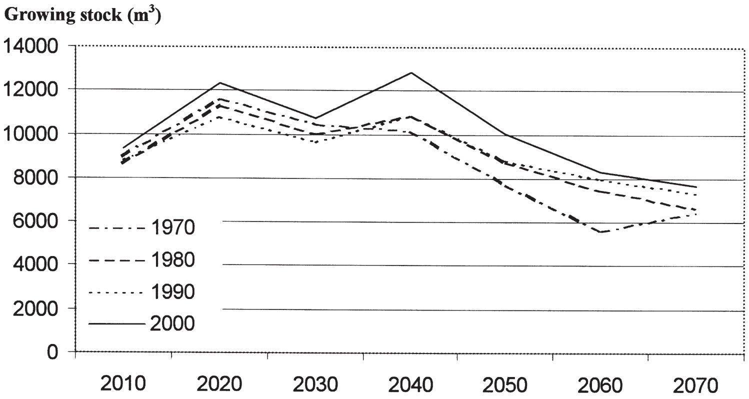

Fig. 3. Predicted long-term growing stock according to different data origins.

The predicted long-term harvest potentials in Fig. 2 showed similar patterns over time for the different data origins. The deviations between the data origins were relatively small in the first 10-year periods, but larger in later 10-year periods. In the period 2041–2050, for example, the annual predicted harvest according to the 1970 data was 658 m^3 while it was 761 m^3 according to the 2000 data. Over the entire period (70 years), however, the deviations were relatively small, i.e. the summarized predicted harvests over the 70 years were 34350 m^3, 34670 m^3, 34160 m^3 and 36250 m^3, respectively, predicted in 1970, 1980, 1990 and 2000. The predicted long-term growing stock in Fig. 3 showed similar patterns as the harvest level, i.e. small deviations in early periods, and larger in later. The figure also shows that the growing stock predicted in 1970 in the long run (from 2040) provided the lowest values, while the growing stock predicted in 2000 constantly provided the highest values. In 2070, for example, the growing stock predicted in 1970 and 2000 were 6435 m^3 and 7642 m^3, respectively.

4 Discussion

Considering the totality of a large-scale forestry scenario model is important in order to evaluate the model's applicability in management planning and to build user confidence in it. A perfect data- and research design for an empirical evaluation of the totality would be to apply a wide range of forest conditions over a large area where forest developments and treatments were described continuously and in details over a long period. Such data do not exist, however.

The test of AVVIRK-2000 performed in the present study was based on data from a relatively small forest property. Still, however, the inventories on the property were based on continuously, intensive and well-documented inventory design, and the descriptions of all treatments over these years were accurate. This means that the uncertainty related to the basic data used for the evaluation was reduced to a minimum. Although the test area was relatively small, the property also comprised forest from all development phases (Table 2) and a relatively wide range of forest conditions was represented (Table 3).

Compared to normal rotation ages seen under Norwegian conditions (60 to 120 years), the tests involved a relatively short period of time (30 years). The results would, of course, get more reliable if data for a longer period was available. However, a test period of 30 years should be sufficiently to reduce potential problems related to short-term changes in growth and/or mortality caused by the annual fluctuations in temperature and precipitation or by stochastic incidents related to wind and snow damages.

Although the treatments carried out in the 30-year period were described in detail, there were some uncertainties related to the application of these treatments in the model. For thinnings, the amount only could be mimicked. The actual appliance of a thinning with respect to number of trees removed out and mean diameter before and after the removal could not mimicked. The removal in AVVRIK-2000 is modelled as "a thinning from below", i.e. the mean diameter of the removal is smaller than the mean diameter before the removal. There is no reason to believe that actual thinnings carried out in the 30-year period have been different from such a strategy. It is also worth mentioning that since the thinning removals were very low compared to the removals from final harvests (Table 2), the effect of potential discrepancies with respect the thinning will be marginal at the forest level.

There is, of course, also some uncertainty related to the fact that all final harvests in the model are assumed to take in the middle of a 10-year period, while they in practice have taken place early, in the middle or at the end of the period. Here one simply has to assume that the actual harvest were evenly distributed over the 10-year period, and that the over- and underestimating of growth in individual stand this necessarily leads to, is levelled out at the forest level. Large-scale forestry scenario models and analyses mainly deal with the strategic level (i.e. the forest level) of the forest planning process. The detailed dynamics and development of individual stands are in this perspective less important.

The deviations between observed and predicted values seen in a short-term perspective (period 1971–2000), i.e. a difference between the potential harvests for the period 2001–2010 based on 2000 data and predicted harvest potentials for the same period based on 1970 data of 3.6% (Table 5), a difference between observed growing stock in year 2000 and growing stock predicted from 1970 of 2.6% (Table 5) and a difference between observed annual growth for the period 1991–2000 and predicted annual growth for the same period based on 1970 data of 5.2% (Table 6), must be regarded as small, and as well within the ranges that can be expected when the numerous sources of uncertainty related to large-scale forestry scenario analyses and management planning in general are considered.

The most important biological sub-models of AVVIRK-2000 are diameter growth models, height development models and a mortality model. Although AVVIRK-2000 comprise more than the individual biological sub-models, some of the deviations seen at the forest level for growth, growing stock and harvest level could possibly be explained by means of observed and predicted values for diameter, height and number of trees. The predicted values for diameter, height and number of trees at the stand level were not available, however. Still, a more general discussion of the sub-models and their performance may be useful in order to explain the results.

As mentioned earlier, the immediate response in the discussion related to the reliability of the large-scale forestry scenario models was a judgment saying that the Norwegian growth models had overestimated growth in the past. There is no evidence in the present work supporting such a conclusion. If any tendencies could be said to exist, the most apparent one is an underestimation of growth. The observed growing stock (Table 5) and the observed growth (Table 6) were in most cases larger than the corresponding predicted values. One cannot, of course, make any categorical conclusions based on the present work. However, since the oldest data used to develop the biological sub-models of AVVIRK-2000 (Table 1) originate back to before 1920 and the predictions were made for the period 1971–2000, it is natural to question whether the results seen could be a consequence of a general increase in forest growth. Several examples from Europe, where trends over time are studied, have indicated that diameter- and height growth have been increasing over the past decades (see e.g. Spiecker et al. 1996). Also in the Nordic countries, positive growth trends have been seen (e.g. Eriksson and Johansson 1993, Elfving and Tegnhammar 1996). In a Norwegian study, carried out by Elfving et al. (1996), no such trends could be settled, however. On the other hand, a recent study of the possible influence of nitrogen and acid deposition on forest growth in Norway, indicate quite large increases in growth for the southernmost part of the country (Solberg et al. 2004). Based on the trends seen in Europe, and partly also in Norway, it is therefore probably more likely with an underestimation of growth and growing stock, as seen for the present study, than an overestimation, as long as historical empirical data are used to develop the biological sub-models applied in the scenario models.

It is also worth mentioning that some newly developed models for prediction of mortality in even-aged forest (Eid and Øyen 2003), based on representative Norwegian NFI data, indicated a somewhat higher mortality rate than the one applied in the present study, i.e. the mean annual mortality rate for Norway spruce dominated forest in Norway was 0.58%, while the corresponding rate of the mortality model applied in AVVIRK-2000 (see Table 1, Braastad 1982) was 0.40%. The new mortality models also showed that the annual mortality rate was positively correlated to site quality. Since the mean site quality of the test site was relatively high (Table 3), one would expect an even higher mean mortality rate than 0.58%. This means that it is more likely that the mortality of the test site is underestimated than overestimated. Isolated, an underestimation of mortality produces an overestimation of growing stock. The fact that the opposite tendency was seen in the present study (Table 5), draws further attention to a possible underestimation due to the applied diameter- and/or height growth models.

Irrespective of whether there actually is an underestimation of growth or not, the long-term effects of the differences with respect to growing stock seen in year 2000 were relatively large (Figs. 2 and 3). While the observed growing stock in year 2000 was 9640 m^3 and the predicted growing stock in the same year predicted in 1970 was 9388 m^3 (Table 5), i.e. a difference of 2.6%, the predicted total potential harvests for the period 2001–2070 based on 2000 data was 36250 m^3, while the corresponding potential predicted in 1970 was 34350 m^3, i.e. a difference of 5.2%, and the growing stock in year 2070 predicted in 2000 was 7642 m^3, while it was 6435 m^3 predicted in 1970, i.e. a difference of 15.8%. Although these differences are quite large, the implications may not be severe since the absolute quantities predicted in such a time horizon is less important. It is vital, however, to avoid tendencies with respect to the relative relations between alternative scenarios.

The consequence of an evaluation process like the one performed in the present work could be a calibration of the model in accordance with the test results. When Nabuurs et al. (2000) tested EFISCEN on historic Finnish NFI data, it was found necessary to improve certain parts of the biological basis, i.e. the modelling of age development, the thinning regimes and the growth responses after thinnings. Although deviations between observed and predicted values were seen, no calibration of the applied model (FOLPI) was suggested when Manley (1998) compared actual wood supply with the supply derived from alternative scenarios in New Zealand. The same conclusion is drawn from the present test of AVVIRK-2000. Considering the numerous uncertainties related to management planning in general, the differences between observed and predicted values should be seen as small. Hence the model may be applied for practical purposes without fundamental changes or calibrations of the biological model basis.

This does not mean, however, that the model is proved to be ”correct”. Such a conclusion can never be the result of a test like the one performed in the present study. On the other hand, if a test fails to falsify a model, this may help to build user confidence of the model. The present evaluation of AVVIRK-2000 should be seen as a contribution in this direction. A large-scale forestry scenario model will never reach a state where it can be regarded as ”correct” and/or ”completed”. There should be a constant focus on knowledge gaps and model testing, and calibrations should continue as long as the model is in use.

5 Conclusions

The biological sub-models applied in the large-scale forestry scenario model AVVIRK-2000 have been extensively evaluated and tested by comparing observed and predicted values. The present work was an attempt to test the totality of the model, including the interactions between the sub-models and other parts of the model, and thereby evaluate the applicability of the model for use in management planning. In general the differences between observed and predicted values were small, and well within the ranges that one may expect when the sources of uncertainty related to large-scale forestry scenario analyses and management planning in general are considered. The data used for the tests were limited with respect to period of time and forest area, and should not be seen as a final validation. As long as the model is in use, further tests should continue and subsequent possible calibrations should be performed.

Acknowledgements

This work was financially supported by the Forest Trust Fund, the Norwegian Ministry of Agriculture, as a part of research project No.143434/110.

References

Aasland, T. 1992. Taksering av Aas skog, Gjøvik, 1990. Department of Forest Sciences, Agricultural Univ. of Norway, Ås. Aktuelt fra skogforskningen 18/92. 23 p. (In Norwegian).

Blingsmo, K. 1984. Diameter increment functions for stands of Birch, Scots pine and Norway spruce. Norwegian Forest Research Institute, Ås, Norway. Research paper of the Norwegian Forest Research Institute 7/84. 22 p. (In Norwegian with English summary).

Braastad, H. 1966. Volume tables for birch. Norwegian Forest Research Institute, Ås, Norway. Reports of the Norwegian Forest Research Institute 21: 23–78. (In Norwegian with English summary).

— 1974. Diameter increment functions for Picea abies. Norwegian Forest Research Institute, Ås, Norway. Reports of the Norwegian Forest Research Institute 31: 1–76. (In Norwegian with English summary).

— 1975. Yield tables and growth models for Picea abies. Norwegian Forest Research Instiute, Ås, Norway. Reports of the Norwegian Forest Research Institute 31: 357–540. (In Norwegian with English summary).

— 1977. Tilvekstmodellprogram for bjørk. Norwegian Forest Research Institute, Ås, Norway. Research paper of the Norwegian Forest Research Institute 1/77. 17 p. (In Norwegian).

— 1980. Growth model computer program for Pinus sylvestris. Norwegian Forest Research Institute, Ås, Norway. Reports of the Norwegian Forest Research Institute 35: 265–360. (In Norwegian with English summary).

— 1982. Natural mortality in Picea abies stands. Norwegian Forest Research Institute, Ås, Norway. Research paper of the Norwegian Forest Research Institute 12/82. 46 p. (In Norwegian with English summary).

Brantseg, A. 1967. Volume functions and tables for Scots pine. South Norway. Norwegian Forest Research Institute, Ås, Norway. Reports of the

Norwegian Forest Research Institute 22: 695–739. (In Norwegian with English summary).

Camenson, D., Sleavin, K. & Greer, K. 1996. Spectrum: an analytical tool for building natural resource management models. In: Päivinnen, R., Roihuvuo, L. & Siitonen, M. (Eds.). Large-scale forestry scenario models: experience and requirements. European Forest Institute Proceedings 5: 133–142.

Eid, T. 2002. Områdetakster – bruk av data i langsiktige konsekvensanalyser? In: Woxholt, S. (Ed.). Kontaktkonferanse mellom skogbruket og skogforskningene i Buskerud og Vestfold, Krødsherrad, 27.–29. August 2002. p. 50–54. Department of Forest Sciences, Agricultural Univ. of Norway, Ås. Aktuelt fra skogforskningen 3/02. (In Norwegian).

— 2003. Registreringer i Aas skog – skogtilstand i år 2000 og utvikling fra 1960 til 2000. Oppdragsrapport fra Skogforsk 8/03. 24 p. (In Norwegian.)

— & Hobbelstad, K. 2000. AVVIRK-2000 – a large-scale forestry scenario model for long-term investment, income and harvest analyses. Scandinavian Journal of Forest Research 15: 472–482.

— & Øyen, B.-H. 2003. Models for prediction of mortality in even-aged forest. Scandinavian Journal of Forest Research 18: 64–77.

Elfving, B. & Tegnhammar, L. 1996. Trends of tree growth in Swedish forests 1953–1992: an analysis based on sample trees the National Forest Inventory. Scandinavian Journal of Forest Research 11: 26–37.

— , Tegnhammar, L. & Tveite, B. 1996. Studies on growth trends of forests in Sweden and Norway. In: Spiecker, H., Mielikäinen, K., Köhl, M. & Skovsgaard, J.P. (Eds.). Growth trends of European forests. Springer, Berlin. p. 61–70.

Eriksson, H. & Johansson, U. 1993. Yields of Norway spruce (Picea abies (L.) Karst.) in two consecutive rotations in southwestern Sweden. Plant and Soil 154: 239–247.

Gisnås, A. 1981. Taksering av Aas skog, Gjøvik 1979. Department of Forest Mensuration, Agricultural Univ. of Norway. Fagnytt fra Institutt for skogtaksasjon 1/81. 9 p. (In Norwegian).

Hobbelstad, K. 1998. Er det noe galt ved bruk av balansekvantumsberegningene? In: Woxholtt, S. (Ed.). Kontaktkonferanse skogbruk – skogforskning. Elverum 5. og 6. November 1997. p. 40–43. Department of Forest Sciences, Agricultural Univ. of Norway, Ås. Aktuelt fra skogforskningen 1/98. (In Norwegian).

Hoen, H.F. & Eid, T. 1990. En modell for analyse av behandlingsstrategier for en skog ved bestandssimulering og lineær programmering. Norwegian Forest Research Institute, Ås, Norway. Research paper of the Norwegian Forest Research Institute 9/90. 35 p. (In Norwegian).

— & Gobakken, T. 1997. Brukermanual for bestandssimulatoren GAYA v1.20. Department of Forest Sciences, Agricultural University of Norway. Internal report. p. 59. (In Norwegian).

Hofstad, O. 1998. «Riktig» avvirkning. Norsk Skogbruk 12: 26–27. (In Norwegian).

Huang, S., Yang, Y. & Wang, Y. 2003. A critical look at procedures for validating growth and yield models. In: Amaro, A., Reed, D. & Soares, P. (Eds.). Modelling forest systems. CABI publishing, London, UK. p. 271–294.

Hynynen, J., Ojansuu, R., Hökkä, H., Siipilehto, J., Salminen, H. & Haapala, P. 2002. Models for predicting stand development in MELA system. Finnish Forest Research Institute, Helsinki, Finland. Metsäntutkimuslaitoksen tiedonantoja – Research Papers of the Finnish Forest Research Institute 835. 116 p.

Johnson, K., Stuart, T. & Crimm, S. 1986. FORPLAN Version 2: An overview. USDA Forest service, Land Management Planning Systems Section, Washington D.C. 90 p.

Lappi, J. 1992. JLP: A linear programming package for management planning. Finnish Forest Research Institute, Suonenjoki, Finland. Metsäntutkimuslaitoksen tiedonantoja – Research Papers of the Finnish Forest Research Institute 414. 134 p.

Lundström, A. & Söderberg, U. 1996. Outline of the Hugin system for long-term forecasts of timber yields and possible cut. In: Päivinen, R., Roihuvuo, L. & Siitonen, M. (Eds.). Large-scale forestry scenario models: experience and requirements. European Forest Institute Proceedings 5: 63–77.

Manley, B. 1996. Application of the IFS/FOLPI forest estate modelling system to large-scale forestry scenario modelling in New Zealand. In: Päivinen, R., Roihuvuo, L. & Siitonen, M. (Eds.). Large-scale forestry scenario models: experience and requirements. European Forest Institute Proceedings 5: 295–305.

— 1998. Forest scenario analyses in New Zealand. In: Nabuurs, G.-J., Nuutinen, T., Bartelink, H. & Korhonen, M. (Eds.). Forest scenario modelling for ecosystem management at the landscape level.

European Forest Institute Proceedings 19: 73–88.

Martell, D., Gunn, E. & Weintraub, A. 1998. Forest management challenges for operational researchers. European Journal of Operational Research 104: 1–17.

Myrbakken, S. 1998. Hva er riktig avvirkningsnivå? Norsk Skogbruk 10: 8–9. (In Norwegian).

Nabuurs, G.J. & Päivinen, R. 1996. Large scale forestry scenario models – a compilation and review. Working Paper European Forest Institute 10. 174 p.

— , Schelhaas, M-J. & Pussinen, A. 2000. Validation of the European forest information scenario model (EFISCEN) and a projection of Finnish forests. Silva Fennica 34(3): 167–179.

Nersten, S. 1973. Aas skog. Utviklingen i tidsrommet 1960–70 og noen framtidsperspektiver. Department of Forest Mensuration, Agricultural Univ. of Norway. Fagnytt fra Institutt for skogtaksasjon 4/73. 38 p. (In Norwegian).

Nilsson, S., Sallnäs, O. & Duinker, P. 1992. Future forest resources of Western and Eastern Europe. International Institute of Applied System Analysis. The Parthenon Publishing Group, UK. 496 p.

Sallnäs, O. 1990. A matrix growth model of the Swedish forest. Studia Forestalia Suecica 183. 23 p.

Siitonen, M. 1993. Experiences in the use of forest management planning models. Silva Fennica 27(2): 167–178.

Solberg, S., Andreassen, K., Clarke, N., Tørseth, K., Tveito, O.E., Strand, G.H. & Tomter, S. 2004. The possible influence of nitrogen and acid deposition on forest growth in Norway. Forest Ecology and Management 192: 241–249.

Spiecker, H., Mielikäinen, K., Köhl, M. & Skovsgaard, J.P. 1996. Conclusion and summary. In: Spiecker, H., Mielikäinen, K., Köhl, M. & Skovsgaard, J.P. (Eds.). Growth trends of European forests. Springer, Berlin. p. 369–372.

Strand, L. 1967. Høydekurver for bjørk. P: 291–296 in Braastad, H. (Ed.). Yield tables for birch. Norwegian Forest Research Institute, Ås, Norway. Reports of the Norwegian Forest Research Institute 22: 265–365. (In Norwegian).

Tveite, B. 1967. The relationship between mean height by Lorey's formula (H_L) and some other stand height in spruce and pine stands. Norwegian Forest Research Institute, Ås, Norway. Reports of the Norwegian Forest Research Institute 22: 483–538. (In Norwegian with English summary).

— 1976. Bonitetskurver for furu. Norwegian Forest Research Institute, Ås, Norway. Internal report. p. 40. (In Norwegian).

— 1977. Site-index curves for Norway spruce (Picea abies (L.) Karst.). Norwegian Forest Research Institute, Ås, Norway. Reports of the Norwegian Forest Research Institute 33: 1–84. (In Norwegian with English summary).

Vanclay, J.K. & Skovsgaard, J.P. 1997. Evaluating forest growth models. Ecological Modelling 98: 1–12.

Vestjordet, E. 1967. Functions and tables for volume of standing trees. Norway spruce. Norwegian Forest Research Institute, Ås, Norway. Reports of the Norwegian Forest Research Institute 22: 543–574. (In Norwegian with English summary).

Weintraub, A. & Bare, B. 1996. New issues in forest land management from an operations research perspective. Interfaces 26: 9–25.

Total of 46 references