Use of Uncertain Inventory Data in Forestry Scenario Models and Consequential Incorrect Harvest Decisions

Tron Eid

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Uncertainty in long-term timber production analyses usually focus success of regeneration, growth/mortality of trees and future fluctuations of timber prices/harvest costs, while uncertainty related to inventory data is paid less attention. At the same time, evaluations of inventory methods usually stop when the error level is stated, while the uncertainty accompanied by using the data is seldom considered.

The present work addresses uncertain inventory data in long-term timber production analyses. Final harvest decisions, i.e. possible outcome intervals with respect to timing and expected net present value-losses due to incorrect timing, were considered. A case study was presented where inventory data errors according to different error levels were generated randomly. The selected error levels were based on observations from practical forest inventories in Norway. The analysis tool was GAYA-JLP. The impact of errors on decisions was derived through repeated computations of management strategies maximising net present value without harvest path constraints.

A real rate of discount of 3 % and an error level of 15 % resulted in expected net present value-losses of 1 NOK ha^{-1} for basal area, 63 NOK ha^{-1} for mean height, 210 NOK ha^{-1} for site quality, 240 NOK ha^{-1} for stand age, and 499 NOK ha^{-1} when random errors occurred simultaneously for all these variables. The expected net present value-losses varied considerably. The largest losses appeared for stands with ages around optimal economical rotation ages. The losses were also relatively large for young stands, while they were relatively low for overmature stands.

The experiences from the case study along with considerations related to other sources of uncertainty may help us to get a more realistic attitude to the reliability of long-term timber production analyses. The results of the study may also serve as a starting point in a decision oriented inventory planning concept, in which alternatives for inventory design and intensity are based on considerations with respect to inventory costs as well as net present value-losses.

Keywords forest management, uncertain inventory data, final harvest decisions, expected net present value-losses, inventory planning

Author's address Department of Forest Sciences, Agricultural University of Norway, P.O. 5044, N-1432 Ås, Norway **Tel** +47 64 948 901 **E-mail** tron.eid@isf.nlh.no

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1 Introduction

Large scale forestry scenario models and the use of them for long-term timber production analyses require knowledge from disciplines such as forest inventory, forest biology and production, economics, mathematics and operations research. The characteristics of such analyses, i.e. the multidisciplinary concept, the long time horizon involved, and the randomness of nature, involves much uncertainty. Quite often questions concerning uncertainty related to such analyses focus success of regeneration, growth/mortality of trees and development and fluctuations of timber prices/harvest costs over time, all factors where the uncertainty only exceptionally can be reduced by any human action. Long-term timber production analyses and the uncertainty related to inventory data (present state of the forest) tend to be paid less attention, in spite of the fact that accuracy can be improved, and accordingly uncertainty reduced, by changing the design or intensity of the inventory. At the same time, however, evaluations of inventory methods usually stop when the expected error level of the methods is stated, while the uncertainty accompanied by application of these data is ignored.

In a "decision oriented inventory planning" concept the uncertainty accompanied by using erroneous data is considered. A basic requirement for decision oriented inventory planning is to express the value of the information derived from the inventory in monetary terms. The problem should comprise the entire planning process, i.e. inventory planning with respect to intensity and design, and the costs involved with this, as a start, and decisions with respect to treatments in individual stands, including the corresponding cash flow and net present value (NPV), as a final step.

Cochran (1977) and Hamilton (1978) suggest cost-plus-loss analyses as one possible approach to decision oriented inventory planning. The approach assumes the total costs to be minimised. The total costs include the costs of performing the inventory and the expected loss as a result of future incorrect decisions due to uncertain inventory data. The costs of an inventory are usually quite simple to determine. It is harder to operationalise the determination of the future loss related to uncertainty. Examples of applied cost-plus-loss analyses, however, which address inventory optimisation in forest stands with respect to design, intensity and timing related to uncertainty, are given by Ståhl (1994), where the "loss part" of the problem was approached by imitating random errors through simulations, and by Ståhl et al. (1994), where uncertainty was approached in a Bayesian framework with state variables handled as probability distributions instead of point estimates.

Also the present study deals with topics related to the uncertainty of the initial description of forest stands. In addition to decision oriented inventory planning, general problems related to the reliability of long-term timber production analyses are discussed. Final harvests are focused, i.e. possible outcome intervals with respect to timing and expected NPV-losses as a result of incorrect timing. The problems are illustrated through a case study from a forest comprising 25 stands where random errors observed in practical Norwegian inventories are imitated by means of simulations. The computations are carried out with GAYA-JLP (Lappi 1992, Hoen and Eid 1990, Hoen and Gobakken 1997), a large scale forestry scenario model for long-term timber production analyses.

2 Material and Methods

2.1 Accuracy of Inventories for Practical Management Planning

The average size of a forest property in Norway is about 50 ha (Census of Agriculture and Forestry 1991), and individual stands are used as the basic units for almost all forest inventories for practical management planning. In the period from 1990 to 1995 the annually surveyed forest area varied from approximately 3700 km^2 to 6500 km^2 (Skogbruksplanlegging 1998). About 50 % of this area was recorded by field inventories, while the remaining part was covered by photo inventories (Næsset et al. 1992). The field inventories are usually carried out as ordinary relascope inventories, i.e. stand height (mean height by basal area) is computed from height measure-

Table 1. Accuracy of inventories for practical planning in Norway.

Variable	Source	Inventory method	No. of planners	No. of sites for each planner	D (%) Min.	D (%) Max.	SD (%) Min.	SD (%) Max.
Volume	Eid (1992)	Field	2	2	0.8	1.5	19.9	27.9
	Eid (1992)	Photo	1	1	4.6	-	14.6	-
	Eid (1996)	Photo	2	3	5.4	29.7	16.4	25.3
	Eid and Nersten (1996)	Photo	1	1	6.5	-	24.5	-
	Eid and Nersten (1996)	Field	8	1	1.6	15.4	11.9	17.8
Age	Eid (1992)	Field	2	2	1.3	2.7	21.7	22.7
	Eid (1992)	Photo	1	1	1.3	-	15.2	-
	Eid (1996)	Photo	2	3	0.5	11.3	13.3	25.2
	Eid and Nersten (1996)	Photo	1	1	6.1	-	11.3	-
	Eid and Nersten (1996)	Field	8	1	8.5	16.8	7.7	15.5
Site quality	Eid (1992)	Field	2	2	2.0	3.8	12.2	15.7
	Eid (1992)	Photo	1	1	7.4	-	13.3	-
	Eid (1996)	Photo	2	3	2.3	11.5	10.2	22.0
	Eid and Nersten (1996)	Photo	1	1	6.2	-	13.8	-
	Eid and Nersten (1996)	Field	8	1	7.3	17.7	12.9	15.3

ments of sample trees selected by means of the relascope, and basal area is measured by the relascope at subjectively selected sample plots. Determination of height in photo inventories is usually based on measurements done by interpreters using stereo-plotters, while determination of density usually is based on ocular estimation, and expressed by crown closure. In a few cases the basal area is determined directly by the interpreters. For the field inventories, stand site quality and stand age are mainly determined through field measurements of subjectively selected samples in each stand. For the photo inventories, site quality and age are mainly determined by photo-interpretation only. In some cases photo-interpretation and field measurements are combined.

Several studies have been carried out over the past 5–10 years in order to quantify the accuracy of different stand variables in inventories for practical management planning. All these studies involve intensive inventories used as reference to be compared with the practical inventories. The reference inventories have in most cases been performed as systematic sample plot inventories within stands. Most of the studies involve determination of the accuracy of volume only. A joint presentation with respect to the accuracy of volume comprising 14 different experiments is given by Eid and Næsset (1998). Some of the studies, i.e. Eid (1992, 1996) and Eid and Nersten (1996) do, in addition to stand volume, also comprise evaluations of stand site quality and stand age. Some results from these studies are presented in Table 1. The accuracy has been quantified as D%, i.e. the mean difference between variable values of the practical inventory and of the reference inventory expressed in percent of the mean values of reference inventory. D% is expressed in absolute values. The accuracy has further been expressed as SD%, i.e. the mean standard deviation of the differences between variable values of the practical inventory and of the reference inventory in percent of the mean values of the reference inventory.

2.2 Random Errors and NPV-Losses

In order to imitate the random errors of inventories for practical management planning in Norway, data sets were generated randomly by using the SAS software package (SAS users guide 1985). 25 Norway spruce (*Picea abies* (L.) Karst.) stands, each with an area assumed to be one ha, were used as reference data set (Table 2). Basal area, mean height weighted by basal area, stand

Table 2. Initial state for the reference data set, period of final harvest and NPV.

Stand no.	Initial state reference data set				Period of final harvest	NPV (NOK ha^{-1})
	Basal area (m^2 ha^{-1})	Mean height by basal area (m)	Site quality (m)	Age (yr)		
1	-	-	23.2	3	10	30767
2	-	-	23.0	8	10	37541
3	-	-	23.1	13	10	45505
4	15.6	8.3	22.8	23	8	52244
5	46.6	22.3	22.9	54	2	127707
6	54.1	24.7	22.9	64	1	167399
7	62.4	27.4	22.9	77	1	220520
8	-	-	20.0	5	>10	18744
9	-	-	19.9	10	10	22864
10	-	-	20.1	15	10	29542
11	15.4	8.7	20.1	27	8	36894
12	26.7	15.4	19.9	42	6	49171
13	33.1	18.7	19.8	51	3	66715
14	33.3	20.3	20.1	58	2	73546
15	50.1	24.9	19.7	80	1	140826
16	-	-	17.1	12	10	14208
17	14.8	8.9	17.2	32	9	26263
18	30.8	16.4	16.9	54	4	45876
19	28.8	18.6	17.1	64	3	48125
20	37.5	20.9	16.9	77	1	72283
21	41.0	22.0	17.0	81	1	86341
22	41.7	21.7	17.1	82	1	87030
23	49.3	22.1	17.1	82	1	103902
24	48.1	22.6	17.0	92	1	110977
25	51.3	23.0	16.7	97	1	121332

age, and site quality according to the H_{40} system, i.e. dominant height in meter at breast height age 40 years (Tveite 1977), were selected for generation of data sets with random errors. 100 different data sets were produced for each variable. The same number of data sets was also produced when random errors within each stand were assumed to occur simultaneously for all four variables. In order to simplify, the random errors for the different variables were in this case assumed to be independent.

The generated data sets were assumed free of systematic errors. Data sets with three different random error levels were generated, i.e. the random error of a generated data set, calculated as the mean standard deviation of the differences between variable values of the generated data set and of the reference data set in percent of the mean values of the reference data set, were 10 %, 15 % and 20 % respectively. Including the three error levels, the analyses comprise a total of 1500 generated data sets, each with 25 different stands.

Long-term timber production computations were made with GAYA-JLP, a large scale forestry scenario model based on simulation of treatments in each stand (Hoen and Eid 1990, Hoen and Gobakken 1997) and linear programming for solving management problems at forest level (Lappi 1992). All components of the model are deterministic. Projections and economic calculations are heavily based on the “average tree” of each stand, i.e. basal area mean diameter (D_{ba}) and mean height weighted by basal area (H_L), and the number of stems ha^{-1} (N). The main features of the projections are diameter increment functions (Blingsmo 1984), where increment is predicted with age, dominant height, site

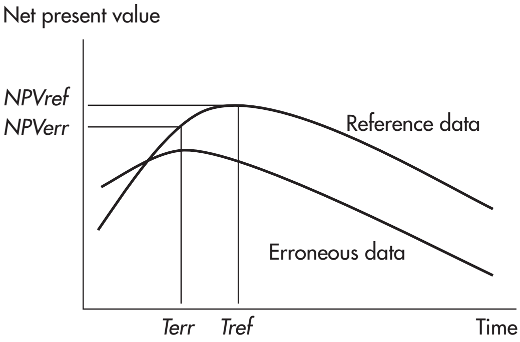


Fig. 1. An illustration of how NPV-losses may arise due to erroneous inventory data.

quality, N and D_{ba} as independent variables, height development models (Tveite 1976, 1977, Braastad 1977) with H_L, age and site quality as independent variables, and a mortality model (Braastad 1982) with N as the only independent variable. Stands in the young growth phase do not require inventory data for basal area and H_L (Table 2) since the model estimates the state of these variables prior to the forest enter the thinning phase. Timber values are estimated from price functions (Blingsmo and Veidahl 1992), and harvest costs from a tariff agreed upon by employers' and employees' organisations (Overenskomst 1996). Timber value- as well as cost calculations directly or indirectly use D_{ba} and H_L as input variables.

Management strategies maximising the NPV without a harvest path constraint were calculated. An annual real rate of discount of 3 % was applied. Projections were performed for ten five-year periods, and all treatments were assumed to take place in the middle of a period. Final harvests were assumed to be clear cutting, immediately followed by planting. The total NPV of the reference data set was approximately 1.836 mills. NOK. This corresponds to a mean NPV of 73453 NOK ha^{-1}. Optimal period of final harvest and NPV of individual stands in the reference data set are presented in Table 2.

Fig. 1 illustrates how NPV-losses may arise due to erroneous inventory data. The upper line shows the true NPV from final harvests in certain time periods with correct data, while the lower line represents the NPV indicated by data with errors. When the decision is based on erroneous data, final harvest is carried out at time *Terr* instead *Tref*, and the resulting NPV-loss is the difference between *NPVref* and *NPVerr*. Formally, the expected NPV-losses of the simulated data were determined as;

Let $NPVerr_{ij}$ be the NPV of stand no. i (i=1, 2, .., m) in data set no. j (j=1, 2, .., n), and $NPVref_i$ the NPV of stand no. i (i=1, 2, .., m) in the corresponding reference data set. The NPV-loss, due to an error for a certain variable, of stand no. i and data set no. j is then calculated as:

$$NPVloss_{ij} = NPVref_i - NPVerr_{ij}$$

The expected NPV-losses of stand no. i (i=1, 2, .., m) are calculated as:

$$NPVloss_i = \left(\sum_{j=1}^{n} NPVloss_{ij} \right) / n$$

while the expected NPV-losses of all stands are calculated as:

$$NPVloss = \left(\sum_{i=1}^{m} \sum_{j=1}^{n} NPVloss_{ij} \right) / mn$$

3 Results

An error level of 15 % results in expected NPV-losses of 1 NOK ha^{-1} for basal area, 63 NOK ha^{-1} for mean height weighted by basal area, 210 NOK ha^{-1} for site quality and 240 NOK ha^{-1} for age (Table 3). The expected NPV-losses with random errors simultaneously for all variables are 243 NOK ha^{-1}, 499 NOK ha^{-1} and 931 NOK ha^{-1} for error levels 10 %, 15 % and 20 %, respectively, i.e. the NPV-losses can be reduced by 688 NOK ha^{-1} (931 NOK ha^{-1} – 243 NOK ha^{-1}) if the error level is reduced from 20 % to 10 %.

With an error level of 15 % and with random errors simultaneously for all variables, NPV-losses vary between 64 NOK ha^{-1} and 1471 NOK ha^{-1} for individual stands (Table 4). The resulting intervals of period for final harvests vary

Table 3. Expected NPV-losses due to random errors for different variables.

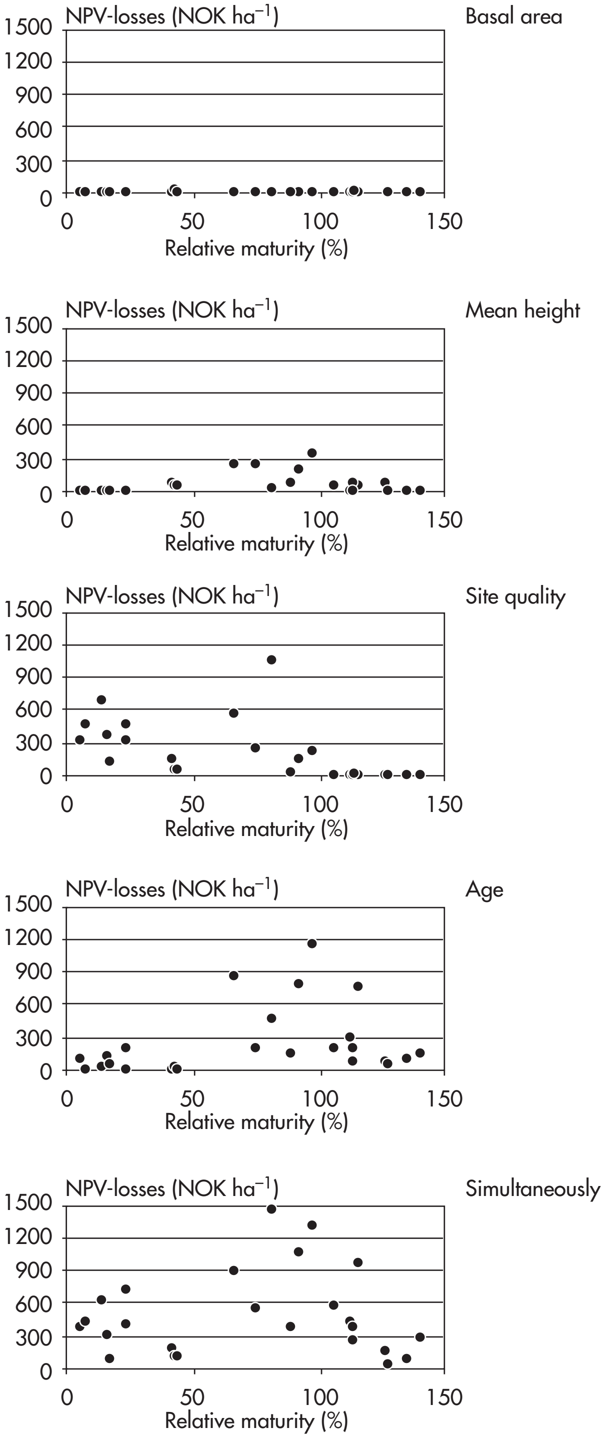
Error level (%)	Expected NPV-losses (NOK ha^{-1}) Basal area	Mean height by basal area	Site quality	Age	Simultaneously
10	0	28	131	105	243
15	1	63	210	240	499
20	3	147	277	497	931

Table 4. Number of outcomes for final harvest in different periods and expected NPV-losses due to random errors simultaneously for all variables. Individual stands. Error level 15 %.

Stand no.	Reference data set		Generated data sets – no. of outcomes final harvest in period											Expected NPV-losses (NOK ha^{-1})
	Age (yr)	Period of final harvest	1	2	3	4	5	6	7	8	9	10	>10	
1	3	10										61	39	410
2	8	10									34	48	18	631
3	13	10								15	39	39	7	740
4	23	8							4	74	21	1		180
5	54	2	34	38	19	9								1342
6	64	1	90	6	3	1								990
7	77	1	99		1									292
8	5	>10										40	60	442
9	10	10									27	36	37	325
10	15	10								4	22	66	8	416
11	27	8							3	53	39	5		116
12	42	6			18	32	11	34	4	1				911
13	51	3	4	16	50	15	14	1						1471
14	58	2	30	42	20	7	1							1080
15	80	1	98	2										158
16	12	10									4	43	53	89
17	32	9								27	57	16		102
18	54	4		1	26	35	25	10	3					559
19	64	3	14	33	38	11	4							391
20	77	1	75	18	7									578
21	81	1	92	4	4									443
22	82	1	93	7										276
23	82	1	93	6	1									382
24	92	1	99	1										64
25	97	1	99	1										88

considerably among the stands. For example in stand no. 25, 99 % of the data sets provide for harvests in correct period, while in stand no. 18 only 35 % of the data sets provide for harvests in correct period. For stand no. 12, 13 and 18 there are intervals of final harvest that comprise six periods, i.e. 30 years.

In Fig. 2, NPV-losses of individual stands for error level 15 % are plotted over relative maturity. Relative maturity is defined as initial stand age (age at the time of inventory in Table 2) in percent of optimal economical rotation ages calculated to 55, 63 and 72 years for site quality H_{40} 21.5 m, $H_{40} \in [18.5$ m, 21.5 m) and $H_{40} < 18.5$ m, respec-



Relative maturity (%)	No. of stands	Expected NPV-losses (NOK ha^{-1})
0–40	7	0
41–80	5	4
81–120	9	1
121–150	4	0
All	25	1

Relative maturity (%)	No. of stands	Expected NPV-losses (NOK ha^{-1})
0–40	7	0
41–80	5	132
81–120	9	92
121–150	4	20
All	25	63

Relative maturity (%)	No. of stands	Expected NPV-losses (NOK ha^{-1})
0–40	7	395
41–80	5	210
81–120	9	160
121–150	4	0
All	25	210

Relative maturity (%)	No. of stands	Expected NPV-losses (NOK ha^{-1})
0–40	7	70
41–80	5	210
81–120	9	454
121–150	4	93
All	25	240

Relative maturity (%)	No. of stands	Expected NPV-losses (NOK ha^{-1})
0–40	7	436
41–80	5	374
81–120	9	773
121–150	4	150
All	25	499

Fig. 2. Expected NPV-losses plotted over relative maturity for individual stands and expected NPV-losses according to different groups of relative maturity. Error level 15 %.

tively. The figure shows that the largest NPV-losses appear in stands with relative maturity near 100 %. The NPV-losses are also relatively large for younger stands. For stands with a high relative maturity the NPV-losses are quite low.

4 Discussion

For an evaluation process, which always should accompany long-term timber production analyses, it is essential to map responses and sensitivity, and gain knowledge about the importance of different input variables used in the scenario model. The experiences from the case study along with considerations of other sources of uncertainty (growth, prices, etc.), may therefore help the users to get a realistic attitude to the reliability of such analyses. The experiences from the case study may also serve as a starting point in a decision oriented inventory planning process, where the alternatives for inventory design and intensity are based on considerations with respect to inventory costs as well as NPV-losses.

The effects of errors depend on how and to what extent a variable is utilised in the scenario model. Important parts of diameter growth-, height development-, timber value/cost calculations in GAYA-JLP are based on the "average tree" of a stand, i.e. a tree described by D_{ba} and H_L. The importance of the four variables with respect to NPV-losses (insignificant losses for basal area, relatively small losses for mean height and large losses for site quality and age (Table 3)), can be explained by how D_{ba} and H_L are influenced by the simulated errors.

For the present case study it is assumed proportionality between basal area and N with respect to errors, i.e. the initial N is changed according to the actual error for basal area, while the initial D_{ba} remains unaffected. An erroneous basal area accordingly only marginally influences diameter growth (Blingsmo 1984) and natural mortality (Braastad 1982) through a changed N. Height development (Tveite 1976, 1977, Braastad 1977) is unaffected by the basal area and timber value/cost calculations (Blingsmo and Veidahl 1992, Overenskomst 1996) are only slightly influenced through the small changes of the predicted diameter growth. The NPV-losses due to an erroneous basal area accordingly become insignificant. H_L is used directly as well as indirectly for diameter growth predictions, height development and timber value/cost calculations. This means that H_L is involved in all important parts of the scenario model. Thus, the result is relatively large NPV-losses due to random errors for this variable. Site quality is, of course, important for diameter growth and height development. Since site quality directly affects the development of the "average tree", i.e. D_{ba} and H_L, also timber value/cost computations are affected by random errors for this variable. Jointly all these effects heavily influence decisions with respect to timing of final harvests, and consequently NPV-losses become relatively large. Also age directly affects the development of the "average tree", and for final harvest decisions the age plays an even more important role than site quality. An erroneous age, therefore, in general implies the largest NPV-losses among the four variables.

When it comes to inventory planning there are several topics related to the experiences from the case study that can be discussed. At the national level, a first step in a decision oriented inventory planning concept could be to asses the appropriateness of the present inventory intensity in Norway, and the costs involved with this. The ha^{-1} costs of a management plan designed for practical planning, including a state description and treatment suggestions, vary according to the size of the property. The costs of plans produced by e.g. the forest owners association in the Inn-Trøndelag district for 1997 varied from 200 NOK ha^{-1} for properties with an area of 10 ha to 100 NOK ha^{-1} for properties with an area of 400 ha (Handbok for driftsplanlegging 1997). Approximately 50 % these costs are connected directly to the inventory work. The rest of the costs are related to calculations and plan presentation, i.e. these costs may basically be regarded as fixed, and independent of the intensity of the inventory. If the inventory costs, varying from 50 to 100 NOK ha^{-1}, are compared to the expected NPV-losses of the case study, it seems to be room for more intensive inventories for practical planning in Norway. It is most certainly possible to reduce the error level from e.g. 20 % to 15 % for less inventory costs than 431 NOK ha^{-1}, which is the reduced NPV-losses of the case study if the error level is changed from 20 % to 15 % (Table 3).

The volume determination has traditionally been the most important state variable in practical inventories for management planning in Norway. The regulations of forest planning have certain rules for inventory design, and volume is the only variable with explicit requirements for accuracy (Norwegian Ministry of Agriculture 1995). Consequently the costs of volume determination in the inventories are considerably higher than costs of site quality and age determination. The results of the case study accordingly suggest changed practices. Since NPV-losses are larger for site quality and age compared to basal area and height (Table 3, Fig. 2), more efforts should be put into the inventory for these variables.

With few exceptions, practical inventories for management planning in Norway have been performed with the same intensity irrespective of the potential production level of the forest area and irrespective of the age of the forest. The case study shows, however, that the expected NPV-losses vary considerably among different stand types (Table 4). In a decision oriented inventory planning concept the potential value of the information should be reflected in the inventory design, i.e. stands with potentially large NPV-losses should be inventoried more intensively than stands with low potentials. When errors are considered simultaneously for all variables, stands with relative maturity (i.e. initial stand age in percent of optimal economical rotation age) around 100 % generally have the largest losses (Fig. 2). The expected NPV-losses for the oldest stands (relative maturity > 120 %) are relatively low, since decisions with respect to final harvest here (i.e. harvest in period 1) in most cased remain the same in spite of large errors. Generally this means that less attention should be paid to the inventory when the decision is “obvious”, as for the oldest stands, and more attention should be paid to the inventory when the decision is “less obvious”, as for the stands where the relative maturity do not deviate much from 100 %.

The variations with respect to NPV-losses (Table 4) show that the composition of the stands in a forest with respect to initial state is important for the level of the overall NPV-losses (Table 3). The selected stands of the case study provide for one example among an infinite number of possible compositions. For example, a forest composed of more stands with poor site qualities and/or more young stands would produce lower overall NPV-losses than those of the case study.

The present work considers random errors only. Systematic errors are probably at least as important when it comes to incorrect harvest decisions. For example, an underestimated site quality of 17.7 %, as observed by Eid and Nersten (1996), indicate that many stands will be harvested too late compared to the optimum, thus large NPV-losses will appear. Eid (1991) carried out extensive forest level computations where consequences of systematic errors on potential harvests, treatments decisions and NPV were mapped.

Future inventories are not considered in the case study, i.e. decisions with respect to final harvests in old stands taken in a distant future are based on an inventory carried out when these stands were young. For site quality maps that are used unchanged for practical management planning over several decades this may be relevant (Eid and Økseter 1999). However, usually inventories are carried out periodically every 10–20 years, thus the NPV-losses for the youngest stands may be of less interest if appropriate new information is available at the time when they are scheduled to be harvested. Ståhl et al. (1994) applied cost-plus-loss analyses for making periodic decisions (every 5th year) with respect to whether a new inventory should be implemented or not. The criterion for implementing a new inventory at a certain stage was whether the cost of performing the new inventory was not higher than the expected decrease in losses as a result utilizing information from of this inventory.

The results of the case study do, of course, also depend on the assumptions made for the timber production analyses. First of all, the case study is simplified in the sense that final harvest timing is the only decision considered, while numerous additional decisions have to be taken in the real world. Important examples are decisions related to the operational planning of the harvests where the decision-maker may have to respond temporarily to high timber prices or to rapidly decreasing tree vitality. In such cases appropriate information about timber volume, timber quality or tree vitality is essential, and losses involved with poor data quality may be considerable. Implementing a real rate of discount of 3 % is another important assumption made for the analyses. By for example changing the real rate of discount from 3 % to 4 %, fewer of the oldest stands would have high NPV-losses, while more old stands would be involved if the real rate of discount was changed to 2 %.

Also the selected management strategy, i.e. maximisation of NPV without any constraints, is important for the conclusions. A management strategy involving a non-declining harvest path constraint would also enforce more attention to the oldest stands (relative maturity >120 %) because such a strategy makes it necessary not only to consider the timing of the final harvest for different stands, but also the priorities between a large number of overmature stands. In addition, appropriate accuracy of the data in young stands would in general become more important because these stands potentially could be used for accelerating the harvests in periods with few old stands in order to fulfil the required non-declining harvest path. Random errors in connection with constraints may also produce problems related to infeasible solutions (e.g. Pickens and Dress 1988, Weintraub and Abramovich 1995) or to bias in the solutions (e.g. Kangas and Kangas 1999).

For a complete discussion of uncertainty related to long-term timber production analyses, also problems related to model errors of the numerous functions used for predictions (e.g. Kangas, 1996), to the stochasticity of future growth (e.g. Larsson, 1994; Pasanen, 1998) and to the stochasticity of future prices and costs (e.g. Ståhl, 1994; Leskinen and Kangas, 1998) should be addressed.

A debate related to the reliability of long-term timber production analyses has been going on in Norway over the past years (e.g. Hobbelstad 1998, Hofstad 1998, Myrbakken 1998). The background for the discussion has been decreased; instead of the expected increased, potential harvest levels for quite a large number of properties when new management plans have been produced. The main explanation for these results is probably lack of consistency between treatment assumptions made in analyses, and the actual performance of the treatments in the forest. The thinning practices are one example of such inconsistency. Long-term timber production analyses made 20–30 years ago assumed quite intensive thinning programmes, while most timber quantities cut during this period have been based on final harvests.

There may, of course, be other explanations for the declining potential harvest levels seen for these properties, for example inventory errors or failures related to some of the above referenced topics of uncertainty. To provide the users of the large scale forestry scenario models with realistic expectations, and a sound scepticism to the results of the analyses, is important to avoid such analyses to come in discredit when discrepancies between projections and reality are discovered. When it comes to actions towards the uncertainty, beyond a general warning of the existence of it, one step is actually to change the inventory planning and performance in a direction indicated by the results of the case study. This would reduce the uncertainty of the decisions and increase the profit of the decision-makers.

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