Scenario-Based Analysis of Possible Management Alternatives for Lithuanian Forests in the 21st Century

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Forest policy making increasingly draws on scenarios based on the simulation of forest resource dynamics. The simulation is utilised to evaluate regimes of stand treatments, reveal consequences of inadequate management, and define sustainable use alternatives. The paper presents large-scale forestry scenario model KUPOLIS that has been developed in 1997-2000. The use of the model is demonstrated in envisioning the Lithuanian forestry for the XXI century.

Key words: Forest resources, scenario modelling, strategic planning, timber yield, long-term forecasts

Introduction

Forest policy makers search for efficient measures in an environment where an increasing variety of forest products have to be produced from a decreasing or relatively stable forest land area. When facing the controversy, the large-scale forestry scenario models may be helpful. National forestry scenario models have been designed to deal with specific national problems and circumstances, making use of data available in a particular country (Nabuurs & Päivinen 1996).

Modelling of forest resource dynamics and use is a complicated task as it covers rather different spheres of theoretical and applied sciences. The traditional view to the forest only as the source of timber has changed and a much wide range of societal requirements must be considered. The Pan-European criteria for sustainable forest management (MCFPE 1998) can be adopted as guiding principles for modelling large-scale scenarios. Nabuurs *et al*. (2001) has exemplified the use of the criteria by simulating four different management regime scenarios for the whole Europe.

Large-scale forestry scenario model KUPOLIS (Petrauskas & Kuliešis 2000) was designed to assist forest policy makers. The main aim was to predict the development of forest resources under different economic and environmental conditions at the country level.

Traditionally, large scale forestry scenario modelling is based on optimisation or iterative simulation. Optimisation is used in JLP (Lappi 1992), MELA (Siitonen 1993, Siitonen and Nuutinen 1996), GAYA (Hoen 1996), SPECTRUM (Camenson *et al*. 1996), DTRAN (Hoganson 1996), and TAMM (Alig and Adams 1996). Iterative simulation is used in well known models as IIASA (Sallnas 1996), HUGIN (Lundström and Söderberg 1996), and HOPSY (Hinssenen 1994).

This study aims to present large-scale model KUPOLIS and reveal possible forest management alternatives for Lithuanian forests in the 21rst century.

Methods and materials

Data sources

In Lithuania, standwise inventory data are periodically collected for the strategic forest management and operational planning. Each compartment has a detailed description with more than 100 variables including administrative, soil, stand descriptors, as well as descriptors of non-timber values, such as stand capacity for the feeding wild animals, area coverage by berries, recreational value, etc. Data of the last two inventories are stored in an electronic form. The ongoing 5th cycle of inventory features a wide application of digital forest maps.

Lithuania's forest land area at present is over 2.16 million hectares. Forest land area covered by stands is 1.89 million hectares. Eight tree species (Table 1) covering more than 99 per cent of all forest stands.

50 per cent of Lithuanian forests are state owned, other forests are private or reserved for privatisation. Forests are divided into 4 groups. Strict reserve and special-purpose (group I and II) forests comprise 14.6 per cent of the total forest land area covered by stands. The remaining forests (groups III and IV) are protective and commercial. No cuttings are performed in forests of group I. In group II, forest stands are felled when they reach natural maturity, e.g. at the age of 200 years for Scots Pine. At present a very small part of forests of group II have attained the age of natural maturity. The scenarios are modelled for state and

Table 1. Forest resources in Lithuania (2000)

Tree species	Forest land area covered by stands, 1000 ha	Growing stock, million m^3 (overbark)
Pine *(Pinus sylvestris L.)*	702.1	144.7
Spruce *(Picea abies (L.) H. Karst.)*	441.9	84.9
Birch *(Betula pubescens Ehrh. + Betula verrucosa Ehrh.)*	375.2	60.8
Aspen *(Populus tremula L.)*	52.4	11.2
Black Alder *(Alnus glutinosa L.)*	108.5	19.8
Grey Alder *(Alnus incana L.)*	111.3	10.8
Oak *(Quercus robur L.)*	33.6	6.0
Ash *(Fraxinus excelsior L.)*	50.8	7.6
Others	12.2	1.7
Total	1888.0	347.5

private forests belonging to forests of groups III and IV, excluding stands that have not undergone the standwise inventory. In forecasting forest area and use, only reforestation on the forest land was considered. Data on natural or artificial afforestation on non-forest land are not included in our calculations. According to expert opinions (Kuliešis and Petrauskas 2000b), the afforested land area in the next three decades will amount to at least 0.36 million hectares.

Modelling approach and generation of scenarios

The model consists of three main modules (Figure 1) that simulate the use and dynamics of:
- timber resources,
- supplementary (non-timber) forest resources,
- preservation and recreation functions.

The first module has four subsystems: regeneration, stand growth, timber use, and economic evaluation. Two other modules are still under development. All subsystems are linked so that changing parameters of one subsystem will affect the simulation results of others in the following steps of iteration.

Though the stand is the basic unit of simulation, any aggregated or sampled data can be used for simulation in case the structure of data record is analogical to the stand record. The smallest scale of the model application is one compartment (stand), while the biggest scale covers all forests of Lithuania, i.e. more than 1 million compartments.

The length of simulation is 5-20 years. The number of steps is unlimited. As a result of each step, two new virtual databases are generated: i) data of stands that

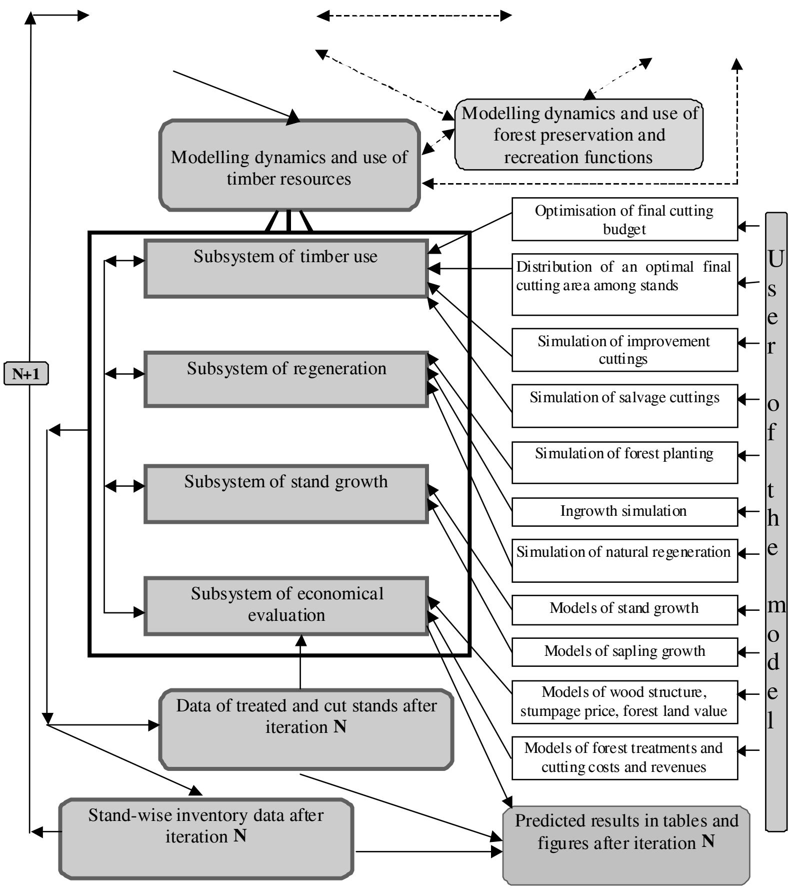

Figure 1. Principle scheme of model KUPOLIS

remain to grow forming the initial data set for a new step, and ii) database of timber removed during all kinds of cuttings and natural mortality.

Default values of model parameters comply with the forestry legislation of Lithuania, including the forest distribution into functional groups, maximal permissible time for reforestation after clear cuttings, rules and regulations on cutting ages, preferable tree species, etc. There are two options of generating scenarios. The first option is used for the operational planning where the user of the model can change parameters within the legislation requirements. In the second option, the user is a decision maker who can influence changes in legislative acts and wishes to test the new strategies.

Each subsystem predicts the development at the stand level. An exception is the model of optimisation of the final cutting budget that generates optimal solutions at the calculation unit level, and uses aggregated data based on age classes. Calculation unit refers to a group of stands of the same tree species and functional class.

The forest regeneration subsystem provides a possibility to deal with four following strategies (Petrauskas & Kuliešis 2000):

1. Planting of tree species according to valid silvicultural rules and goals;
2. Simulation of the present forest planting practice in future;
3. Planting according to the wishes of < decision maker (expert opinion);
4. Continuation of the tree species composition from the former stand.

The natural regeneration is predicted in three cases: i) when enough undergrowth is present, ii) on histosols or iii) when experts allow natural regeneration due to economic reasons. To sustain the current tree species biodiversity, the natural regeneration and ingrowth models apply random selection of tree species composition and density from the whole variation of the real stands on the specified soil type. In the case of the ingrowth, the number of trees is corrected using a coefficient that depends on the stocking level of the present stand (Petrauskas 2000a).

The modelling of the stand growth is based on regression models (Kuliešis 1993) developed for eight dominant tree species (cf. Table 1). The mean gross annual increment is determined for each tree species and stand. The growth of other species is described by the same models with the closest regularities of growth. The forecast of undergrowth and ingrowth height for the first step uses the regression models by Kuliesis (1993) multiplied by the correction coefficient that depends on the stocking level of the former or present stand (Petrauskas 2000a). Height growth models of young naturally regenerated saplings have been developed by Kuliešis on the basis of forest inventory data (Petrauskas 2000a).

The subsystem of intermediate cuttings can generate two types of strategies. The first type strategies are those that well comply with the present silvicultural recommendations. The original models are based on an optimal number of trees and their optimal spatial distribution that should be left after improvement cuttings (Kairiūkštis and Juodvalkis 1985). Here, they are simplified and have three main parameters: relative basal area (stocking level), average height of tree species and tree species composition of a stand. The simplification accommodates the absence information on the spatial distribution of trees in standwise inventory data.

In the second type of strategies, the main objective of the treatment is the species composition of target trees and the stocking level of the stand at the rotation age (Kuliešis *et al*. 2000). The main aim of the method is to balance timber use and increment and increase stability and productivity of stands. The starting age for using this method is 15-20 years but not later than 0.5 of the rotation age. The points of stocking level at the starting age and rotation age establish a linear trend for each stand. The trend is used to determine thinnings on all following steps of simulation until the stand is regenerated. Thinnings are performed when the actual stocking of a stand exceeds the corresponding stocking level of the trend by determined size. The stocking level of a stand during cuttings cannot be decreased lower than determined limit (Kuliešis and Tebėra 1997). The initial and final points of the stocking trends, thinning start, upper stocking limit and lower limit of the stocking after the thinning can be changed according to the goal function of the user. The user has a possibility to regulate the amount and size of timber that will be cut by final cuttings. In all cases, undesirable and less valuable tree species are thinned first. The subsystem of intermediate cuttings does not evaluate natural disasters. Therefore, possible limits of salvage cuttings are determined depending on the natural mortality that is calculated as part of the net annual increment (Kuliešis 1993, Kuliešis and Petrauskas 2000a).

The main requirements for the objective function in the subsystem of final cuttings are:

- continuing and sustainable use;
- smoothing of age class structure.

In the long term forecasts, these requirements are satisfied best by model "Optina" developed by Lithuanian forest researchers Deltuvas and Misheikis (Ä□ėņóāąń and Ģčųåéźčń 1975) and later improved by

Vitunskas (Витунскас 1988) (Formula 1). The minimisation goal of the formula seeks to find the smallest average area in a set of age class ranges. The length of the range varies from one age class area (area of mature stands) to the area of the whole calculation unit (all age classes in the full rotation period).

$$L_j = \min\left\{ \min_{k=1\div N}\left\{ \frac{n}{(k-1)\cdot n + a}\sum_{i=1}^{k} F_{ij} \right\}, \frac{1}{N}\sum_{i=1}^{N} F_{ij} \right\} \quad (1)$$

L_j = clear cut area for n year of the calculation unit in step j, ha

n = age class length (usually 10 years), years

a = time period for which an extra area of average size clear cut of mature stands is reserved, years ($a = 1$)

F_{ij} = area of age class i on step j, ha

k = number of age classes used in the calculation of clear cut area (changes from **1** to **N**)

i = age class index counting backward from matured stands **N** to **1**

j = step index

N = number of age class in a full rotation period

Formula 1 does not describe the timber use and increment balance. However, the optimisation includes a constraint ensuring that the amount of clear-cut volume does not exceed increment.

The model uses principles of dynamic programming and allows reaching the mentioned goals in the shortest time period. Another positive feature of the model is the possibility to fix the buffer of mature stands. Decision makers can influence the final solution at each step by changing the calculated optimal solution through the ratio coefficients that can decrease the annual final cutting budget or increase it as long as the volume of mature stands is not exceeded. The subsystem generates optimal or conditionally optimal solution (in case the ratio coefficients are used) for each calculation unit at each step. The distribution model within the subsystem calculates the priority indexes for each mature, overmature or damaged stand. In case there are several stands with the same priority indexes and, according to the calculated cutting budget, not all of them should be cut, the random selection of stands is used.

The subsystem of economic evaluation calculates three parameters: forest land value, stumpage price, and predicted costs and revenues of all forest operations starting from growing seedlings and ending with timber logging to the roadside. Due to uncertainty of prices of round timber and forestland as well as costs of forest operations, these calculations are reliable only for a short time operational planning. By varying interest rate, timber price or forest operation costs, the profitability of the whole forest sector can be analysed.

Strategy definition

The total number of scenarios in each step can be determined by multiplying the number of subsystems by the average number of possible scenarios in each subsystem. Analysis of the tremendous number of scenarios is technically possible but not pragmatic in decision-making. Our decision was to simulate the core strategy that embodies the vision of forestry experts and serves as a measure stick for comparing other strategies or scenarios.

The main goal of the core thinning strategy is to increase the stability and productivity of mature stands. In the core scenario, stand treatments were simulated according to the target tree species composition and stocking level of the stand at the rotation age. The core thinning strategy is presented in Tables 2 and 3.

As an alternative, thinnings were modelled applying a method that currently is practiced in Lithuania (Kairiūkštis and Juodvalkis 1985).

Table 2. Strategy of stand treatments. Soils are defined according to Buivydaitė *et al.* (2001)

Thinning strategy	Soil type	Tree species
Low intensity	All histosols	All
Average intensity	Half of gleyic luvisols, and all other non-mentioned soils	All
High intensity	Half of gleyic luvisols	Pine and spruce

Table 3. The parameters of stocking trends

Thinning strategy (intensity)	Initial stocking point	Stocking at the rotation age	How much real stocking should exceed objective stocking trend to start thinnings	How much stocking of the thinned stand could be lower than the objective stocking
Low	Actual stocking	0.65	0.15	0.10
Average	0.75	0.75	0.15	0.10
High	0.5	0.85	0.15	0.10

The forest planting in the core strategy was simulated according to the expert vision on the forest plantation establishment, natural regeneration and stand tending. According to the expert assessment, pure and mixed birch stands may occupy up to 30 per cent of the area on rich and temporary surplus humid sites. The second simulated strategy is the continuation of the current forest regeneration practice for a century. The third strategy assumes regeneration strictly in compliance with regeneration standards of 1990s.

The core final use strategy supposes the optimal (or conditionally optimal) final use where a 5-year clear cutting reserve was set for all coniferous, oak and ash and a 1-year reserve was set for other deciduous species. Over-mature stands of black alder, aspen and grey alder are rapidly losing the quality of accumulated timber. Due to the surplus of these species, the core final use was corrected by increasing the amount of the clear-felled timber by 30 per cent on the first and the second steps. Besides the core final use strategy, two alternatives were simulated. The saving use strategy means leaving the whole area of mature coniferous and hardwood deciduous stands (10-years age class) as well as a half of softwood deciduous (10-years age class) areas as reserve. According to this strategy, timber is accumulated for the future, and the levelling of the structure of age classes is continuing for a longer period. The maximal final use strategy does not leave any area of mature stand reserve (the reserve may amount to one-year clear cut area only, to ensure a continuous use).

Results

Future species composition

In case the existing forest regeneration and silvicultural standards were followed strictly, the area of oak and ash would double, while the area of aspen, grey alder and birch would considerably shrink during the 21st century (Figure 2 (A)). Most of latter species would be substituted by spruce. If the present forest planting and regeneration practice was continued for a century, the areas of spruce and ash would increase almost twice (Figure 2(B)). Areas of pine and birch would decrease being pushed out by spruce even on some typical pine sites. The core strategy (Figure 2(C)) does not predict significant changes in forest area distribution by tree species, except a remarkable increase in the area of oak and a decrease of aspen and white alder. Black alder has the most stable area, remaining unchanged in all three scenarios.

Thinnings

At the end of the forecasted period, the average stocking level is increased by 10 per cent using the

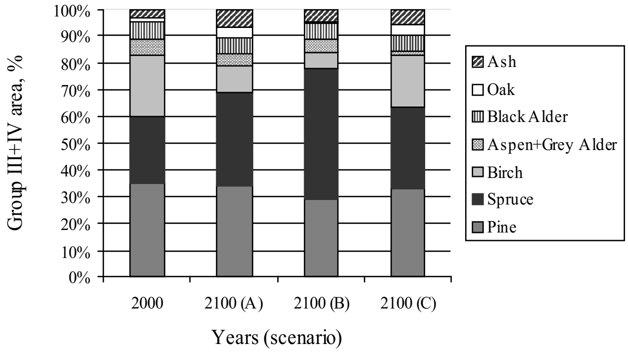

Figure 2. Scenarios of species substitution in Lithuanian forests of group III-IV.
A – forest planting according to present silvicultural rules and goals. B - simulation of the present forest planting practice in the future. C- forest planting according to the wishes of a decision maker (experts opinion)

core strategy and by just 3 per cent using the traditional thinning strategy (Figure 3). The curve of mean volume dynamics shows a typical accelerated growth of stands in state forest and especially in the private forests (Figure 4). An intensive (core) tending strate-

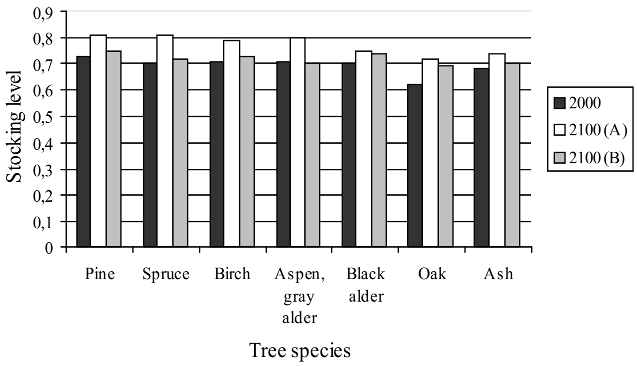

Figure 3. Scenarios of average stocking level index in forests of groups III and IV.
A –core thinning strategy. B – traditional thinning strategy

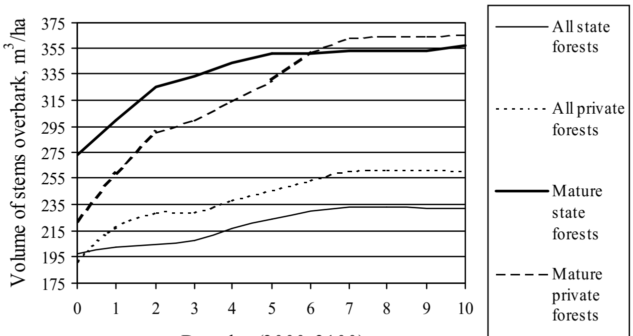

Figure 4. Forecast of the mean growing stock dynamics in stands of forests of group III-IV. The core strategy

gy of young stands would allow forming a rather high mean volume of mature stands. Volume growth intensity in mature stands is greater than the increase of the mean volume in all stands. Private forests have a higher potential productivity due to richer soils. However, the potential can be realised under the condition that young stands in private forests are treated not worse than in state forests. By using the core thinning strategy, increment losses and salvage cuttings would be reduced.

Final cuttings

All three final use strategies attempt to level the age class distribution and guarantee sustainable and constantly increasing timber use. Differences of these strategies lie in the size of the remaining reserve of mature stands. They are greatest during the first three decades (Figure 5). Timber use during the first decade varies from 3.6 to 4.8 million m^3/year. During the last decade, cutting volumes are similar in all three scenarios and reach 6.6 million m^3 of stemwood annually. All final use strategies reveal a decrease in cutting volumes in the sixth decade. The main reason for this is the age class structure of coniferous stands preconditioned by forest use and regeneration during the last three decades.

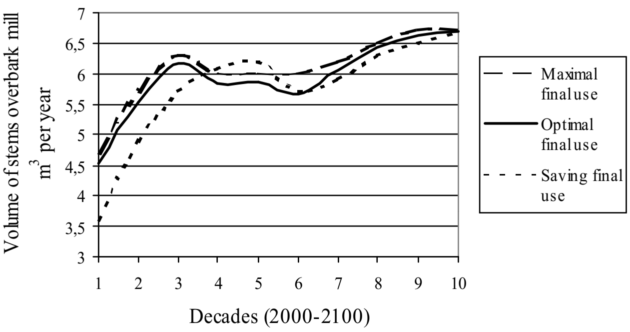

Figure 5. Forecast of the final cuttings in Lithuanian forests of group III-IV applying various use strategies

The cuttings of pine, spruce and ash will grow whereas cutting of birch will remain stable (Figure. 6). Despite the increasing area of oak stands, the cutting of oak decreases since the area of mature stands will shrink. Even in the case of successful oak regeneration, the first to take advantage of this work would be only the third or the fourth generation of the Lithuanian population. A decrease in removable grey alder stock is proportional to the reduction in its area. The decrease in the use of aspen is not so significant as shrinkage of its areas because aspen quite often is removed in stands of other species.

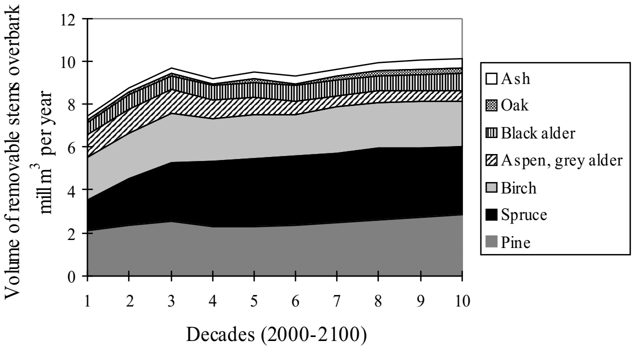

Figure 6. Species structure of the total use in Lithuanian forests of group III-IV. The core strategy

3.4 Balancing timber use and increment

In the core strategy, the rate of precommercial and commercial thinnings will rise from 2.2 million m^3/year during the first decade to 2.9-3.0 million m^3/year during decades 4-10 (Figure 7). The forecasted salvage cuttings make up 0.6-0.7 million m^3 annually. 0.4-0.5 million m^3/year of small–sized and low value stemwood will inevitably be left in forest to decay. The remaining of the growing stock increment is accumulated in stands. The greatest accumulation is forecasted during the first decade, while during decades 9-10, the accumulation is minimal, since the optimal volume of mature stands is attained. According to the optimal and saving final use strategies, the total use significantly differs for decades 1-3 only, later the difference decreases. This is caused by the fact that the scenario of optimal use allows increasing allowable cut of softwood broadleaves. At present, the accumulation of mature softwood broadleaves is high, and leaving them unfelled leads to a poor stock quality. The timber use in the maximal final use strategy over decades 1-7 is much closer to the mean gross annual increment. However, in decades 8-10, having normalized the age class structure and increased stand productivity, the

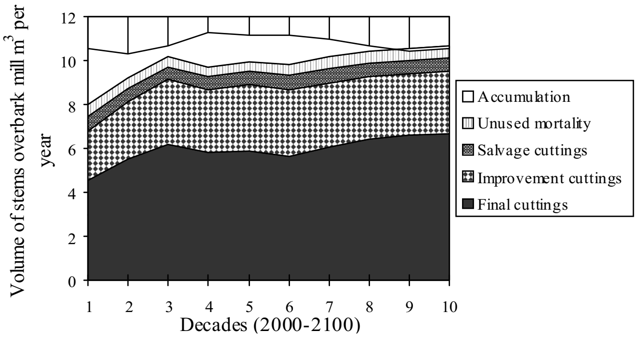

Figure 7. Balance of the gross mean annual increment and cuttings in forests of groups III and IV. The core strategy

level of timber use converges for all three scenarios, showing the total use of 10 million m³/year of stemwood overbark. During the first decade, the total use should not exceed 7.5 million m³/year.

We have compared the dynamics of felling intensity in state owned and private forests. In state forests, 5.5-6.0 m³/ha/year are removed by all kinds of cuttings (Figure 8). In private forests, cutting intensity is lower than in state forests until the sixth decade. An especially great difference is observed during the first 10 years. This is caused by several reasons. First, the present volume of state forests is greater, especially in mature stands. Second, the small average size of private holdings limits the rates of final harvest. Third, no cuttings are performed in forests reserved for privatisation, except salvage cuttings. The fourth reason is the difference in age class structures of state and private forests.

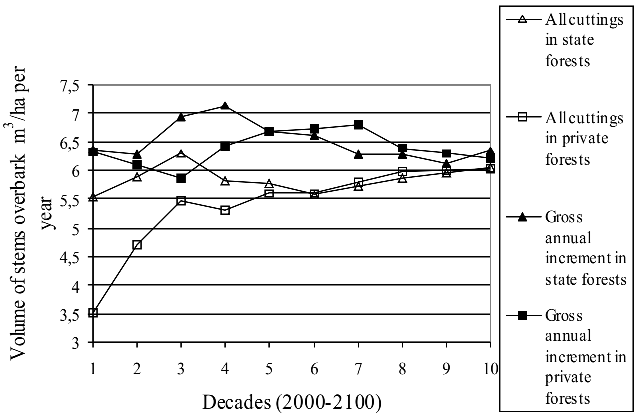

Figure 8. Forecast of the total wood use and mean gross annual increment in forests of groups III and IV. The core strategy

Differences in the total use intensity are mainly preconditioned by variation in the final use. During three decades, the final use intensity in private forests increases from 1.8 to 3.4 m³/ha. During the fifth decade, cutting intensity in the forests of both ownership forms becomes similar and further remains alike.

According to standwise inventory data, the mean gross annual increment in state and private forests is very similar (Figure 8). Increment decrease is forecasted for two and three decades in state and private forests, respectively. This is related to the accumulation of mature and premature stands, increased use and a greater amount of young age class areas yielding less timber.

If more intensive thinnings are introduced without a delay, a significant rise in increment can be expected in state forests in the third decade. In private forests, similar increase is expected in the fourth decade. In decades 5-6, the increment will reach 6.6 m³/ha in all forests.

The dynamics of timber resources

The core use strategy predicts an increase in growing stock resources by 90 million m³ over 100 years, i.e. 0.9 million m³ annually. In the case of saving and maximal use strategies, the expected increase is 96 and 84 million m³, respectively (Figure 9). The maximal use strategy fails to sustain a constant augmentation of the growing stock volume in decades 2-4 due to the present age class structure. In decades 8-10, growing stock resources in forests of groups III and IV will become stable, because the age class structure is optimised and the stands are grown in order to increase the volumes of mature stands.

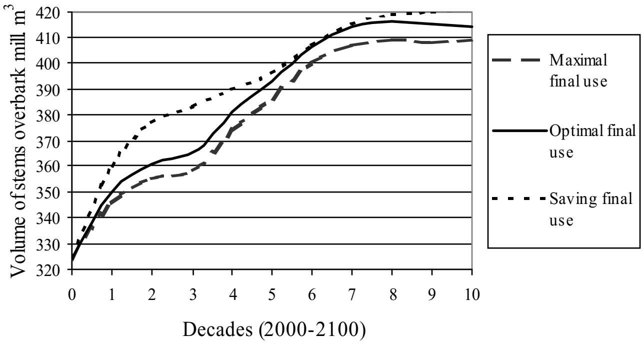

Figure 9. Dynamics of growing stock resources in forests of groups III and IV when applying various final use strategies

Stock accumulation in private forests (Figure 10) is highest over decades 1-2, because of the lack of mature stands and uneven timber use. Further, the stock accumulation gradually decreases and in the tenth decade is negative due to the levelling of the age class structure and the timber use balance. In state forests, the stock is accumulated most rapidly during decades 4-6. After accumulating 230 million m³ of stem-

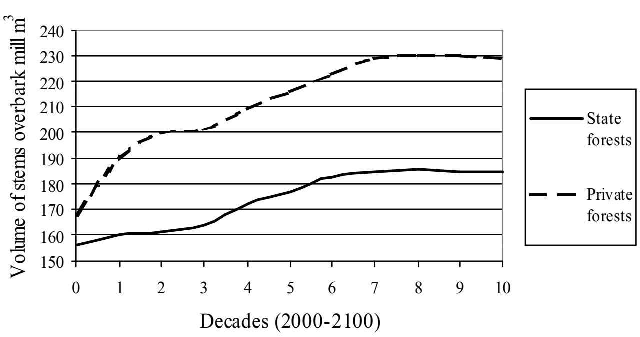

Figure 10. Forecast of the growing stock dynamics in forests of groups III and IV. The core strategy

wood resources in private forests and 185 million m[3] in state forests, it would be possible to attain the desirable conditionally optimal forest yield and use level in decades 9-10. During the next century, forest areas will undoubtedly enlarge due to afforestation (cf. Section 2.1) and timber resources will be even higher.

The mean stand growing stock will increase due to the rise of the total growth and improvement of its accumulation in forests. Another reason is a higher mean stand age compared to the present (by four years in state forests and by seven years in private forests). The average age of stands should reach 57-58 years at the end of the simulation period and subsequently remain stable.

We have simulated several scenarios but, in this paper, we will confine in-depth analysis to the core scenario that best fulfils the criteria of sustainability. With its 18 million tons carbon dioxide emissions per year (data of 1995), Lithuania constitutes just 0.08 per cent of the global carbon dioxide emission (Kairiūkštis 1997). The normalisation of the forest age class structure would allow offsetting the increase in carbon emissions even if they double during the next two decades. Thus the presented scenario of forest management regime with a larger timber reserve should fulfil the requirements of the Kyoto Protocol (Watson *et al*. 2000). Otherwise, only 7 per cent in all energy balance of Lithuania are covered by wood based fuel. Rational use of cutting and sawing residues could increase this to 12 per cent. Increasing cuttings during the first three decades would augment the amount of wood waste fuel.

***Economic assessment of the core forestry strategy in Lithuania*.**

Simulation of the core forestry strategy allows us evaluating the profitability of the state forest sector with respect to timber use. The evaluation was done for the nearest three decades due to unpredictable timber market and world economy situation in the distant future. For calculating direct costs of silvicultural treatments and timber harvesting, current normative prices were used. The prices are based on the latest statistics and approved by the Department of Forests and Protected Areas under the Ministry of Environment. Significant changes in the costs structure of forest operations are inevitable. Labour, capital, and energy costs as well as labour productivity should significantly increase after Lithuania joins the European Union. The prediction of revenues is also uncertain, even if the current timber prices are close to the of West European level. The sensitivity analysis of Lithuanian forest sector profitability under the simulated core forestry scenario was done by Cinga (Činga 2000). An increase in labour costs by 20 per cent would set the profitability of the state forest sector at zero level for two decades. Only in the third decade state forest sector could expect slightly positive net revenues. If, in addition to increased labour costs, we add 10 per cent increase in capital and energy costs, the Lithuanian state forest sector becomes unprofitable for the two coming decades. The rise of forest labour efficiency and the decrease of forest management costs must be considered. It is evident that state forestry decision makers will have a hard work to manage Lithuanian state forests without state subsidies.

Discussion

As any large-scale forestry scenario model, KUPOLIS has its weak and strong sides. Two methodological principles allow us minimising the accumulation of deviations of the results in a long time horizon (100 years). The annual budget of final cuttings is re-optimised at each step using the principles of dynamic programming, while other forest management activities are modelled using the iterative simulation. The experience of EFISCEN (Nabuurs *et al*. 2001) shows that already after 50 years projection, deviations start to accumulate and enhance each other through feedback mechanisms. The weakest point of the model is that it does not use direct measurement data of tree increment. Therefore, even if the model used for deriving the gross annual increment from growing stock measurements is reliable, the bias of simulated results can be inevitable. Preliminary analysis of mean gross annual increment data collected by the National Sampling Inventory of Lithuanian Forests (Kuliešis 2000) shows, that the standwise inventory underestimates the actual increment by 7-15 per cent. This might be explained by several reasons:

- Systemic reduction of growing stock through the standwise inventory process,
- Inadequacy between the radial increment that was fixed during the construction of growth models and actual increment at present,
- Acceleration of increment determined by the global climate change.

This issue needs a more thorough investigation using a higher number of tree increment data of the National Forest Inventory and permanent investigation plots.

A key problem in applying KUPOLIS to an operational planning at an estate level is the absence of the adjacency constraint in the subsystem of final cutting. Due to periodically recurring windfalls, clear cutting areas must be adjoined in spatial and time scale. We should emphasize that forest management regime strategies were elaborated without taking into consideration of effects by climatic fluctuations and natural disturbances on the timber increment. Also, interactions between the market situation and timber use have been not considered.

Nevertheless, the model has found its applicability at the national level and forest enterprise level. At the national level, two negative tendencies in forest regeneration practice have been revealed. If strictly following forest regeneration according to previous standards of goal tree species, the area of birch would decrease by 50 per cent over 100 years. In case forests are regenerated according to the current species composition of young stands, during 100 years, the area of pine stands will remarkably decrease, while spruce will expand. At an individual forest enterprise level, the model is used as a tool for forest management planners to find the minimal level of cuttings that is needed to ensure profitability. Also, the levels of sustainable and maximal timber use can be estimated.

Considering the results simulated for Lithuania, the assumptions of the presented scenario should be discussed along with the sustainability of forest management practices.

According to our core forest management strategy, the mean growing stock in forests of groups III and IV will rise from present 190 m^3/ha through 230 m^3/ha in 2050 to 245 m^3/ha in 2100. Biodiversity, conservation and nature-oriented forest management scenario for European forests (Nabuurs *et al*. 2001) shows the rise of the mean growing stock from 142 to 250 m^3/ha and remains at the same level as in the maximum sustainable production scenario in 50 years period. The average age of simulated forests in Lithuania will rise by 6 years during 100 years period, while in Europe, following two marginal scenarios, it could increase by 17 years or decrease by 8 years (Nabuurs *et al.* 2001). In the first case, European forests get older due to increasing area of set aside areas from 4 to 12.3 million hectares or 8.6 per cent of all forests. In our scenario, 15.8 per cent (forests of groups I and II) were fully excluded from the timber use calculations. Due to the ingrowth subsystem based on random simulation, natural mixture of tree species in stands is warranted for the whole simulation period despite of decreasing profitability. This prevents us from overestimating the future incomes as well as allows ensuring at least the current level of tree species diversity.

We cannot directly compare Lithuanian and European simulation figures, since a lot of specific factors are affecting the forecasted results. Our core strategy is an increasing timber use strategy based on timber increment balance. At the same time, the strategy envisions a close to nature-oriented forest management as described by Nabuurs *et al*. (2001) rather than management for the maximal sustainable production.

Resume

The presented core forest management strategy is based on the gross annual increment balance and its regulation. Forest growth results may vary depending on forest regeneration method and stand thinning regimes. These depend on economic conditions and the development of forestry and timber industry in Lithuania. Growing stock scenarios may be compared to the actual forest use and applied to scrutinise reasons for differences between the forecasted and actual forest use.

The loss of unusable timber can be minimised by the intensification of silvicultural treatments, especially in young stands. Management intensification would ensure long-term annual use of 8 million m^3 of merchantable wood from the present forest area of groups III and IV. In second and third decades, the use may exceed 8 million m^3/year due to significant accumulation of mature aspen, alder and birch and an increased share of mature coniferous stands. The planned intensive management should increase the total growing stock and volume of mature stands. Finally, it will increase the stability and resistance of forests as well as their ecological value.

The study has revealed that a simulation can disclose unfavourable forest use periods and identify the consequences of unsuitable management. Timely modifications of forest regeneration, growing and use strategy may smooth down the negative economic effect of unfavourable periods and improper management, harmonize the development of forestry and timber processing sectors.

Under changing economic conditions, facing new demands by the society, or having improved forest resource assessment data, it is always possible to investigate new forest management and use alternatives by means of KUPOLIS.

The model can be developed further in two main directions. First, the current version can be improved by creating modules of non-timber forest resources, preservation and recreation functions, and adding adjacency constraints to the subsystem of final cuttings through the use of digital maps. The second direction is to replace standwise forest inventory data by the data of national statistical forest inventory enabling the investigation of the bias in timber increment results.

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МОДЕЛИРОВАНИЕ СЦЕНАРИЕВ ВЕДЕНИя ЛЕСНОГО ХОЗЯЙСТВА И АНАЛИЗ АЛЬТЕРНАТИВНОГО РАЗВИТИЯ ЛЕСНЫХ РЕСУРСОВ ЛИТВЫ В XXI ВЕКЕ

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Резюме

Лесная политика постоянно опирается на результаты лесохозяйственной практики, не менее для нее важно предвидение результатов возможных сценариев развития лесного хозяйства на будущее. Для моделирования сценариев лесного хозяйства Литвы и оценки развития лесных ресурсов страны, при альтернативных сценариях ведения хозяйства, была разработана модель KUPOLIS. В основу модели положены модели роста, правовые и хозяйственные нормативы регулирования ведения лесного хозяйства страны, требования для обеспечения непрерывного, стабильного и неистощительного лесопользования на длительную перспективу.

Применение модели демонстрируется представлением развития лесного хозяйства и лесных ресурсов Литвы на XXI век. В статье приводятся результаты оценки разных сценариев развития лесного хозяйства страны. Оценка существующей практики лесовосстановления страны показывает существенное увеличение еловых древостоев и соответственное уменьшение площадей сосняков в лесах будущего. Увеличение площадей дубняков, предвиденное документами развития лесного хозяйства страны потребует существенного увеличения средств для лесовосстановления. Интенсивный уход за молодняками на более продуктивных условиях местопроизрастания позволит снизить натуральный отпад, увеличить стабильность древостоев и долю древесины, накапливаемой для главного пользования. Интенсификация лесного хозяйства послужит лучшему выполнению лесами природоохранных функций.

Ключевые слова: лесные ресурсы, моделирование сценариев, стратегическое планирование, продукция древесины, долгосрочное предвидение